THE IMPACT OF SOCIO-ECONOMIC AND HUMAN BEHAVIOURAL FACTORS ON THE WATER OF THE FONTEIN SPRUIT CATCHMENT – A WATER MANAGEMENT MODEL STUDY IN A DEVELOPING COMMUNITY

by

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DECLARATION

I, the undersigned hereby declare that the work contained in this dissertation is my own original work, and has not previously, in its entirety or in part, been submitted at any university or technikon for a degree.

Pretorius -- 2002-09-13 --

E Pretorius **Date**

SUMMARY

A world water crisis has been predicted as early as 1977 and since then, water professionals call this coming crisis to the attention of the world community at various conferences, summits and congresses. Recent assessments conducted for the United Nations and for the World Commission on Water indicated that almost half a billion people face water shortages in 29 countries and by 2025, almost two-thirds of the people are forecast to experience some form of water stress. Although this global water crisis tends to be viewed as a water quantity problem, water quality is increasingly being acknowledged as an important factor in water scarcity. In many developing countries water quality has become the principal limiting factor to water availability. The water quality situation in developing countries is highly variable reflecting social, economic and physical factors, state of development as well as climatic and geographical factors.

In recent years several studies have been done in South Africa to determine the quantitative and qualitative characteristics of urban runoff and their impact on receiving waters. These studies suggest that there was a large difference in the type of pollutants that were observed in the receiving waters and that the major factor affecting the type of pollution is the type of development that the catchment is undergoing. The studies conducted on the high-density informal settlements imply that any form of urban development that includes shacks and/or informal houses will have a detrimental effect on the quality of urban runoff. Low-cost, high-density type urbanisation, with its informal housing and shack areas, is an inescapable part of South Africa and will continue to play a major role in this country for many years to come. In recent years, South Africa has experienced a massive increase in urbanisation, a large proportion of which takes the form of high-density, informal settlements that developed around existing metropolitan areas. Based on current patterns of growth, the extent of this form of urbanisation is predicted to treble within 20 years. This rapid growth of urban areas in South Africa has been accompanied by increased quantities of contaminated urban runoff and this, in turn, has accelerated the degradation of streams, rivers, lakes and estuaries. Urban runoff acts as an efficient transport mechanism for bacteria, viruses, nutrients, organic substances, heavy

metals and other pollutants. Alone or in combination, these substances cause water quality problems, pose potentially serious risks to human- and environmental health through contact recreation and through the use of untreated water. Therefore, it is vitally important that the scientific and engineering society continue to study these urban catchments and to develop new and innovative ways of dealing with the problems associated with urban runoff.

The study area provided a unique opportunity for the investigation, implementation and evaluation of an integrated water quality management programme, as it is a typical example of a community with rapid, largely uncontrolled, growth of low-cost, high-density housing developments. The research project was primarily aimed to gain a better understanding of the major causes of pollution in the study area, and once the principle contributing factors had been identified and investigated, a Water Quality Management Plan was developed. The research project was based on the assumption that water quality problems arising from developing communities can be managed using an integrated approach to ensure that the receiving water environmental objectives can be met on a sustainable basis and that the management practices and interventions to deal with pollution problems from developing communities can be sustained by addressing the socio-economic and human behavioural factors contributing to the problems. The Water Quality Management Plan is therefore an integrated plan addressing the management of water quality in the community in the study area, and also permits the extrapolation of the results to catchments with similar land use and human activities, locally as well as regionally.

OPSOMMING

'n Wereld water krisis is reeds vanaf so vroeg as 1977 voorspel en sedertdien het kundiges op die gebied van water hierdie komende krisis onder die aandag van die wereld gemeenskap tydens verskeie konferensies, berade en kongresse gebring. Onlangse beramings wat uitgevoer is vir die Verenigde Nasies en vir die Wereld Kommissie vir Water het aangedui dat bykans 'n half biljoen mense in 29 lande 'n water tekort in die gesig staar en teen 2025 word voorspel dat bykans twee derdes van die mense 'n vorm van water stres sal ervaar. Alhoewel daar geneig word om na hierdie wêreldwye water krisis te kyk as 'n water kwantiteit probleem, word water kwaliteit toenemend erken as 'n belangrike faktor in water skaarste. In baie ontwikkelende lande het water kwaliteit die hoof beperkende faktor vir water beskikbaarheid geword. Die water kwaliteit situasie in ontwikkelende lande is hoogs veranderlik en reflekteer sosiale, ekonomiese en fisiese faktore, stand van ontwikkeling sowel as klimaats en geografiese faktore.

Verskeie studies is die afgelope jare in Suid-Afrika gedoen om die kwantitatiewe en kwalitatiewe eienskappe van stedelike afloop en hulle impak op die ontvangende water te bepaal. Hierdie studies stel voor dat daar 'n groot verskil is tussen die tipe besoedeling stowwe wat in die ontvangende water geidentifiseer is en dat die hoof faktor wat die tipe besoedeling bepaal, die tipe ontwikkeling is wat die opvanggebied ondergaan. Die studies wat uitgevoer is op die hoë digtheid informele nedersettings impliseer dat enige vorm van stedelike ontwikkeling wat tydelike en/of informele huise insluit 'n nadelige effek op die kwaliteit van stedelike afloop sal hê. Lae koste, hoë digtheid tipe verstedeliking, met sy informele en tydelike behuising gebiede, is 'n onvermydelike deel van Suid-Afrika en sal voortgaan om 'n belangrike rol in hierdie land te speel vir nog etlike jare. Suid-Afrika het in die afgelope jare 'n massiewe toename in verstedeliking ondervind waarvan 'n groot deel die vorm aanneem van hoë digtheid, informele nedersettings wat rondom bestaande metropolitaanse areas ontstaan het. Gebaseer op huidige groeipatrone word voorspel dat die mate van hierdie vorm van verstedeliking binne 20 jaar sal verdriedubbel. Hierdie vinnige groei van stedelike areas in Suid-Afrika word

vergesel deur verhoogde hoeveelheid van besmette stedelike afloop en dit het die degraduering van strome, riviere, mere en riviermondings bespoedig. Stedelike afloop tree op as 'n doeltreffende vervoermeganisme vir bakterieë, virusse, voedingstowwe, organsiese stowwe, swaar metale en ander besoedelende stowwe. Hierdie stowwe, alleen of in kombinasie, veroorsaak waterkwaliteitsprobleme en hou potensiaal gevaarlike risikos vir menslike en omgewingsgesondheid in deur water kontak tydens rekreasie en deur die gebruik van onbehandelde water. Dit is daarom lewensbelangrik dat die wetenskaplike en ingenieurswese samelewing voortgaan om hierdie stedelike opvanggebiede te bestudeer en om nuwe en innoverende maniere te ontwikkel om probleme te hanteer wat geassosieer word met stedelike afloop.

Die studiegebied het 'n unieke geleentheid voorsien vir die ondersoek, implementering en evaluering van 'n geïntegreerde water kwaliteitsbestuurprogram, aangesien dit 'n tipiese voorbeeld is van 'n gemeenskap met snelle, grootliks onbeheerde, groei van lae koste, hoë digtheid behuisingsontwikkelings. Die navorsingsprojek was primêr daarop gemik om 'n beter begrip van die hoofoorsake van besoedeling in die studiegebied te verkry, en nadat die hoofbydraende faktore geïdentifiseer en ondersoek is, is 'n Waterkwaliteitbestuursprogram ontwikkel. Die navorsingsprojek was gebaseer op die veronderstelling dat, eerstens, waterkwaliteitsprobleme wat onstaan uit ontwikkelende gemeenskappe bestuur kan word deur 'n geïntegreerde benadering te volg om te verseker dat die ontvangende water omgewingsdoelwitte bereik kan word op 'n volhoubare basis. Tweedens dat die bestuurspraktyke en ingryping om besoedelingsprobleme van ontwikkelende gemeenskappe te hanteer volhou kan word deur die sosio-ekonomiese en menslike gedragsfaktore wat bydra tot die probleem aan te spreek. Die Waterkwaliteitsbestuurplan is dus 'n geïntegreerde plan wat die bestuur van water kwaliteit in die gemeenskap van die studiegebied aanspreek en laat ook die ekstrapolering van resultate tot ander opvanggebiede met dieselfde landgebruik en menslike aktiwiteite, plaaslik sowel as streeksgewys toe.

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CHAPTER 1 INTRODUCTION AND PURPOSE OF THE STUDY

1.1 Background

A world water crisis is coming. Accelerating demand is exceeding the finite resource over widening regions of the globe. This impending water crisis is not new: professionals have been predicting this coming scarcity since Mar del Plata in 1977 and New Delhi in 1980. The pace of international conferences has quickened in the 1990's, beginning with Dublin and Rio in 1992 and culminating with The World Water Forum in the Hague in March 2000, as water professionals call the coming crisis to the attention of the world community (Duda & El-Ashry, 2000). Recent assessments conducted for the United Nations and for the World Commission on Water indicated staggering numbers: almost half a billion people face water shortages in 29 countries and by 2025, almost two-thirds of the people on our planet are forecast to experience some form of water stress – for over a billion of them, the shortage will be severe and socially disruptive (WMO, 1998; WSSCC, 1999).

Although this "global water crisis", according to Ongley (2001), tends to be viewed as a water quantity problem, water quality is increasingly being acknowledged as a central factor in water scarcity. The contribution of water quality to this crisis is mainly through the loss of a wide variety of beneficial uses, including large-scale ecological dysfunction and collapse, loss of economic opportunity and its role in public health and poverty (Ongley, 2001). In many developing countries water quality has become the principal limiting factor to water availability. The water quality situation in developing countries is highly variable reflecting social, economic and physical factors, state of development as well as climatic and geographical factors (Steynberg, Venter, De Wet, Du Plessis, Holhs *et al.*, 1995; Thornton, Rast, Holland, Jolankai & Ryding, 1999; Ashton & Bhagwan, 2001; Schoeman, Mackay & Stephenson, 2001). Because the range of polluting activities is inconsistent from one country to another and the nature of environmental and socio-economic impacts is equally variable, there is no "one-size-fits-it-all" solution. There are, however, some common denominators in the types of actions that are required for sustainable solutions (Loucks, 2000; Ongley, 2001). The challenge for national and local authorities, and one of the subjects of this research project, is how to carry out water quality planning, control- and management programmes that are cost-effective and sustainable.

1.2 Rationale and motivation for the study

South Africa is a semi-arid country, with an average annual rainfall of approximately 500 mm, significantly less than the world average of 860 mm. Rainfall is irregular in both time and space and the country experiences frequent, unpredictable droughts and floods, sometimes in different parts of the country in the same season (DWAF, 1994; Schreiner & Naidoo, 1999). Many regions of the country also experience severe water shortages and the demand for water has far exceeded the local supply in the key inland economic centers (Smakhtin, Ashton, Batchelor, Meyer, Murray *et al.*, 2001). In past decades, water resources development focused predominantly on structural solutions such as the construction of water shortage reservoirs and water transfer schemes (Basson, Van Niekerk & Van Rooyen, 1997; Smakhtin *et al.*, 2001). At present, the combined capacity of large and small water supply reservoirs in South Africa amounts to 37 000 mm^3; this is equivalent to almost 74% of the total country's mean annual runoff and represent a very high level of resource capture (Smakhtin *et al.*, 2001). The country is thus fast approaching the limit of its exploitable water resources. As a result, the country has entered an era in which its water resources must be protected, in order to ensure that sufficient water is available in the future. This philosophy of sustainable management of water resources is neatly encapsulated in the slogan of the Department of Water Affairs and Forestry (DWAF): "Some, for all, forever". The National Water Policy of 1997 (DWAF, 1997) sets out the principles on which water resources will be protected and managed in the future. The recognition that water must be managed on the basis of the entire hydrological cycle is one of the key issues of this policy. If the country fails to manage and protect the water resource adequately in one phase of the hydrological cycle, then the resource is affected everywhere else in the cycle. The impact that contaminated urban runoff has on the water resource is thus a matter of great concern.

In recent years, South Africa has experienced a massive increase in urbanisation, a large proportion of which takes the form of high-density, informal settlements that develop around existing metropolitan areas. Based on current patterns of growth, the extent of this form of urbanisation is predicted to treble within 20 years (Simpson, 1991; Wright, Kloppers & Fricke, 1992; Schoeman *et al.*, 2001). This rapid growth of urban areas in South Africa has been accompanied by increased quantities of contaminated urban runoff and this, in turn, has accelerated the degradation of streams, rivers, lakes and estuaries

(Kloppers, 1989; Wright *et al.*, 1992; Lord & Mackay, 1993). Urban runoff acts as an efficient transport mechanism for bacteria, viruses, nutrients, organic substances, heavy metals and other pollutants. Research in the United States of America showed that 50% of the 129 priority pollutants listed by the United States Environmental Protection Agency (USEPA) have been detected in urban runoff (Schoeman *et al.*, 2001). Alone or in combination, these substances cause water quality problems, pose potentially serious risks to human- and environmental health through contact recreation and through the use of untreated water (Grabouw, 1996; Chapra, 1997; Ashton & Bhagwan, 2001; DWAF, 2001a). The World Health Organisation (WHO, 1997) rates poor water quality as one of the leading causes of illness and death, while diarrhoeal disease remains the leading cause of infant and child morbidity and mortality in developing countries. The World Health Report, which was published in 1999, indicated that water related diseases caused an estimated 3.4 million deaths in 1998, of which approximately 2.2 million was caused by diarrhoeal diseases (WSSCC, 1999).

During the past thirty years many studies have been conducted worldwide to determine the quantitative and qualitative characteristics of urban runoff and their impact on receiving waters (Geldreich, 1976; Cordery, 1977; Whipple, Berger, Gates, Ragan & Randall, 1978; Qureshi & Dutka, 1979; Callender, Carter, Hahl, Hitt & Schultz, 1982; Hollon, Owen & Sewell, 1982; Symons, Whitworth, Bedient & Haughton, 1989; Guillemin, Henry, Uwechue & Monjour, 1991). In recent years several studies have also been done in South Africa (De Villiers & Malan, 1985; Simpson, 1986; Du Preez & De Villiers, 1987;

Stephenson & Green, 1988; Kloppers, 1989; Kelbe, Mulder, Bodenstein, Hattingh & Verwey, 1991; Umgeni Water, 1991; Wimberley, 1992; Wright *et al.*, 1992; MacKay, 1993, Jagals, 1994; Pretorius, 1996). The earlier studies concentrated on formal and developed urban areas, while the studies during the nineties were mainly conducted in high-density informal settlements:

- De Villiers and Malan (1985) investigated a small urban catchment near Durban, South Africa;
- Simpson (1986) investigated a small catchment located in Pinetown (KwaZulu Natal) in the coastal summer rainfall region. This catchment supports commercial, light industrial and residential land use;
- Stephenson and Green (1988) studied two larger catchments in Johannesburg in the inland summer rainfall region. The Montgomery Park catchment represented a formal low-density residential suburb with a small amount of commercial and light industrial land use and a solid waste disposal site. The Hillbrow catchment had high-density residential land use, with some commercial land use;
- Kloppers (1989) made a comparative study of the stormwater quality in two catchments namely, Three Anchor Bay and Mitchell's Plain. Three Anchor is a low density, middle class residential area and Mitchell's Plain a medium density working class area;
- Kelbe *et al.* (1991) and Umgeni Water (1991) monitored and researched the impacts that polluted stormwater from peri-urban settlements (low density relative to this study) have on the receiving water quality, the environment and human health in the Durban area of KwaZulu Natal;

- Wimberley (1992) and Van Veelen (1994) assessed the effect of urban runoff from Alexandra on the water quality of the Jukskei River through water and pollutant mass balances and detailed studies of the geographical and water quality characteristics upstream and downstream of Alexandra;
- Wright *et al.* (1992) investigated the impact of polluted run-off from the Khayelitsha urban catchment, in the False Bay area, where groundwater, sandy soils and low-intensity winter rainfall determine the characteristics of the urban runoff; and
- Jagals (1994) studied the effects of diffuse effluents from Botshabelo on the microbiological quality of water in the Modder River. Botshabelo is a high-density area with low-cost and informal housing.

The studies suggest that there was a large difference in the type of pollutants that were observed in the receiving waters and that the major factor affecting the type of pollution is the type of development that that portion of the catchment is undergoing (Campbell, 2001). The studies conducted on the high-density informal settlements imply that any form of urban development that includes shacks and/or informal houses will have a detrimental effect on the quality of urban runoff. The provision of water and waterborne sewerage does not necessarily mean less pollution, but can even increase pollution by providing additional means for transporting the pollutants (Wright *et al.*, 1992; Schoeman *et al.*, 2001). An alarming factor that was however identified is the fact that the quality of the urban runoff documented in some of these studies was worse than that of treated effluent. The study done by Jagals (1994) has shown that the urban runoff from the study area contribute far greater microbiological pollution to the receiving waters than the effluent from the sewerage outfall works originating in the same urban area.

The problems caused by polluted urban runoff appear to be ubiquitous and inevitable. It has therefore become necessary to focus on all the various components that have an impact on water quality, to reduce the pollutant loads carried by urban runoff, and hence, to mitigate the adverse effects on receiving water quality. Under the heading "Future research needs and priorities", in the document by Ashton and Bhagwan (2001), *Guidelines for the appropriate management of urban runoff in South Africa*, they concluded the following: "Low-cost, high-density type urbanisation, with its informal housing and shack areas, is an inescapable part of South Africa and will continue to play a major role in this country for many years to come. Experience has shown that well-proven engineering solutions from high-cost, low-density communities are not always applicable to low-cost, high-density urban areas. Therefore, it is vitally important that the scientific and engineering society continue to study these urban catchments and to develop new and innovative ways of dealing with the problems associated with urban runoff".

This study is an attempt to address the above mentioned aspect in compiling, as the final product of the research project, a Water Quality Management Plan (WQMP) whereby management guidelines are introduced to direct both authorities and developers in the selection of the most appropriate method to address water quality problems in their catchment to ensure the protection and maintenance of healthy, functioning aquatic ecosystems that in turn, are essential for supporting the various demands placed on water resources. The rationale of the research project is thus to explore the key aspects of water quality that should enter into this holistic management programme by identifying the impact of socio-economic and human behavioural factors of a developing community in the south-eastern suburbs of Bloemfontein, South Africa, on the quality of the receiving waters, the Fontein Spruit.

1.3 Objectives and hypotheses

From the previous discussion it is clear that urban runoff can and have a serious impact on the quality of surface waters in South Africa. A balanced combination of sound urban environmental management practices, active participation of affected parties and improved legislation, will be required to achieve adequate reduction in pollution levels in runoff from urban areas (Ashton & Bhagwan, 2001; Campbell, 2001; Coleman, 2001; Schoeman *et al.*, 2001; Wood, Uchronska & Valashiya, 2001). Appropriate solutions to urban runoff management problems are multi-faceted, reflecting the diversity and complexity of the problems themselves (Ashton & Bhagwan, 2001). There is, therefore, an opportunity to invent a new water quality management paradigm that is more cost-effective and sustainable. This requires a process whereby the dependency on conventional engineering approaches is broken and the focus is placed on innovative alternative management practices that are cheaper and more sustainable for the community involved.

The formulation of the first objective of the study resulted from the above-mentioned realisation and can be stated as follows:

1.3.1 Objective 1:

To integrate socio-economic, human behavioural, environmental and technical aspects at planning level when designing water quality management options.

A second objective of the research project, and complementary to the first objective is:

1.3.2 Objective 2

To develop a water quality management model that will permit the extrapolation of results and experiences to catchments with similar land use and human activities, locally as well as regionally.

The formulation of the hypotheses was based on the objectives of the study and states that:

1.3.3 Hypothesis 1

Water quality problems arising from developing communities can be managed using an integrated approach to ensure that the receiving water environmental objectives can be met on a sustainable basis.

In addition, but secondary to the first hypothesis, it is stated that:

1.3.4 Hypothesis 2

The management practices and interventions to deal with pollution problems from developing communities can be sustained by addressing the socio-economic and human behavioural factors contributing to the problems.

Hypothesis 3 is a synthesis of the first two hypotheses and states that:

1.3.5 Hypothesis 3

A water management model that address water quality problems in catchments in a holistic manner can be developed when an integrated approach, which addresses the socio-economic and human behavioural factors that impact negatively on water quality, is taken.

1.4 Study area

The study area, which is the catchment of the Fontein Spruit, is located within the municipal area of Bloemfontein, the capital of the Free State, and one of the provincial capitals of South Africa. Figure 1.1 indicates the geographical location of the study area and the location of Bloemfontein in relation to the rest of South Africa. The Fontein Spruit is a natural water course running from the Blou Dam, a small reservoir, to its confluence with the Bloem Spruit at the lower end of the catchment. It is approximately 3.7 km in length and drains an area of about 16.8 km^2. The rainfall during the summer months from October to April amounts to 86% of the total annual rainfall, and it is mainly in the form of short-duration, high-intensity thunderstorms. The summer runoff is thus relatively high and most of the discharge is in the form of storm flow. The large volume of stormwater runoff thus represents a significant threat to the social and economic health of the surrounding community.

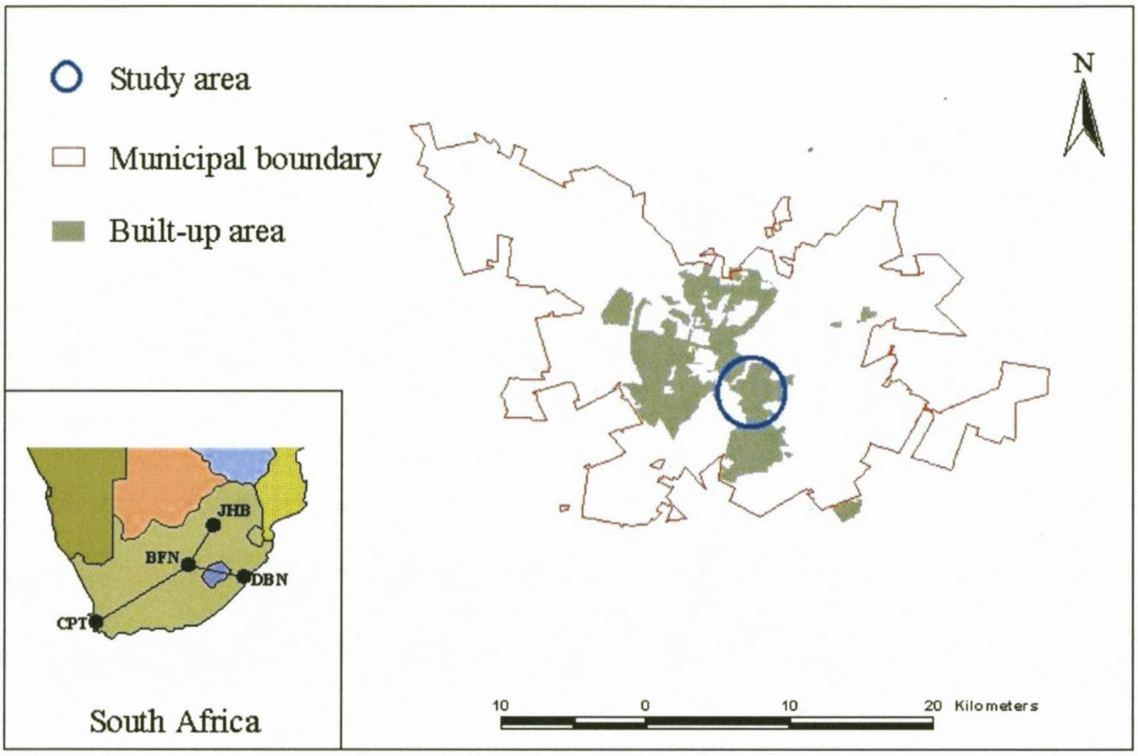


Figure 1.1 Geographical location of study area

The study area is a typical example of a community with rapid, largely uncontrolled, growth of low-cost, high-density housing developments. It consists of several residential sections, namely the developed sector of Erlich Park, and the developing and informal sectors of Mangaung and Heidedal. The developed sector was planned and is maintained and serviced by the local authority. This sector constitutes the higher socio-economic group of the study area. There is less planning and control in the developing sector and even less in the informal sector, where there are virtually no services or control. These residents are respectively at middle and low socio-economic levels. The study area therefore provides a unique opportunity for the investigation, implementation and evaluation of an integrated water quality management programme. The study area, the land use and composition of residential sections of the catchment, are discussed in detail in Chapter 4.

1.5 Structure of the research project

The flow diagram in Figure 1.2 illustrates the framework of the research project and the different tasks conducted during the project. The first undertaking was to identify the objectives, conduct a preliminary survey and from these results, design the project. The next assignments included field monitoring, data analysis and processing, as well as data interpretation and assessment. The field monitoring, indicated by the dashed line in the figure, consisted of the monitoring and assessment of the water quality in the study area, as well as the identification of the community characteristics with regard to socio-economic conditions. The water quality assessment also entailed the microbiological, chemical and physical analysis of the water samples in a laboratory to establish the water quality conditions of the drainage basin. The community characteristics were identified by means of a data capturing form. After completion of the field monitoring, the data were interpreted and assessed and appropriate interventions and strategies were identified as solutions to the water quality problems in the study area. The last task in the flow diagram is the Water Quality Management Plan (WQMP), which was compiled after all the information and experienced gained through the research project had been taken into consideration. A detailed methodology of the research project is given in Chapter 4.

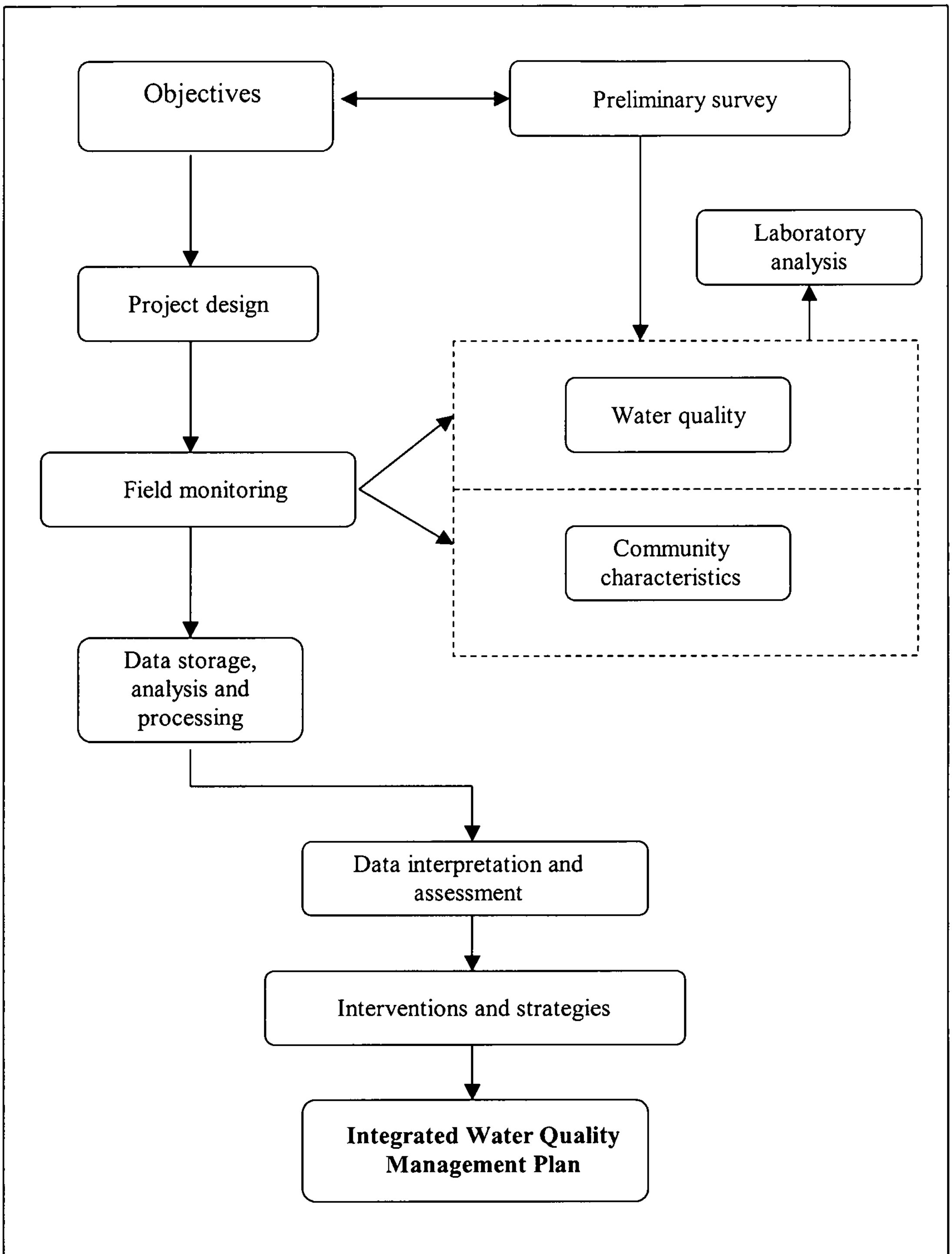


Figure 1.2 Framework of research project

CHAPTER 2 THEORETICAL BACKGROUND

2.1 The hydrological cycle

The presence of water distinguishes the planet Earth from other planets. Water is moving all the time, changing from liquid to gas or solid and back again. Evaporation from the sea and other open water surfaces, as well as transpiration of plants, produces water vapour. Condensation of that vapour results in precipitation as rain. Rainwater infiltrates soils and forms ground water as it fills up crevices, runs off into rivers and is stored in lakes and wetlands, or in ice fields, from which it again undergoes evaporation and/or transpiration. This continual process of transformation and redistribution is known as the hydrological, or water cycle.

Although the cyclic nature of the phenomenon is easily grasped, two factors – time and quality – are often overlooked (Tchobanoglous & Schroeder, 1987; Miller, 2000). The time scale is important because the natural storage of surface water and groundwater can impose significant time delays in the cycle, while the quality of water at any point in the cycle is a dynamic variable. Water is "pure" only in the vapour state, and impurities begin to accumulate as soon as condensation occurs. Gases dissolve into droplets forming clouds, and these gases strongly affect water quality. Gases can travel great distances before precipitation occurs, thus the cause and the effect of atmospheric pollution often occur at different locations. Rainfall that reaches the land surfaces, as well as water in other forms, *e.g.* snowmelt and hail, have a limited number of subsequent pathways. It can either soak into, or move over the land surface.

The force of moving stormwater over the land surface provides the energy for the movement of contaminants to receiving water. Aquatic ecosystems are thus the ultimate sinks for virtually all natural and anthropogenic materials from the land surface, as well as those transported in the atmosphere (Davies & Day, 1998; Thornton *et al.*, 1999; Ashton & Bhagwan, 2001, Schoeman *et al.*, 2001).

2.2 The concept of sustainability

The hydrological cycle forms the basis on which water resources must be managed in order to ensure that sufficient water of appropriate quality remains available in the future. The terms *sufficient water quantity* and *appropriate water quality* are embedded in the philosophy of sustainability and this concept is also emphasised in the definition of sustainability as given in the Brundtland Commission's report *Our Common Future* (WCED, 1987):

> *"Development is sustainable if it meets the needs of the present without compromising the ability of future generations to meet their own needs".*

The focus of this definition is thus on meeting the needs of both current and future generations so as to achieve sustainability of water resources. Since the Brundtland report, sustainable development has become a fashionable term in today's development discourse (Mashinini & De Villiers, 2001) and the focus of discussions and debates throughout the world (Jordaan, Plate, Prins & Veltrop, 1993; World Bank, 1994; Gleick, Loh, Gomez & Morrison, 1995; Barrow, 1998; Falkenmark, 1998; Loucks, 2000; Walmsley, Carden, Revenga, Sagona & Smith, 2001). Sustainability is thus not a new concept, nor is sustainability issues new issues. A more recent definition of sustainable water resource systems as given by the American Society of Civil Engineers (ASCE, 1998) and the United Nations Educational, Scientific and Cultural Organisation (UNESCO, 1999) are:

"Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental and hydrological integrity."

The current interest in sustainable water resource management is therefore based on the realisation that some of our actions/behaviour as well as the activities that we, who inhabit the earth today, perform could be causing irreversible damage and may adversely affect not only our lives but also the lives of those who follow us (Loucks, 2000). Human behaviour is, however, manipulated or influenced by the social and economic environment in which we live. The impact of socio-economic and human behavioural factors on the quality of the water resource are thus of great concern when addressing the sustainability of the water resource. If these factors have a negative impact (pollute) on the water resource, we fail to manage and protect the water resource in any subdivision of the hydrological cycle and the resource will be affected everywhere else in the cycle with the result that it will not be sustainable in the long run, nor be a valuable asset for the people or community of the area.

2.3 The concept of pollution

Pollution is a relative concept and there are a number of definitions, not all of which are applicable to the aquatic environment. A most encompassing definition, according to Pegram, Görgens and Quibell (1998) is *"an alteration in* *the physical, chemical and biological quality or energy of the ground or surface water environment caused by human activity".* GESAMP (1988) define pollution of the water resource as the *"introduction by man, directly or indirectly, of substances or energy, which result in such deleterious effects as the impairment of water quality with respect to its use in agricultural, industrial, economic and recreational activities".* According to Pegram *et al.* (1998), the need to link pollution to the water environment implies that the following definition is the most appropriate:

> *"Pollution is defined as the introduction of substances or energy to the water environment at levels which have an unacceptable impact on the water environment or its users".*

The National Water Act (Act 36 of 1998) neatly encapsulated all of the above ideas when it defines pollution with regard to the water resource as follows:

"...the direct or indirect alteration of the physical, chemical or biological properties of a water resource as to make it:

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

For the purpose of the study, the term *pollution* refers to the contamination of water by noxious substances. Pollutants can enter the water environment naturally or through human (anthropogenic) activities. Most pollution from human activities occurs in or near urban and industrial areas, where pollutants are concentrated. Some pollutants come from single, identifiable sources, other come from dispersed and often difficult to identify, sources. The different types of pollution sources are thus categorised into three groups that reflect their different characteristics:

- Point sources – may be defined as identifiable effluent sources emanating from a discrete defined conveyance with potentially quantifiable flow and quality;
- Incidents – may be defined as accidental discharges or failure of management systems which occur infrequently at unforeseen locations, and thus have a transient nature; and
- Non-point sources – represents all other sources, including instream activities, the contributions from which occur over a dispersed area and cannot be directly identified.

(Pegram *et al.*, 1998; Thornton *et al.*, 1999; Miller, 2000)

As point sources are easily identifiable and the volume of water and waterborne materials are easier to quantify than non-point source pollution, pollution control efforts of the past was directed primarily towards point sources. In recent years, however, it has become clear that a large portion of the contaminant load to surface and ground water originate from the land around these waters (*e.g.* farm fields, city streets), rather than from specific point sources (*e.g.* effluent from municipal waste water treatment plants, discharged of industrial factories). This is because non-point sources is intimately linked to the hydrological cycle: as rainfall reaches the land surface it soak into, or move over the land surface, providing energy for the movement of contaminants to the receiving waters. Even though non-point source contamination are not necessarily significantly different from point source contamination, the fact that rainfall and snowmelt are the primary driving forces, the movement of non-point source contaminants is more erratic and less frequent and the duration is usually shorter than the typically more continuous point source discharge. In spite of uncertainties about many of its complicated facets, there is little disagreement that non-point source pollution is a major cause of water quality degradation. For the purposes of the study the focus was on non-point source pollution. The rationale for this approach was the fact that the study area is directed primarily towards non-point source contamination.

The generic characteristics of non-point sources according to Pegram *et al.* (1998), which distinguish them from point or incident sources, include:

- Contamination generation occurs over an extensive area;
- Without management, discharge enters surface or ground water in diffuse manner at intermittent intervals, usually driven by climatic events;
- Monitoring and quantification of non-point source discharge is complicated, and therefore source contributions to surface or groundwater are difficult to assign;
- Land- and runoff management is usually more effective than control or treatment of discharge;

- Performance monitoring of land management practices, is usually more appropriate than compliance monitoring of discharge effluent standards;
- The extent of non-point source contamination is related to natural catchment conditions compounded by climatic events, which means that impacts vary greatly between geographic regions and between years; and
- The water quality constituents usually associated with non-point sources in South Africa are suspended solids, nutrients, faecal bacteria, salinity and toxic compounds.

Classification of non-point sources may be based on a range of criteria (Novotney, 1995; Pegram *et al.*, 1998; Quibell, 2000), each of which has advantages, as well as limitations. The following four general classes of non-point sources are identified by Pegram *et al.* (1998) and the Department of Water Affairs and Forestry (DWAF, 1999a), examples of each are presented in Table 2.1:

- **Concentrated**: localised high contamination areas with significant pollution potential, from which the surface wash off or leachate can be captured, including but not limited to mines, confined animal facilities, waste disposal sites, construction sites and certain industrial sites.
- **Diffuse-collected**: extensive areas from which surface runoff or leachate is collected into conveyancing systems, such as irrigation return flow from agricultural fields and stormwater runoff from urban areas.

- **Diffuse-uncollected**: extensive areas from which discharge to surface or ground water occurs in a diffuse and intermittent manner from the atmosphere or land.
- **Instream activity:** impacts on the integrity (health) of the aquatic habitat, including water quality, through activities directly in the surface water or in the riparian zone (aquatic environment), such as construction, dredging, ploughing, dumping, household or recreational activities.

Table 2.1 Examples of the general classes of non-point sources (from Pegram *et al.*, 1998)

Concentrated	Diffuse-collected	Diffuse-uncollected	Instream activity
Waste disposal sites	Irrigation drainage	Agricultural lands	Construction
Confined animal facility	Urban stormwater	Urban areas	Dredging
Mines		Informal settlements	Agriculture
Construction sites		Rural settlements	Livestock
Industrial sites		Transport infrastructure	Recreation
		Atmospheric deposition	

The relationship between these contaminant sources, the water environment and water users may be simplified into four generic elements. *Production* represents the generation of contamination at a source, *delivery* reflects the contaminant pathway between source and receiving water body, while *transport* is related to movement and transformation of the contaminant through the receiving water environment, which represent the resource upon which *use* is dependant (Pegram, Quibell & Görgens, 1997; Quibell, 2000). These four elements represent the process of water quality contamination and are based on constituents' availability and/or the availability of the medium in which the constituents are being transported. The next section provide some insight into what constitutes non-point source pollution by identifying specific contaminants and providing some indication of the potential problems that might result from their presence.

2.4 Types of pollutants and their effects on aquatic ecosystems

In the section below some important physical and chemical factors (water quality constituents) are discussed, as well as the major classes of non-point source pollutants which can affect aquatic ecosystems, such as sediments, nutrients (nitrogen and phosphorous), trace elements and heavy metals, macro-pollutants (litter, organic debris) and micro-organisms. It is important to note that any number of the known chemicals may conceivable be present in water, particularly in polluted water. They may occur in undetectable small amounts and may or may not have toxic effects. Others, such as the major ions, are present in greater or lesser quantities in natural water. Other inorganic substances are also present but usually at concentration orders of magnitude lower than those of the major ions. These inorganic substances include compounds of nitrogen and phosphorous and a host of elements present in trace quantities. Many of the heavier elements are extremely toxic but are seldom present at toxic concentrations under normal ambient conditions (Davies & Day, 1998). However, the number of soluble organic compounds that may occur in waters are far more than the inorganic substances. Most are products of the metabolism or decomposition of organisms and most are harmless to the biota. Although many organics are not intrinsically toxic, in large quantities (*e.g.* sewage) they may encourage the presence of decomposer microbes, which use up oxygen (O_2) and so make the water unfit for use. The effects of a few of these physical and chemical factors, as well as certain pollutants, are identified and discussed in the following sections.

2.4.1 Temperature

Water temperature can be a critical water quality characteristic in many streams. The temperature of water, particularly temperature extremes, can control the survival of certain flora and fauna residing in a body of water (Brooks, Folliott, Gregersen & Thomas, 1991). The type, quantity and well being of flora and fauna will frequently change with a change in water temperature. In general, an increase in water temperature causes an increase in the biological activity, which in turn places a greater demand on the dissolved oxygen (DO) in a stream (Maidment, 1993). Higher temperature reduces the solubility of DO in water, decreasing its concentration and thus its availability to aquatic organisms (Botkin & Keller, 1995; Davies & Day, 1998). The rate at which chemical reactions occur, however, increases with increasing temperature, for example photosynthesis and respiration. Therefore under conditions of increased temperatures caused by thermal pollution, organisms use more energy, which in turn requires more oxygen, even though less oxygen is available at higher temperatures. Thus, systems already lacking oxygen (due to organic pollution, for example) may be placed under even greater stress by the combined effects of organic pollution and increased temperature (Brooks *et al.*, 1991; Botkin & Keller, 1995; DWAF, 1996a).

2.4.2 pH

The pH value is a measure of the hydrogen ion activity in a water sample. For surface water, pH values typically range between 4 and 11 (DWAF, 1996a). Technically, the pH of water is the negative log, base 10, of the hydrogen ion (H+) activity in moles per litre (Brooks *et al.*, 1991). So by definition, as the (H^+) increases, the pH value decreases and the solution becomes more acidic; as (H^+) decreases, the pH value increases, and the solution becomes more alkaline. 'Alkalinity' is determined as 'acid neutralising capacity', which, in fresh water, is usually largely due to bicarbonate and carbonate ions (Davies & Day, 1998). The pH value at any time is an indication of the balance of chemical equilibrium in water and affects the availability of certain chemicals or nutrients in water uptake by plants. The pH of water also directly affects fish and other aquatic life (DWAF, 1996a). Generally, pH values less than 4.8 and greater than 9.2 are toxic (Brooks *et al.*, 1991). Most freshwater fish seem to tolerate pH values from 6.5 to 8.4; most algae cannot survive pH values greater than 8.5 (Brooks *et al.*, 1991).

2.4.3 Dissolved oxygen

Dissolved oxygen (DO) content is a measure of the ability of surface water to support aquatic life. The DO concentration of a water body is determined by the solubility of oxygen, which is inversely related to temperature, air pressure and dissolved solids (Brooks *et al.*, 1991; Maidment, 1993). Dissolved oxygen is a transient property that fluctuate rapidly in time and space (Brooks *et al.*, 1991). Under natural conditions the concentration of dissolved oxygen fluctuates diurnally, depending on the relative rates of photosynthesis and respiration. It is usually lowest near dawn, increasing during the day, peaking in the afternoon and decreasing at night (Davies & Day, 1998). Oxygen levels are naturally low where organic matter accumulates, because aerobic decomposer micro-organisms require, and so consume, oxygen. Certain oxygen-consuming chemical effluents reduce oxygen levels in water, but the most common anthropogenic causes of low oxygen levels are organically rich effluents such as sewage, and eutrophication (Davies & Day, 1998).

2.4.4 Biochemical oxygen demand and chemical oxygen demand

The biochemical oxygen demand (BOD) is an approximate measure of the amount of biochemical degradable organic matter present in a water sample (Chapman, 1992). It is defined as the amount of oxygen required for the aerobic micro-organisms present in a sample to oxidise the organic matter to a stable inorganic form (Chapman, 1992; Maidment, 1993; DWAF, 1996a). The BOD test is widely used as an indicator of the intensity of municipal and industrial wastes, and is important in protecting aquatic life from oxygen deficiency (Maidment, 1993).

The chemical oxygen demand (COD) is a measure of the pollutant loading in terms of complete chemical oxidation using strong oxidising agents (Brooks *et al.*, 1991). The COD test is widely used as a measure of the susceptibility to oxidation of the organic and inorganic materials present in water bodies and in the effluents from sewage and industrial plants. The COD test is non-specific, *i.e.*, it does not identify the oxidisable material or differentiate between organic and inorganic material present (Chapman, 1992). Similarly it does not indicate the total organic carbon present, since some organic compounds are not oxidised by the dichromate method whereas some inorganic compounds are oxidised (Chapman, 1992). Nevertheless, COD is a useful, rapidly measurable variable for many domestic and industrial wastes and has been in use for several decades.

2.4.5 Total dissolved solids

The total amount of material dissolved in a water sample is commonly measured as total dissolved solids (TDS), as conductivity or as salinity (Brooks *et al.*, 1991; DWAF, 1996a). TDS represent the total quantity of dissolved material, organic and inorganic, ionised and un-ionised, in a sample of water. Conductivity is a measure of the ability of a sample of water to conduct an electrical current, and is therefore a measure of the amount of ions in a solution (Maidment, 1993). TDS and conductivity are usually closely related for a particular type of water (Davies & Day, 1998). Salinity refers to the saltiness of water and for most purposes can be considered to be equivalent to TDS (Maidment, 1993; Davies & Day, 1998).

There are several reasons why TDS are an important indicator of water quality. Dissolved solids effect ionic strength, which has an impact on the mobility and transformation of metals and ionisable chemicals (Maidment, 1993). TDS are a major determinant of aquatic habitat that affects both aquatic biota and irrigated plants. Many aquatic plants and animals are adapted to fresh water or to salt water and cannot survive when the dissolved solids concentration is too high or too low (Brooks *et al.*, 1991; Maidment, 1993). TDS also affect saturation concentrations of dissolved oxygen and influences the ability of a water body to assimilate wastes. The rate of degradation of organic wastes is lower in salt water than in fresh water, whilst eutrophication rates also depend on TDS (Maidment, 1993). Domestic and industrial effluent discharges and surface runoff from urban, industrial and cultivated areas are examples of the types of sources that may contribute to increased TDS concentrations (DWAF, 1996a). Eventually TDS may increase until the water can no longer be used or provide a proper wildlife habitat.

2.4.6 Suspended solids and turbidity

All particles in the water column are called 'suspensoids' and they contribute to what is called 'total suspended solids' (TSS) (Davies & Day, 1998). Suspensoids also contribute to turbidity as they interfere with the passage of light through water. Turbidity is an indicator of the property of water that causes light to become scattered or absorbed. The lower the turbidity, the deeper light can penetrate into a body of water and, hence, the greater the opportunity for photosynthesis and higher oxygen levels (Brooks *et al.*, 1991; Maidment, 1993). Suspended clays, silts, organic matter, plankton and other inorganic and organic particles cause turbidity. Natural turbidity in rivers often increases with rainfall, as particles from surface soils, or from the hyporheos washed into the river (Davies & Day, 1998). When the flow rate returns to normal, most of these suspended particles drop to the riverbed.

Suspensoids that settle out may smother and abrade riverine plants and animals, fill up the interstices between rocks, deprive riverine animals of firm substratum to cling to, and blanket their food. Aquatic ecosystems subject to excessive sedimentation may be dominated by a few species of organism that are best able to cope with these alterations in habitat (Davies & Day, 1998). Suspensoids may, because of their small size, have a considerable surface area, and many of them carry electrical charge. A variety of dissolved substances, including phosphate and heavy metal ions can therefore become adsorbed onto surfaces of the particles. The consequences can be significant in that essential elements or nutrients may become unavailable. The particles themselves may also settle to the bottom and become part of the sediments.

Practices such as overgrazing, non-contour ploughing and removal of riparian vegetation, accelerate the rate of erosion and result in increased quantities of suspensoids entering streams (Gregory & Walling, 1985; Brooks *et al.*, 1991; Davies & Day, 1998). Various other anthropogenic activities (*e.g.* the release of sewage and industrial discharges into rivers; physical perturbations resulting from the construction of roads and bridges; air pollution and mismanagement of reservoirs) have been implicated in the increasing turbidity of streams (Gregory & Walling, 1985). When increases in anthropogenic-derived suspensoids are as infrequent as natural flooding is, the communities of organisms living in a stream may well handle them. Continuously high levels of suspensoids, on the other hand, which frequently occur in the study area, may have serious consequences for the biota in the river (DWAF, 1996a).

2.4.7 Nutrients

Nutrients provide chemical building blocks for sustaining life in aquatic systems. Some are required in large quantities for cell development and hence are classified as macronutrients, amongst others. These are carbon, oxygen, nitrogen, phosphorous, sulphur, silica, and iron (Chapra, 1997). Smaller quantities of micronutrients, such as manganese, copper, and zinc, are also necessary. In natural systems (*i.e.* water bodies relatively isolated from and undisturbed by human activities), nutrients are commonly derived from weathering and leaching of nutrients from rocks and soils. Most nutrients are not toxic to aquatic organisms, even in relatively high concentrations. When present in aquatic systems in high concentrations, nutrients may, however, significantly alter the structure and functioning of biotic communities because they stimulate plant growth, which in turn affects all the other components of the ecosystem. The quantity of nutrients dissolving naturally in water, depends on various climate and catchment characteristics, but the actual concentration may be significantly modified by the activities of the biota (Davies & Day, 1998). Studies on water quality usually focus on two macronutrients, nitrogen and phosphorous.

2.4.7.1 Nitrogen

Nitrogen is essential for living organisms as a constituent of proteins and genetic material (Chapman, 1992). Plants and micro-organisms convert inorganic nitrogen to organic forms. In the environment, inorganic nitrogen occurs in a range of oxidation states as nitrate (NO_3^+) and nitrite (NO_2), the ammonium ion (NH_4^+) and molecular nitrogen (N_2). It undergoes biological and non-biological transformations in the environment as part of the nitrogen cycle. The major non-biological processes involve phase transformation such as volatilisation, sorption and sedimentation (Maidment, 1993). The biological transformations consists of (Maidment, 1993):

- Assimilation of inorganic forms by plants and micro-organisms to form organic nitrogen;
- Reduction of nitrogen gas to ammonia and organic nitrogen by micro-organisms;
- Complex heterotrophic conversions from one organism to another;
- Oxidation of ammonia to nitrate and nitrite (nitrification);
- Ammonification of organic nitrogen to produce ammonia during decomposition of organic matter; and
- Bacterial reduction of nitrate to nitrous oxide and molecular nitrogen under anoxic conditions (denitrification).

Inorganic nitrogen is primarily of concern due to its stimulatory effect on aquatic plant growth and algae. Surface water from the surrounding catchment area, the discharge of streams containing human and animal excrement, agricultural fertilisers and organic industrial wastes are the major sources of inorganic nitrogen which enter aquatic systems (Chapman, 1992; DWAF, 1996a). In catchments with a high degree of human activity, the inorganic nitrogen arising from these activities can greatly exceed "natural" sources. In addition, many groups of bacteria are able to transform organic nitrogen to inorganic nitrogen during the decomposition of organic material (DWAF, 1996a).

Inorganic nitrogen is seldom present in high concentrations in unpolluted surface water (Maidment, 1993). This is because inorganic nitrogen is rapidly taken up by aquatic plants and converted into proteins and other organic forms of nitrogen in plant cells. In South Africa, inorganic nitrogen concentrations in unimpacted, aerobic surface water are usually below 0.5 mg/l but may increase to above 5–10 mg/l in highly enriched water (DWAF, 1996a). Where effluent discharges containing high ammonia or nitrate concentrations have impacted on aerobic water, background inorganic nitrogen concentrations rise. A decrease in the dissolved oxygen concentration and an increase in the COD and pH will usually accompany this (DWAF, 1996a).

Organic nitrogen consists mainly of protein substances (*e.g.* amino acids, nucleic acids and urine) and the product of their biochemical transformations (*e.g.* humic acids and fulvic acids) (Chapman, 1992). It is subject to the seasonal fluctuations of the biological community, as it is formed in water principally by phytoplankton and bacteria, and cycled within the food chain. Increased concentrations of organic nitrogen could therefore indicate pollution of a water body (Chapman, 1992).

2.4.7.2 Phosphorous

Phosphorous is an essential nutrient for living organisms and exists in water bodies as both dissolved and particulate types (Chapman, 1992; Chapra, 1997). From a water quality perspective, phosphorous is important because it is usually in short supply relative to the other macronutrients. This scarcity is due to three primary factors (Chapra, 1997):

- It is not abundant in the earth's crust and the phosphate minerals that do exist are not very soluble;
- It does not exist in a gaseous form; and
- Phosphate tends to absorb strongly to fine-grained particles. The settling of these particles, along with sedimentation of organic particles containing phosphorous, serves to remove phosphorous from the water to the bottom sediments.

In South Africa, phosphorus is seldom present in high concentrations in unpolluted surface water because plants actively take it up (DWAF, 1996a). Many human activities, however, result in phosphorous discharge in natural water. Human and animal wastes contain substantial amounts of phosphorous. Elevated levels of phosphorus may thus result from point-source discharges such as domestic and industrial effluents, and from diffuse sources in which the phosphorus load is generated by surface and subsurface drainage (Maidment, 1993; DWAF, 1996a; Chapra, 1997). Non-point sources include atmospheric precipitation, urban runoff and drainage from agricultural land, in particular from land to which fertilisers have been applied (Chapman, 1992; Maidment, 1993). The flow regime is a major factor in the mobility, availability and spatial distribution of phosphorus within a river. During rainfall events, phosphorus levels may be elevated by runoff from the land and by re-suspension and flushing of deposited material from the riverbed to the water column (DAWF, 1996).

2.4.7.3 Eutrophication

The term "eutrophication" was originally used to describe the natural ageing process whereby a lake is transformed from a lake to a marsh to a meadow (Chapra, 1997). This process can take thousand of years to occur naturally. The process can, however, be quickened by excess nutrients from human activities (DWAF, 1996a; Chapra, 1997; Davies & Day, 1998; Thornton *et al.*, 1999). This "over fertilisation" results in excessive plant growth and the phenomenon is generally referred to as eutrophication. In general, eutrophication can have a number of deleterious effects on water bodies (Chapra, 1997). These include:

- The profuse growth of floating plants decreases water clarity and some species produce unsightly scums. Further, certain floating plants can clog filters at water treatment plants and overgrowth of rooted plants can hinder navigation and recreation by clogging waterways;
- Plant growth and respiration can affect the system's water chemistry. Most notably, oxygen and carbon dioxide levels are directly affected by plant activity. Oxygen has implications related to the survival of organisms such as fish. The bottom water of thermally stratified systems can, In particular, become totally devoid of oxygen due to the decomposition of dead plants. Carbon dioxide can impact on pH; and
- Eutrophication can alter the species composition of an ecosystem. Native biota may be displaced as the environment becomes more productive. Certain species of algae result in taste and odour problems in drinking water. Further, certain blue-green algae can be toxic when consumed by animals. Many of these problems become prominent as the water body becomes more eutrophic.

2.4.8 Trace elements and heavy metals

'Trace elements' include all elements, both metallic and non-metallic, that occur in small (trace) quantities in the natural environment (Davies & Day, 1998). Examples are elements like beryllium and boron and also the rarer heavy metals. The term 'heavy metal' refers to all metals with atomic weight greater than that of calcium, and thus includes metals like iron, manganese, zinc, mercury and lead (Davies & Day, 1998). Most trace metals can be highly toxic, even at slightly elevated levels. The actual effects of trace metals in water are difficult to ascertain, because their toxicity is controlled by a number of chemicals and physical factors. These factors include the chemical species of the metal, the presence of other metals and organic compounds, the flow rate and volume of water in which they occur, the nature of the sediments, the temperature, the pH and the salinity (Davies & Day, 1998). Various heavy metals find their ways into the aquatic ecosystem as a result of human activities. Mines are the most obvious sources of trace metals, but pollution also stems from heavy industries that manufacture products, which contain metals as structural elements (Davies & Day, 1998). The main problem with trace elements and heavy metals is that they do not break down and so are very persistent pollutants.

2.4.9 Macro-pollutants

This class of non-point source pollutant consists primarily of the ubiquitous litter and organic refuse that can enter receiving water from stormwater runoff and/or illegal dumping (Thornton *et al.*, 1999). Few areas of the world are free from some type of litter and debris. When present in large quantities, litter is not only unsightly, but can obstruct stormwater drainage systems, leading to localised flooding and related water damage to human developments (Novotney, 1995). Litter that is not biodegradable (largely plastics) forms a major component of urban and industrial wastes (Van der Leeden, Troise & Todd, 1990). Introduction of this type of waste into receiving water is obviously a function of the frequency of refuse collection and street sweeping. In developing countries this is often very infrequent (Hayuma, 1983).

Inorganic litter is typically made up of durable goods (such as appliances, tyres and furnishings), non-durable goods (such as newspapers and the like) and containers and packaging materials. The occurrence of these materials in waterways is usually due to deliberate dumping which can be aggravated by a lack of refuse removal or lack of provision for small-scale disposal (Novotney, 1995). In-stream disposal of these items can introduce numerous contaminants to water bodies, including compounds such as refrigerants and volatile organics and hydrocarbons, which affect both human and environmental health. In the United States of America, inorganic debris accounts for the majority of the macro-pollutant load and comprises 71% of the municipal waste stream of 160 million tons/year, much of which can potentially be recycled (Thornton *et al.*, 1999).

Organic debris can be subdivided into unwanted human litter (*e.g.* cabbage leaves, carrot tops and vegetable matter often left over in marketplaces at the end of the business day), and naturally-occurring organic debris (*e.g.* leaf litter). Both categories of organic debris can enter water courses, as the result of urbanisation and the associated increase in impervious surface. In the United States of America, these organic components of the waste stream account for 29% of the annual municipal waste load; virtually none of which is recovered or composted (Thornton *et al.*, 1999). The input of excessive quantities of organic debris into receiving water bodies, as a result of stormwater drainage, can destroy the populations of benthic-dwelling organisms by increasing the biochemical oxygen demand associated with bacterial decomposition of the material.

Water quality impacts of macro-pollutants generally centre around aesthetic problems. As noted above, it can, however, also include reduced oxygen concentrations, deleterious changes in benthic communities, modification of stream-flow regimes, and the enhanced spread of human disease vectors. Non-biodegradable litter, like plastic, also has the potential to destroy higher trophic level organisms. Even when properly disposed of, leachate from landfills and disposal sites often contain many of the nutrients, toxins, and oxygen-consuming substances implicated in water quality deterioration (Novotney, 1995; Thornton *et al.*, 1999). Hence careful selection of such sites is indicated, as is provision of the means to treat or otherwise control the inevitable leachate that will be generated from such sites. Many communities find composting, recycling, alternative packaging, and energy recovery programmes increasingly cost effective as the global resource-base declines and the world economy shrinks. Even developing countries are finding that waste recovery carries with it substantial and sustainable economic and employment-related benefits that have repercussions throughout the country.

2.4.10 Micro-organisms

The principal micro-organisms of concern in freshwater include bacteria, fungi, algae, protozoa, worms, rotifers, crustaceans, and viruses (Tchobanoglous & Schroeder, 1987; Davies & Day, 1998; Hunter, 1998). The most common risk to human health associated with water stems from the presence of disease-causing micro-organisms. Many of these micro-organisms originate from water polluted with human excrement. Human faeces can contain a variety of intestinal pathogens, which cause diseases ranging from mild gastroenteritis to the serious and possible fatal, dysentery, cholera and typhoid (Chapman, 1992; Grabouw, 1996; Chapra, 1997). Depending on the prevalence of certain other diseases in a community, other viruses and parasites may also be present. The most common groups of pathogens associated with water pollution are summarised in Table 2.2.

Intestinal bacterial pathogens are distributed world-wide, the most common waterborne bacterial pathogens being *Salmonella, Shigella,* enterotoxigenic *Escherichia coli, Campylobacter, Vibrio* and *Yersinia*. Other pathogens occasionally found include *Mycobacterium, Pasteurella, Leptospira* and *Legionella* and the enteroviruses (poliovirus, echovirus and Coxsackievirus). Adenoviruses, reoviruses, rotaviruses and the hepatitis virus may also occur in water bodies and all viruses are highly infectious. *Salmonella* species, responsible for typhoid, paratyphoid, gastroenteritis and food poisoning, can be excreted by an apparently healthy person acting as a carrier and they can also be carried by some birds and animals. Therefore, contamination of water bodies by animal or human excrement introduces the risk of infection to those who use the water for drinking, food preparation, personal hygiene and recreation (Tchobanoglous & Schroeder, 1987; Chapman, 1992; Grabouw, 1996). Section 2.5 examines the diseases associated with these pathogens and the impact thereof on human health.

Table 2.2 Some waterborne pathogenic organisms (from Chapra, 1997)

Category	**Description**	**Species and groups**
Bacteria	Microscopic, unicellular organisms that lack a fully-defined nucleus and contain no chlorophyll.	*Vibrio cholerae* *Salmonella* *Shigella* *Legionella*
Viruses	A large group of submicroscopic (10-25 nm) infectious agents. They are composed of a protein sheath surrounding a nucleic acid core and, thus, contain all the information required for their own reproduction. However, they require a host in which to live.	Hepatitis A Enteroviruses Polioviruses Echoviruses Coxsackieviruses Rotaviruses
Protozoa	Unicellular animals that reproduce by fission.	*Giardia lambia* *Entamoeba histolytica* *Cryptosporidium* *Naegleria fowleri*
Helminths	Intestinal worms and wormlike parasites.	Nematodes *Schistosoma haematobium*
Algae	Large group of nonvascular plants. Certain species produce toxins.	*Anabaena flos-aquae* *Microcystis aeruginosa* *Aphanizomenon flos-aquae*

2.5 Impact of water quality on human health

Entering the 21st century, the Earth is the home for six billion people. Many of those live in wealth, but one billion people lack safe drinking water and almost three billion people (half of the world's community) lack adequate sanitation (Hunter, 1998; WSSCC, 2001). Unhygienic conditions and the lack of water and sanitation services cause more than two million children to die each year from water-related diseases (UNICEF, 2000; WHO, 2000; DWAF, 2001a; WSSCC, 2001). Developing communities suffer most from these diseases as these deaths represents approximately 15% of all child deaths under the age of five in developing countries. Furthermore about 10% of the population of the developing world are infected by intestinal worms and it is estimated that 6 million people are blind from trachoma (WSSCC, 2001). Waterborne diseases are thus the most important concern about the quality of water. Waterborne diseases are typically caused by enteric pathogens, which belongs to the group of organisms basically transmitted by the faecal-oral route (Grabouw, Taylor & Wolfraadt, 1996; UNICEF, 2000; WHO, 2000). They are mainly excreted in faeces by infected individuals, and ingested by others in the form of faecal contaminated water or food. Water plays a role in the transmission of pathogens, which are not faecally excreted. Some of the most prevalent water-related diseases and their causes are given in Table 2.3, while the major waterborne diseases of Africa are discussed in the next section (section 2.5.1 – 2.5.2).

2.5.1 Amoebic dysentery

A common waterborne diarrhoeal disease of Africa is amoebic dysentery, which can be ingested in contaminated food. Amoebic dysentery is caused by a protozoan parasite and it inhabits the intestines and may also invade the livers of humans (Davies & Day, 1998; Hunter, 1998). In most people, the amoeba, *Entamoeba histolytica*, causes no harm, but if the organism invades the tissue of the intestine through a fissure or rapture, then diarrhoea follows, with an accompanying loss of blood (Davies & Day, 1998). Fortunately, the disease is relatively easily controlled if medical support is to hand.

Table 2.3 Typical diseases associated with water (from Tchobanoglous & Schroeder, 1987; revised by Van Rooyen, 2002)

Category & method of contraction	**Disease**	**Causative agent**	**Symptoms**
Waterborne: Ingesting contaminated water	Amebiasis (amoebic dysentery)	Protozoan (*Entamoeba histolytica)*	Prolonged diarrhoea with bleeding, abscesses of the liver and small intestine
	Shigellosis (dysentery)	Bacteria	Severe diarrhoea
	Cholera	Bacteria (*Vibrio cholerae)*	Extremely severe diarrhoea, dehydration, high death rate
	Gastroenteritis	Virus	Mild to severe diarrhoea
	Gardiasis	Protozoan	Mild to sever diarrhoea, nausea, indigestion, flatulence
	Leptospirosis	Bacteria Spirochete	Jaundice, fever
	Salmonellosis	Bacteria	Fever, nausea, diarrhoea
	Typhoid fever: an example of Salmonellosis	Bacteria	High fever, diarrhoea, ulceration of small intestine
Water-washed: Washing with contaminated water	Shigellosis	Bacteria	Mild to sever diarrhoea
Water-based: Worm infections involving water as one stage in cycle	Guinea worm	Worm	Arthritis of joints
	Schistosomiasis	Worm	Tissue damage and blood loss in bladder and the bowel

2.5.2 Cholera

Cholera is a waterborne disease all too familiar in southern Africa. The relationship between cholera and contaminated and inadequate water supplies has long been well known and yet the disease still regularly takes its toll (UNICEF, 2000; WHO, 2000). The availability of clean water for drinking and washing is still inadequate in most of South Africa's rural areas, townships and informal settlements, so outbreaks of the disease are likely to continue. Cholera, caused by the enteric bacterium *Vibrio cholerae*, can spread with frightening rapidity and ease (Grabouw *et al.*, 1996; Davies & Day, 1998; Hunter, 1998). Routes for infection include any untreated or unboiled water, vegetables or fruit washed in contaminated water, food handled by infected people, contamination of food or water by faeces from an infected person, contamination of food by flies that have been in contact with infected people or their faeces, and direct contact with an infected person.

The fact that cholera is waterborne was established as long ago as 1854 in London, well before bacteria were discovered (Davies & Day, 1998). Ingested *Vibrio* bacteria multiply rapidly in the human gut, irritating the wall of the intestine and causing massive outpourings of fluid, accompanied by acute diarrhoea. It is not the diarrhoea that kills but the accompanying uncontrolled loss of body fluids, which leads to rapid dehydration and shock: death can occur within a frightening few hours of initial infection. The spread of the disease is complicated by the fact that people may unwittingly 'carry' the disease showing no symptoms whatsoever. Effectively, cholera should be a rare disease but a common illness. Simply boiling water before drinking, washing or preparing food will destroy the organism, so cholera is an easily preventable disease (Coetzee & Bourne, 1996).

2.5.3 Giardias

Giardias are a waterborne intestinal disease. These flagellated single-celled protozoans, mostly belonging to the species *Giardia intestinalis*, are ubiquitous parasites of the human gut and urinary tract (Davies & Day, 1998; Hunter, 1998). They normally do little harm, but recently there has been growing concern about the development of forms that are difficult to get rid of and cause severe diarrhoea. Fortunately, Giardias can be relatively easily treated if medical assistance and the appropriate drugs are to hand, but this is frequently not the case in rural Africa.

2.5.4 Typhoid fever

Although typhoid is commonly contracted through the ingestion of food or milk contaminated with the bacterium *Salmonella typhi*, it can also be waterborne (Coetzee & Bourne, 1996; Davies & Day, 1998). Human faeces may contaminate water supplies when sewage enters water supplies. Like the pathogen that causes cholera, *Salmonella* is a bacterium. It causes gastroenteritis accompanied by headaches, abdominal pain, vomiting and diarrhoea. Young children and the frail are most vulnerable to the disease and reduced overcrowding in human settlements, provision of adequate sanitation will go a long way toward reducing the ravages of this disease (UNICEF, 2000; WHO, 2000).

2.5.5 *Cryptosporidium*

Cryptosporidium is waterborne protozoan parasite that is ingested in untreated and poorly treated water. Rates of infection can reach 70% in areas with little or no proper sanitation (Davies & Day, 1998; UNESCO, 1999). It causes diarrhoea and bowel cramps and can be very unpleasant. Of course and tragically, young children and the frail are particularly susceptible to the organism. *Cryptosporidium* is becoming a matter of concern even in First World cities because it is difficult to trace in water supplies. It is also difficult to kill off during the process of purification of potable water unless specific, expensive steps are taken.

2.5.6 *Escherichia coli*

Escherichia coli is a non-pathogenic bacterium that occurs universally in the intestinal tracts of humans and many other mammals. As such, its presence in water supplies is used as an indicator of faecal pollution. *E. coli* is normally a harmless, and perhaps a useful, intestinal organism in humans. Where water supplies are contaminated and untreated, the bacterium, however, may change its nature, causing diarrhoea and gastroenteritis and become one of the greatest killers of young children and the frail in Africa (Huttley, 1990; Davies & Day, 1998; Hunter, 1998). Furthermore, the organism may also cause infections of organs such as the appendix, kidneys and gall bladder and one of the peritoneal cavities.

2.6 Chapter summary

This chapter has been written to provide some insight into what constitutes non-point source pollution by identifying specific contaminants and providing some indication of the potential problems or impacts that might result from their presence. The approach adopted has been to outline specific water constituents and categories of contaminants ranging from the microscopic and elemental to the macroscopic, which commonly impact on the natural waters throughout the world, and to give some indication of the quantities observed in various locales. Comments has been offered only on the impact of these contaminants on the aquatic ecosystem, and further discussion on the standards, guidelines and other criteria used to establish the critical levels at which these contaminants impact negatively on the aquatic ecosystem is given in the next chapter.

CHAPTER 3 WATER QUALITY MANAGEMENT

3.1 The history of water quality management in South Africa

The broader context within which water quality management occurs, largely determines the viability and success of measures to control pollution in South Africa. This context is not only determined by the current policies with regard to water resource management, but also by the evolution of these policies over the last few decades, as well as the wider institutional and socio-political environment in the country as a whole (DWAF, 1999c). The next section discusses the history of water quality management in South Africa as well as the evolution of our policies from the early nineties up to the promulgation of the new National Water Act (Act 36 of 1998).

3.1.1 The Union Health Act

The first national legislation to manage water quality was promulgated in 1919 (DWAF, 1999c). The Public Health Act of the Union of South Africa, 1919 (Act 36 of 1919) allowed the chief Health Officer to prevent effluent from sewage treatment works from being discharged into water courses. It was a requirement that sewage or sewage effluent had to be disposed off on land. This act distinguished non-point sources from point sources, some of which are still impacting on water quality today (DWAF, 1995; DWAF, 1999c).

3.1.2 The Water Act of 1956

From the pre-1950 to the past-1950 era South Africa underwent a change from an agriculturally based economy to one in which industry and mining played a major role. These changes coincided with the evolution from the Department of Irrigation in early stages to the present day Department of Water Affairs and Forestry. In 1956 the Water Act was promulgated. This Water Act was aimed at the control of industrial use of water and the treatment and disposal of effluent (DWAF, 1995).

By 1956 it also became clear that reconciling water supply with water demand would be increasingly difficult and that the re-use of effluent would have to play a major role in the management of the country's scarce water resources (Van der Merwe & Grobler, 1990). The earlier requirement that prohibited the disposal of effluent to natural water courses had to fall away. In fact, the water act required that all effluent be returned to the water body from which it was originally abstracted. The Act recognised the fact that effluent that is returned to the water environment could lead to deterioration in water quality and therefore required that all effluent complied with Uniform Effluents Standards (DWAF, 1995). These Standards contained the General Effluent Standard, the Special Standard and later also the Special Standard for Phosphate. This approach presented several advantages (DWAF, 1999c):

- It was administratively very simple, and could be implemented at regional level with little input from the head office water quality management component;
- Dischargers knew what was expected of them and could design pollution management works accordingly; and

- The system was also uniform across the country, but still recognised that some water resources needed a higher degree of protection, and hence specified them as Special Standard areas.

While the advantages streamlined the control of point sources, the Act offered a number of disadvantages (DWAF, 1999c):

- It did not address non-point sources;
- It treated all source types identically, in spite of obvious differences in the make-up and impacts of their effluents, technology available for treatment, and the differing economics of the sources;
- Standards were based on technology that soon became outdated; and
- It did not allow for specifying different standards where the volume of effluent or number of pollution sources warranted more stringent water quality management.

3.1.3 The Water Amendment Act

The promulgation of the Water Amendment Act (Act 96 of 1984), broadened water quality management as it gave the DWAF wider powers to address any activity that could render the water resource less fit for use, and allowed for site-specific standards to manage pollution (DWAF, 1999c). For the first time the Act made provision for managing non-point source pollution and the formulation of standards based on both the characteristics of the source and of the receiving water resource.

3.1.4 The policies of the early 1990s

Even though water quality management has traditionally been more advanced than other areas of environmental management in South Africa (Marjanovic, Miloradov & Van Zyl, 1998), there had been "a steady decline in water quality country-wide", as is stated in the *Executive Summary of Water Quality Management Policies and Strategies in the RSA*, published by the DWAF in April 1991. The 1991 policy reflects a major change in the direction of water quality management. Previously water quality management was dealt with as an isolated problem. The 1991 policy announced an "overarching general management system" for the management of both water quality and quantity issues within the parameters of general developmental and environmental management (Barnard, 1999; Glazewski, 2000). The approach outlined in the 1991 policy statement, and adopted by the DWAF, was the Receiving Water Quality Objectives (RWQO) approach together with a pollution prevention approach for hazardous pollutants. The RWQO approach was based on the assimilative capacity of water resources. This approach, may, however, lead to the deterioration of the water resource to a point where it was just fit for use (DWAF, 1999c). The DWAF, therefore, advocated an "anticipatory or precautionary" approach to water quality management. This mean that positive action should be taken to avert or minimise the risk of impact on the water environment, even if and when these impacts could not be directly proven. In 1995 the DWAF expanded on its precautionary approach to water quality management (DWAF, 1995). This document, *Procedures to Assess Effluent Discharge Impacts*, emphasised a pollution hierarchy whereby dischargers would firstly investigate all means to prevent the introduction of waste to the water environment. Only if this was not technically feasible or economically viable, would consideration be given to adopting the specified minimum standards, or calculated standards based on the RWQO, where these standards were not stringent enough. This pollution hierarchy recognised the current global trend with respect to pollution management (*i.e.* pollution prevention and the principles of the ISO 14000 series).

Within a period a little less than a decade the DWAF has thus transformed its water policy in the management of South Africa's water resources from a strong supply orientation approach to a catchment based management, demand management and participatory management approach (Bofilatos & Karodia, 2000). During the last part of the nineties, two further documents, which are of special reference to the study, emanated from this approach by the DWAF. The first is the National Water Policy for South Africa published in 1997 and the second is the National Water Act, which was promulgated in 1998 (Act 36 of 1998).

3.1.4.1 The White Paper on a National Water Policy for South Africa

This document refers to the management of our water resources with particular reference to catchment management, water conservation and demand management, water allocations and the institutional arrangements required to implement the water policy. It places a strong emphasis on redressing the imbalances of the past regarding access to water and place a strong focus on the sustainable and the beneficial use of water by all sectors (Bofilatos & Karodia, 2000). The main water quality management functions, according to the policy, which should be approached in an integrated manner, are resource allocation, resource protection, resource use and conservation, monitoring, planning, development and operation (Marjanovic *et al.*, 1998). The complexity of an integrated approach to water quality management, as defined by the policy, requires optimum rather than simply beneficial solutions and practices. This requirement will have, according to Marjanovic *et al.* (1998), profound and far reaching consequences how water quality is managed in the future. The other consequence of the National Water Policy is that water quality management will be implemented on the catchment level, but will remain subject to national authority. An institutional framework will thus reflect the central responsibility of the National Government as custodian of the nation's water resources.

The policy further requires two separate sets of measures for water quality management. The first are resource-directed measures, which set clear objectives for the desired level of protection for each resource. The second are source-directed controls that aim to control what is done to the water resource so that the resource protection objectives are achieved. These include source reduction measures that aim to reduce or eliminate the production of potential pollutants that could harm the water resources.

The White Paper on a National Water Policy for South Africa thus highlighted some overarching policy considerations and provided the basis for the new National Water Act and the way water quality will be managed in South Africa. The new approach is based on an efficient, transparent, integrated water quality management system with a dual approach to effluent control based on effluent standards and receiving water quality objectives.

3.1.4.2 The National Water Act of 1998

The introduction in 1998 by the DWAF of the National Water Act (NWA) 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 NWA, as a whole, gives effect to the Constitutional right of access to water and the environmental right ensuring its protection and conservation. The fundamental principle that guides the NWA is that water is a national resource, owned by the people of South Africa and held in custodian by the state (NWA, Section 3). This principle allows the state to have total control over the utilisation of the resource and allows for mechanisms to be put in place to manage water resources using a more holistic, ecologically based approach, taking into account the entire water cycle (Hamann, Booth & O'Riordan, 2000).

The following abstracts from the National Water Act highlight the perspectives and approach of the Act towards the management of water quality:

"The purpose of the Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways that take into account amongst other factors:

- Meeting the basic human needs of present and future generations;
- Promoting equitable access to water;
- Redressing the results of past racial and gender discrimination;

- Promoting the efficient, sustainability and beneficial use of water in the public interest;
- Facilitating social and economic development;
- Providing for growing demand for water use;
- Protecting aquatic and associated ecosystems and their biological diversity;
- Reducing and preventing pollution and degradation of water resources;
- Meeting international obligations;
- Promoting dam safety; and
- Managing floods and droughts."

In exercising the implementation of the NWA, the Act provides for Catchment Management Agencies (CMA) to be created in Water Management Areas (WMA). Each CMA will have to draw up a management strategy for their particular WMA and will have to perform vital functions for the implementations of the NWA. The development of these catchment management strategies is the foundation upon which integrated water resource management at catchment level will be implemented: *"The protection of water resources is fundamentally related to their use, development, conservation, management and control. A series of measures are laid down that together intend to ensure the comprehensive protection of all water resources. These measures are to be developed progressively within the context of the national water resource strategy and the catchment management strategies"* (NWA, 1998).

The *"Reserve"* (NWA, Section 16) is probably the most significant innovation of the NWA. With this measure, the NWA seeks to implement two of its most important aims, namely the allocation of adequate water – in terms of quantity and quality – for the country's population, as well as its ecosystems (Hamann *et al.*, 2000). Consequently the Reserve consists of two parts, the basic human needs reserve and the ecological reserve, which need to be proclaimed for each "significant water resource". The human rights reserve relates to the basic right for all persons to have access to a minimum amount and quality of water for living and daily tasks, *e.g.* drinking, food preparation and personal hygiene. This quantity is commonly put at 25 litres per person per day, accessible within cartage of no more than 200 m. The ecological reserve refers to the minimum quantity and quality of water necessary for ecosystem health. However, much like the definition of the human needs reserve, the allocation of water to the ecological reserve is problematic and socially framed. According to Hamann *et al.* (2000) this natural 'right' will increasingly be influenced by the political structure and stakeholder effectiveness of the CMA. The Reserve is therefore institutionally framed and will be a product of allocation politics, not geohydrology (NWA, 1998).

Section 19 of the NWA deals with prevention and remedying of the effects of pollution, and pollution prevention. In this section a general pollution duty is prescribed for an owner of land, person in control of land or a person who occupies or uses land on which any activity or process is or was performed or undertaken, or any other situation exists, which causes, has caused or is likely to cause pollution of a water resource. This duty stipulates that these identified persons must take all reasonable measures to prevent the pollution from occurring, continuing or recurring (NWA, Section 19(1)). Some important features of the duty include:

- "Water resource" is defined in the NWA as including a water course, surface water, estuary or aquifer (Section 1(1)(xxvii));
- The duty envisaged not only current or future pollution, but also historic activities or processes which cause or may cause water pollution and historic pollution;
- Actual water pollution does not need to have occurred before the duty exists, the mere likelihood of pollution is sufficient;
- The reasonable measures to prevent pollution may include:
    - Ceasing, modifying or controlling any act or process that causes pollution;
    - Complying with any prescribed waste standard or management practice;
    - Containing or preventing the movement of pollutants;
    - Eliminating any source of pollution;
    - Remedying the effects of the pollution; and
    - Remedying the effects of any disturbance to the bed or banks of a water course.

Section 19 further allows for a directive to be issued by the catchment management agency where an activity is undertaken on land that causes, has caused or is likely to cause pollution to the water resource: "The person who owns, controls, occupies or uses the land in question is responsible for taking measures to prevent pollution of water resources. If these measures are not taken, the catchment management agency concerned may itself do what ever is necessary to protect the pollution or to remedy its effects and to recover all reasonable costs from the person responsible for the pollution".

The NWA does not specifically differentiate between point and non-point sources of pollution and thus allows for the development of source-specific procedures that address both point and non-point source pollution from the source, which will in fact promote the integrated vision of water quality management (DWAF, 1999c). The NWA reflects thus the most far-reaching environmental law reform made by the government and illustrates an unsurpassed example in South Africa law of how social equity, economic needs and natural resource management can be accommodated in a composite Act of Parliament. The challenge is going to be for administrators, implementers and others (*e.g.* researchers) to ensure that ideals and aspirations are converted into reality.

3.1.5 Other legislation

Other legislation that also addresses the issue of managing water pollution is sections 20 and 24 of the Environment Conservation Act 73 of 1989, which contains enabling legislation for the siting and management of waste disposal sites. The National Environmental Management Act 107 of 1998 can be applied to manage pollution generally, as well as the White Paper on Integrated Pollution and Waste Management. The Conservation of Agriculture Resources Act 43 of 1983 contains guidelines for agriculture-related water management guidelines, while both the Health Act 63 Of 1977 and the Minerals Act 50 of 1991 contain structures that should ensure effective water management.

3.2 The concept of water quality in the management milieu

The previous discussions and chapter have succeeded in highlighting the fact that water is a limited resource, which is subject to many demands. As the population and technology expand, the demands on available water resources increase, as does the complexity of environmental issues (Maidment, 1993). The discussions made it further clear that poor water quality can affect aquatic life as well as the use of water by humans for drinking, recreation, agriculture and industry. Pollution and water quality degradation thus interfere with vital and legitimate water use on any scale (local, regional or international). Water quality criteria, standards and the regulated legislation are used as the main administrative means to manage water quality in order to achieve user requirements (Meybeck, Chapman & Helmer, 1989). The next section gives a preview of the definition of water quality, general water quality objectives, water quality standards and also examines the water quality guidelines as currently used by the DWAF, which was used as reference level in this study.

3.2.1 Definition of water quality

In view of the complexity of factors determining water quality, and the large choice of variables used to describe the status of water bodies in quantitative terms, it is difficult to provide a simple definition of water quality. Furthermore, our understanding of water quality has evolved over the past century with the expansion of water requirements and the ability to measure and interpret water characteristics (Chapman, 1992). The DWAF (1996a) use the term water quality to describe the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for the protection of the health and integrity of aquatic ecosystems. Meybeck and Helmer (1989) define the quality of the aquatic ecosystem by:

- A set of concentrations, specifications and physical partitions of inorganic or organic substances, and
- The composition and state of aquatic biota found in a water body. The quality of the aquatic environment shows temporal and spatial variations due to factors internal and external to the water body.

For the purpose of simplicity the term 'water quality' is used throughout the thesis to describe the overall quality of the aquatic ecosystem.

3.2.2 Water quality criteria

Water quality criteria generally describe the quality of water needed to protect and maintain individual water uses (ECE, 1993). The protection and maintenance of water use, such as drinking water, agriculture and recreation usually impose different requirements upon water quality and, therefore, water quality criteria may be different for these uses (ECE, 1993). Maidment (1993) defines a water quality criterion as that concentration, quality or measure (*e.g.* temperature) that, if achieved or maintained, will allow or make possible a specific water use. A criterion may be a concentration range that, if not exceeded, will protect an organism, an aquatic community, or designated use with an adequate degree of safety (DWAF, 1995). A criterion may also be a narrative statement concerning some desirable condition. While water quality criteria are often the starting point in deriving standards, criteria do not have a direct regulatory impact because they relate to the effects of pollution rather than its causes (AWWA, 1993; Maidment, 1993).

Water quality criteria are defined in the South African water quality guidelines as scientific and technical information for a particular water quality constituent in the form of numerical or narrative descriptions of its effects on the fitness of water for the protection of the natural aquatic environment and for water use (DWAF, 1995). It is defined in different ways in the international literature, for example:

- USEPA (1986): a designated concentration of a constituent that, when not exceeded, will protect an organism or a prescribed water use or quality with an adequate degree of safety;
- Canadian Guidelines (1992): scientific data evaluated to derive recommended limits for water use; and
- Australian Guidelines (1991): scientific and technical information used to provide an objective means for judging the quality needed to maintain a particular environmental value (water use).

3.2.3 Water quality objectives

Water quality objectives aim at ensuring the multipurpose use of fresh water, *i.e.*, its use for drinking, irrigation, recreation and other purposes, while supporting and maintaining aquatic life and/or the functioning of aquatic ecosystems (ECE, 1993). Water quality objectives provide the basis for pollution control regulations and for undertaking specific measures for the prevention, control or reduction of water pollution and other adverse impacts on aquatic ecosystems (ECE, 1993). A water quality objective is defined by the DWAF (1995) as a concentration or level, not to be exceeded for a water body, to ensure its fitness with a given measure of reliability. This is an achievable value, determined by considering the water quality requirements of recognised water users and for the protection of the health of the natural aquatic environment as well as relevant physical, technological, economic and socio-political issues. Water quality criteria serve as a baseline in establishing water quality objectives in conjunction with information on water uses and site specific factors. According to ECE (1993) information is gathered on the basis of:

- "Inventories of current and potential new water uses;
- Inventories of emission sources including point and non-point sources, and of sites of production, use, storage and disposal of hazardous substances which could accidentally be emitted into aquatic ecosystems;
- Results of water quality monitoring and/or water quality assessments and classifications;
- Surveys of specially protected water such as drinking water reservoirs and groundwater, and specially protected areas such as wetlands; and
- Results of hydrological measurements and related information (*e.g.* runoff and hydraulic characteristics of water bodies)".

3.2.4 Water quality standards

The first drinking water standards were issued at least 4000 years ago (AWWA, 1993). The term *standard* may be applied to any definite rule, principle, or measure established by authority (Tchobanoglous & Schroeder, 1987). A water quality standard is defined by Maidment (1993) as the translation of a water quality criterion into a legally enforceable ambient concentration, mass discharge or effluent limitation expressed as a definite rule, measure or limit for a particular water quality parameter. A standard may or may not be based on a criterion. A water quality standard is an international term, which is defined as:

- Canadian guidelines (1992): an objective that is recognised in enforceable environmental control laws of a level of government;
- Australian guidelines (1991): what guidelines (perhaps further modified by social, political and/or economic considerations) become when compliance is mandated by law; and
- USEPA (1986): a standard connotes a legal entity for a particular reach of waterway or for an effluent.

Standards may differ from criteria because of prevailing local quality conditions, such as natural impairment of water quality. For example, some natural water may exceed some water quality criteria even in the absence of anthropogenic pollution. Standards and criteria may also differ from one place to another owing to economic considerations, the perceived importance of a particular ecosystem or the degree of safety required for a particular use (DWAF, 1995). According to Tchobanoglous and Schroeder (1987) two general methods are in use for setting standards: (1) governmental stipulation and (2) a policy of minimum degradation, whilst Maidment (1993) lists the following factors as the basis for the establishment of water quality standards:

- "Established and ongoing practice or experience;
- Existing criteria;

- Bioassays to establish new criteria;
- Evidence derived from accidental human exposure;
- Epidemiological studies;
- Educated guess based on available information and judgement;
- Application of mathematical models (*e.g.*, those that simulate health risks);
- Economic attainability of specific industries; and
- Legal enforceability".

Considering the factors involved in establishing standards, it is clear that they must be dynamic in nature. Water quality standards should be subject to revision and upgrading in the light of ongoing developments. Once established and accepted, standards are, however, considered to be legal requirements and are extremely difficult to change (Tchobanoglous & Schroeder, 1987).

3.2.5 Water quality guidelines

Water quality guidelines are a set of information documents provided for a specific water quality constituent. It consists of the water quality criteria, including the target water quality range (TWQR) for that constituent, together with other supporting information such as the occurrence of the constituent in the natural aquatic environment, the norms used to assess its effects on water uses, how these effects may be mitigated and possible treatment options (DWAF, 1996a). Water quality guidelines are also defined in the international literature as:

- Canadian guidelines (1992): a numerical concentration or narrative statement recommended to support and maintain designated water use;
- Australian guidelines (1991): water quality guidelines translate the criteria into a form that can be used for management purposes; and
- WHO (1984): the level of a constituent that ensures aesthetically pleasing water and does not result in any significant risk to the health of the consumer.

The South African Water Quality Guidelines (WQGs) consist of the guidelines for domestic, recreational, industrial and agricultural water uses as well as guidelines for the protection and maintenance of the health of the natural aquatic environment. The guidelines are used by the DWAF "as its primary source of information and decision-support to judge the fitness of water for use and for other water quality management purposes" (DWAF, 1996a). The South African WQGs, published in eight volumes, describe the acceptable level of substance or constituents for different water users and a summary of each volume is provided in the following sections.

3.2.5.1 Domestic use

Volume one of the WQGs provides the guidelines for domestic use. The subcategories for water use are drinking, cooking, bathing, washing of clothes and gardening. The fitness of the water for each of the subcategories is evaluated for health impacts, for economic impacts such as the increase in cost of staining of laundry, and for economic impacts such as the increased cost of treatment and the corrosion of pipes and others. The constituents that can affect water quality, such as algae, ammonia, arsenic and cadmium are listed.

For each of these a wide range of information is provided, *viz.* occurrence, interactions with other constituents, how it is measured and how data should be interpreted. In a useful table the target water quality range with reference to standards such as milligrams per litre (mg/l) is provided, starting with the range where no adverse effects can be expected followed by the adverse effects as the concentration increases (DWAF, 1996a).

3.2.5.2 <u>Recreational use</u>

Volume two lists subcategories of recreational use as full-contact recreation (swimming or diving), intermediate-contact recreation (water-skiing, canoeing or angling) and non-contact recreation (hiking alongside water bodies and the appreciation of scenic aspects of water). The fitness of water use is considered with regard to its impact on human health such as skin and ear infections and gastroenteric diseases. The impact on human safety is considered with reference to aspects such as poor visibility of underwater hazards and algal growth making rocks slippery. Bad odours, discolouration and staining, objectionable floating matter and nuisance plants are considered under aesthetics. The damage to equipment such as boats, caused by factors such as poor visibility, is also discussed.

3.2.5.3 <u>Industrial use</u>

The subcategories of industrial use include the use of water for cooling, steam generation, as process water, as production water and as utility water. The fitness of the water for use is evaluated according to its corrosiveness, scaling, fouling, forming of blockages, foaming, gas production, contamination, coagulation, turbidity, waste disposal and others. The constituents include its alkalinity, chemical oxygen demand, pH, chloride, iron, manganese, silica, sulphates, and several others.

3.2.5.4 Agricultural use

In volume four the first agricultural category of the fitness of water used for irrigation is considered. The water quality is categorised with reference to whether its constituents make it ideal, acceptable, tolerable, unacceptable or completely unfit for use. In volume five the second agricultural category of the fitness of water for the various livestock production systems is considered. It is evaluated by considering whether it is fit for livestock consumption (referring to the palatability and toxicological effects), for livestock-watering systems (referring to the economic impacts of scaling, the corrosion of pipes and others) and the livestock product quality (referring to consumer health hazards and product quality problems). In volume six the third agricultural category of the fitness of water for various aquacultural purposes is considered. The quality required of water for farming with products such as fish in lakes, dams, fish ponds and tanks is considered.

3.2.5.5 Aquatic ecosystems

In volume seven water quality required for aquatic ecosystems is described. Although aquatic ecosystems are, strictly speaking, not water users, they can be managed properly by applying the same discipline and strategy. The focus in this volume is how to manage water quality in a holistic manner. Aquatic ecosystems are made up of a wide variety of different constituents, components and processes. The management should focus on maintaining the assimilative capacity of water bodies for certain wastes for self-purification; providing an aesthetically pleasing environment; serving as a resource used for recreation; providing a livelihood to communities dependent on water bodies for food; and maintaining biodiversity. A variety of constituents are listed and discussed.

The DWAF initiated the development of the *South African Water Quality Guidelines* as a common basis from which to derive water quality objectives in order to achieve the overarching goal of maintaining the fitness of water for specific use and to protect the health of aquatic ecosystems. These guidelines thus serve as the primary source of information for determining the water quality requirements of different water uses and maintenance of the health of aquatic ecosystems. The data obtained during the field monitoring and from the laboratory analysis were compared and evaluated against the values given in the guidelines. The tables in Appendix 1 were compiled by abstracting the relevant sections from these water quality guidelines that are applicable to the study.

3.3 Water quality management in developing communities

While the previous section deals with the different policies and stipulations for water quality, the focus of this section is on the problems usually encountered with the implementation of water quality in a developing region. As pollution of the aquatic environment takes place within the social, political, institutional and economic environment of a country, these resources determine the location, extent and amount of water resource pollution, and therefore also influence how the sources are managed (DWAF, 1999c; Thornton *et al.*, 1999; Agrawal, 2001). These issues, however, also influence the viability of management approaches, procedures and practices. As point sources of water pollution have been managed and controlled over the last decade, the remaining problem of non-point sources of water has now emerged clearly (Bau, Ferreira, Duarte-Hentiques & De Oliveira-Raposa, 1991; Novotney, 1995; DWAF, 1999c; Thornton *et al.*, 1999; Quibell, 2000). Non-point source pollution, as discussed in Chapter 2, is a leading cause of surface water quality problems and is also a source of groundwater contamination in many areas of the world. Further progress in improving the world's water quality will therefore require accelerated implementation of non-point source management programmes to control diffuse sources of pollutants in addition to ongoing point source control (DWAF, 1999a; Thornton *et al.*, 1999).

It, however, is a reality that most non-point source pollution studies, as well as practical experiences with non-point source control programmes, have occurred in developed nations. This is due in part to previous experiences in developed countries in dealing with degradation of aquatic ecosystems (Novotney, 1995; Thornton *et al.*, 1999; Agrawal, 2001). Non-point source pollution of aquatic ecosystems is more diffuse and subtle in character than point source pollution. The efforts necessary to identify and study non-point source pollution tend to be more technically complex, time consuming and expensive than point source control efforts. As a result, identification of non-point source pollution problems, and initiation of necessary control programmes, is often hindered or ignored in developing countries (Thornton *et al.*, 1999). However, where some attention to non-point source pollution is being given in developing countries, it merely follows the recent trends of what is being done in developed countries by copying blindly without any serious effort of evaluating objectively or even examining field situations (Agrawal, 2001). The numerous differences between developed and developing countries in culture, life-styles, perceptions of environmental quality, apart from the differences in economic resources, levels of technology, and many other factors, however, necessitate some modifications even in the objectives and targets for water quality management with regard to non-point source pollution in developing countries.

According to Novotney (1995), Thornton *et al.* (1999) and Agrawal (2001), the most compelling causative factor for non-point source pollution in developing countries is poverty. Lack of financial resources dictate that local inhabitants use the least expensive land use and land-management techniques. Unfortunately, this often is the most environmentally degrading approach. Although debated among the 'have' and the 'have-not' nations, it seems clear that the ability of developing nations to adequately address non-point source pollution will be limited by the relatively poor economic situation existing in these nations. In addition to the economic status, the political and social conditions in developing countries are usually underlying causes of water quality problems. These factors largely determine the behaviour of individuals within communities and the resources available to manage the water quality impacts of the community, as will be discussed in the next section.

3.3.1 Socio-economic factors influencing water quality management

There is considerable literature on developing communities living and working in poor conditions (Hardoy & Satterthwaite, 1992; Binns, 1996; Morris, Patel & Byerley, 1996; Krige, 1997; Schmidt, 1998; Agrawal, 2001). These communities are focused on the need to survive and therefore find it difficult to share the developed world's concern and awareness of the environment. Many socio-economic issues are significantly influenced by the political culture of a community. Rural or urban orientation could dictate political affiliation and may also influence environmental awareness. Historical events may, furthermore, influence the behaviour and response to proposed interventions. Payment for services and expectations of appropriate service levels are typical examples (DWAF, 1999a).

At present the South African government has committed itself to ensure that all people will have access to at least 25 litres per capita of clean water a day (DWAF, 1994). The department sees this as a bare minimum for health and it should not be regarded as adequate for a full, healthy and productive life. This commitment by the government implies that this water, and the infrastructure needed for individuals to obtain it, will be provided free to those households, which are indigent and unable to pay for services (Goldblatt, 1999). The free provision of water at the 25 litres per capita per day level is, however, a substantial financial commitment and free provision above this basic level would place unsustainable demands on the financial resources of local governments. Payment for municipal services is thus fundamental to the sustainable financial operation of local authorities. According to Cairncross (1992), the principal challenges in the progress and success of water and sanitation programmes will not be the 'hardware' of water and sanitation supply, but the 'software' issues. One key software issue concerns the issue of household and community "willingness to pay" for water and sanitation as the organisation and financing of these programmes hinge upon this response (Rogerson, 1996). According to the DWAF (1999a), willingness to pay determines the actual payment level. It is linked to both affordability and an individual's perceptions and priorities, which are often related to political and social factors (CSS, 1996; Goldblatt, 1999).

The functioning of municipal services is also dependent on their appropriate use by the residents of the community (DWAF, 1999a). Inappropriate use of services may be attributed to several factors such as:

- The lack of an alternative, which is usually associated with inadequate service levels or functioning;
- Ignorance of the implications of behaviour or correct methods of use;
- Impractical or unrealistic conditions associated with services; and
- Direct benefit for individuals such as vandalism and illegal connections.

As discussed in the first part of this chapter, South African government agencies have been actively developing policies, strategies and minimum standards with respect to the delivery of services, housing, land tenure and land restoration. Minimum standards have been set at levels which are considered to provide the basic levels of service to alleviate the plight of disadvantaged communities, but which are also considered to be affordable to the community (DCD, 1996; DWAF, 1999a). However, many developing communities expect and demand high levels of municipal services (DWAF, 1999a). Higher levels of services are often not affordable to the community, and are thus not sustainable in the short to medium term. Services that are unlikely to be maintained may create even more serious pollution problems and the pollution risk to stream and other water resources is therefore increased (DWAF, 1999a).

3.3.2 Key municipal services

The key municipal services investigated in this study were water supply, sanitation, stormwater drainage, solid waste management and energy. Whilst the reasons for including these services in the study are summarised next, the level of services in the study area is discussed in Chapter 4 and the functioning of the services as well as the problems experienced and their associated impact on the water quality of the Fontein Spruit is discussed in Chapter 6.

3.3.2.1 Water supply and sanitation

A clean, safe and reliable water supply greatly improves the quality of life and health of residents in poor and developing settlements. Where access to clean water is restricted, households have to resort to using whatever resources are available, such as streams or pools of standing water, which may be contaminated. This contaminated water promotes the transmission of diseases. The access to water and water services has been substantially altered under the new National Water Act. Legislation has divorced access to water from land ownership, and has removed the previous expectation of permanent rights to water (Schreiner & Naidoo, 1999). The new policy and legislative tools have enabled the government to make some major inroads into changing access to water and water services in South Africa. Since 1994 the DWAF has brought water services to 7 million people at a cost of R4.22 billion (DWAF, 2001a). However, it is unlikely that more than 6 million have gained access to water at the RDP standard of 25 litres at 200 m (Still, 2001). Installations have mainly been in the form of communal taps. These communal taps require water to be carried and stored and high contamination levels can be expected. Problems are further compounded in situations where stand-pipe designs did not allow for soak-aways, which result in pools of stagnant water. In a country where mosquito-borne diseases are spreading, this could introduce another disease vector into already vulnerable communities.

Even though the DWAF made these significant investments in the provision of safe water supplies for all, the health benefit of this investment is limited where inadequate attention is paid to sanitation and to health and hygiene promotion. International experience shows that once people's basic needs are met (especially the provision of clean water), sanitation improvements together with health and hygiene promotion result in the most significant impact on their health. Providing adequate sanitation facilities for the poor remains therefore one of the major challenges in all developing countries. An estimated 18 million South Africans or three million households do not have access to adequate sanitation facilities (DWAF, 2001b). Those who have inadequate sanitation may be using the bucket system, unimproved pit latrines or the bush. In addition there is a disturbing increase in poorly designed or operated waterborne sewerage systems, especially in urban areas. When sanitation systems fail, or are inadequate, the impact on the health of the community, on the health of others and the negative impact on the environment and water resources can be extremely serious as witnessed by the 1.5 million cases annually of diarrhoea in children under the age of 5 years, as well as the recent outbreaks of cholera in certain regions of South Africa (UNESCO, 1999).

Sanitation systems involve the disposal and treatment of wastes. A lack of adequate sanitation or inadequately maintained or inappropriately designed systems can therefore constitute a range of pollution risks to the environment, especially the contamination of surface and ground water resources. Although water systems are able to tolerate a certain degree of pollution there is a limit to the amount that can be assimilated without causing the water quality to deteriorate to such an extent that the water cannot be used. Factors that affect the impact of sanitation systems on water quality are:

- Size and density of the settlement being served;
- Sensitivity of the receiving water resource;
- Type of sanitation system;
- Capacity of the service provider to manage the system; and
- Depth to ground water and the soil type.

Pollution resulting from failed or inadequate sanitation systems is associated with:

- Waterborne disease caused by direct contact with faecal contaminated water;

- The growth of aquatic plants (mostly algae), which in turn results in increased treatment costs, reduced recreational value of the water body, possible growth of toxic algae and loss of bio-diversity; and
- Depletion of the oxygen in the water column, which can also result in a loss of bio-diversity, and complete shift in the natural biota of the stream.

Whilst the financial cost of providing a basic level of sanitation is easily quantifiable, the economic cost of inadequate sanitation on the health of the community and the aquatic ecosystem is not. The World Health Organisation and the United Nations Children Fund (UNICEF, 2000; WHO, 2000) have linked investing in sanitation to:

- Reducing morbidity and mortality and increased life expectancy;
- Savings in health care costs;
- Reduced time caring for the sick and reduced sick leave;
- Higher work productivity;
- Better learning capacities of school children;
- Increased school attendance, especially by girls;
- Strengthened tourism and national pride;
- Direct economic value of high quality water; and
- Reduced water treatment costs.

3.3.2.2 Stormwater, solid waste and energy

Urban development increases the amount of hard surfaces like roads, pavements and roofs that do not allow rainwater to seep into the ground. This means that the rate and volume of water running off and along surfaces is increased. Stormwater management systems are designed to manage runoff, in order to protect the natural environment by preventing erosion of land and water courses and protecting water resources like rivers and lakes from pollution. Wash-off of accumulated material by stormwater is one of the most significant mechanisms for contaminant delivery from a developing community to surface water resources. Sand and other substances (macro-pollutants) carried by runoff can block drainage systems, which result in standing pools of water causing health risks. To reduce these risks, it is important that in areas of high population density such as informal settlements, controlled and regular systems of solid waste management must be in place. Solid waste presents a threat primarily in terms of the direct water quality impacts of litter and household refuse as well as the associated contaminants (DWAF, 1999a; Thornton *et al.*, 1999). The community density has also a significant impact on the relative quantity of solid waste produced, but is dependent on the runoff available to deliver it to local surface water resources.

Although energy is not considered a basic need, it is often required to improve quality of life. According to the White Paper on the Energy Policy of the Republic of South African (Department of Minerals and Energy, 1998), "*ready access to adequate, appropriate and affordable forms of energy is a prerequisite for sustainable socio-economic development and the improvement of quality of life*". Many black South Africans do not have electricity in their homes (Sowman & Urquhart, 1998). Where electricity is absent, the main energy sources used are paraffin, liquefied petroleum gas, coal, and wood. The use of these energy sources for heating and cooking by the residents in a community produces mainly atmospheric contaminants, which are later washed out in rainfall and ash and may be washed into surface water resources.

3.4 Chapter summary

The initial impetus for water quality control arose because of concerns regarding waterborne diseases (Grabouw, 1996). In developed countries much has been done to diminish the threat posed by disease-carrying organisms in natural water. Bacteria, protozoa and viruses, however, still pose problems related to disease transmission and interference with uses of water for recreation. In addition most underdeveloped and developing countries still experience great problems related to pathogens (Chapra, 1997). Thus, water quality management roots is in disease prevention and the approach adopted in the first part of this chapter was to review the history of water quality management in South Africa, the roles and role players in water quality management as well as the different policies and strategies for water quality in South Africa.

The purpose of the second part of Chapter 3 was to establish an understanding of the fact that pollution from densely, populated, and poorly serviced areas, is one of the greatest threats to the quality of South Africa's water resources. Failing sanitation and waste management systems not only create appalling living conditions in many communities, but also cause downstream water quality problems. Faecal pollution from these areas poses health threats to the community, and nutrient pollution contributes to the eutrophication of downstream waters. Both of these are recognised as some of this country's most widespread water quality problems (Pegram *et al.,* 1997). It is clearly indicated in Chapter 3 (section 3.3) that the water quality effects of developing communities have their origins in the complex social and institutional conditions existing in these poor communities. These pollution problems cannot be addressed in the same way as pollution from other sectors and the approach adopted in this study is to manage the water quality using a holistic and integrated strategy.

The necessity of the previous two chapters thus lies in creating an understanding of the different factors that impact on water resources, as well as the effect thereof on human health and the aquatic ecosystem. The next chapter highlights the methodology of the research project that forms the basis of the empirical investigation of which the results are documented in Chapters 5 and 6. The outcome of these investigations was a management model that is in agreement with the National Water Act (1998) and which can be used as an action plan to manage the water quality effects of developing communities.

CHAPTER 4 METHODOLOGY AND STUDY AREA

The theoretical background with regard to water quality management given in Chapter 3, as well as the definitions of water quality concepts in Chapter 2, is the basis on which the study was developed. This chapter outlines the methodology, which was followed in the research project. The rationale for selecting the study area and the approach to determine the impact of socio-economic and human behavioural factors on the water quality of the Fontein Spruit are explained. The different tasks conducted during the study are illustrated in the flow diagram in Figure 1.2 (Chapter 1). The first undertaking was to identify the objectives, conduct a preliminary survey and from these results, design the project. The next assignments included field monitoring, data analysis and processing, as well as data interpretation and assessment. The field monitoring consisted of the monitoring and assessment of the water quality in the study area, as well as the identification of the community characteristics with regard to socio-economic conditions. After completion of the field monitoring, the data were interpreted and assessed and appropriate interventions and strategies were identified as solutions to the water quality problems in the study area. The final assignment of the study was the compilation of the Water Quality Management Plan (WQMP), after all the information and experienced gained through the research project was taken into consideration. The objectives and aims of the study are discussed in Chapter 1. The preliminary investigation, identification of the study area and the methodology followed in the implementation of the other activities are discussed in detail in the next sections.

4.1 Preliminary investigation and identification of study area

4.1.1 Preliminary objectives

The initial objectives of the research project when it started in July 1997 were the following:

- To investigate the hydrological processes and development of urban rivers and water courses with specific reference to Bloemfontein;
- To determine the impact of urban development on these water courses;
- To establish the water quality of the urban rivers and water courses;
- To determine methods/practices for the control of microbiological quality of urban runoff;
- To design and implement the control methods/practises identified; and
- To monitor the results.

A preliminary survey into the hydrological processes and development of urban rivers and water courses in and around Bloemfontein was carried out during this stage of the project. The river investigated was the Modder River and the water courses investigated were the Fontein Spruit, Bloem Spruit and Renoster Spruit. The Fontein Spruit is a perennial tributary of the Bloem Spruit, which is a perennial tributary of the Renoster Spruit with the latter a tributary to the Modder River. All previous hydrological and water quality data of the river and water courses were collected and synthesised in order to obtain a picture of the historical and present water quality conditions. This information was also used to identify any sources of water quality change over time and in different parts of the river. As no data on the microbiological status of the water courses were available a monitoring programme was implemented. The water quality of the three water courses was monitored once a week for a period of four months (August 1997 - November 1997), and also during and after rainstorms to establish a wet weather baseline status of the microbiological quality of the water courses. The water courses and sampling sites are indicated in Figure 4.1.

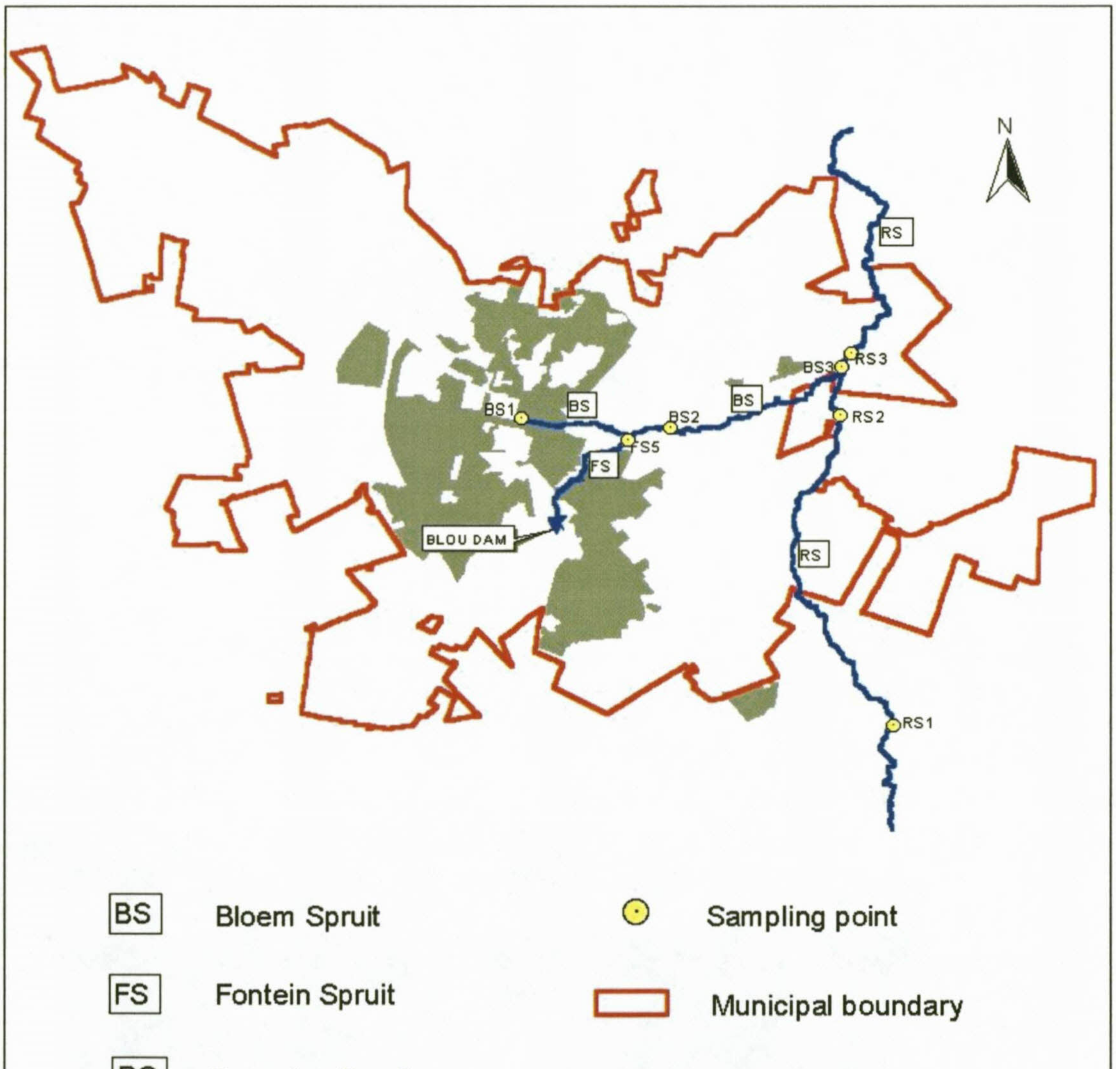


Figure 4.1 Water courses and sampling sites in the Bloemfontein region

The sampled data were analysed during December 1997, and it was established that the level of pollution of all three water courses was high and that the microbiological quality of the water poor. The microbiological data for the three water courses are given in Table 4.1. Three indicator organisms, namely *Escherichia coli, Clostridium perfringens* and somatic coliphages, were assessed to establish the microbiological water pollution. The theoretical background on these organisms, to explain their selection in the water quality monitoring programme, is given in Chapter 2 and in Chapter 4 (section 4.2.1.2).

Table 4.1 Geometric mean levels of microbiological indicator organisms of the water courses in the Bloemfontein region (counts/100 ml); August 1997 – November 1997.

Sampling points	**n-Values**	***E. coli*** **counts/100 ml**	***C. perfringens*** **counts/100 ml**	**Somatic coliphages counts/100 ml**
BS1	17	4.59E+03	3.30E+01	6.00E+02
BS2	17	1.03E+04	4.01E+02	5.65E+03
BS3	17	3.49E+03	4.62E+02	5.38E+03
FS5	**17**	**5.830E+04**	**4.77E+02**	**9.53E+03**
RS1	17	8.00E+01	3.80E+01	2.00E+00
RS2	17	8.30E+01	1.90E+01	1.30E+01
RS3	17	1.81E+03	1.32E+02	6.77E+02

From the table it is clear that the Fontein Spruit could be a possible source of pollution for the two other water courses as the highest values for all three microbiological indicator organisms was recorded at sampling point FS5. This sampling point represent the drainage from the Fontein Spruit catchment and is approximately 0.35 km upstream of the confluence with the Bloem Spruit, and is downstream of sampling point BS1 and upstream of sampling point BS2, as can be seen from Figure 4.1. In order to determine the source of pollution to the receiving waters of the Fontein Spruit, a pollution assessment of the Fontein Spruit drainage basin was planned for the first part of 1998. The pollution assessment clearly indicated that the developing community in the drainage basin had a large impact on the quality of the receiving waters of the Fontein Spruit, also reflecting social, economic and physical factors. The results from this assessment necessitated the re-evaluation of the original objectives of the project and the overall objective of the study was changed to the objectives and aims as discussed in Chapter 1. The study area was also reduced to the Fontein Spruit catchment, which is a sub-catchment of the original study area. The delineation of the Fontein Spruit catchment is illustrated in Figure 4.4.

The next section is an overview of the catchment with respect to various characteristics. These characteristics are the geographical location, geology, vegetation, urban development and land use, including the dwelling density and municipal services.

4.1.2 Study area

4.1.2.1 Geographical location

The study area, which is the catchment of the Fontein Spruit, consists of several residential sections, namely the developed section of Erlich Park, and the developing and informal sections of Mangaung and Heidedal. These are located within the municipal areas of Bloemfontein (Mangaung Municipality), the capital of the Free State, and one of the provincial capitals of South Africa.

Bloemfontein is located between the latitudes 29'10° S and 29'25° S, and the longitudes 26'35° E and 26'48° E, approximately 400 km south-west of Johannesburg and 1000 km north-east of Cape Town (Figure 1.1; Chapter 1).

The Fontein Spruit is a natural water course running from the Blou Dam, a small reservoir, to its confluence with the Bloem Spruit at the lower end of the catchment. It is approximately 3.7 km in length and drains an area of about 16.8 km^2. The topography of the catchment is unbroken and the height above sea level is 1 390 m, with the slope of the Fontein Spruit about 1:750.

4.1.2.2 Climate

The study site is located within the summer rainfall zone of South Africa, which is classified as a sub-humid, warm zone with annual water deficiency (DWAF, 1994; Schreiner & Naidoo, 1999). The mean annual precipitation varies between 500 mm and 600 mm (Rooseboom, Basson, Loots, Wigget & Bosman, 1993) with the mean annual precipitation value for the period 1905 to 1976 given as 533 mm (Hydrological Research Unit, 1981). Rainfall during the summer months, October to April, amounts to 86% of the total amount of rainfall, and is mainly in the form of short duration, high intensity thunderstorms. Therefore summer runoff is relatively high and most of the discharge is in the form of storm flow. The rainfall on the catchment governs stormwater wash-off, and also has an influence on the 'wetness' or 'aridness' of the catchment, and consequently the volume of domestic waste water that can be disposed on-site.

The weather station at Bloemfontein airport (approximately 3 km north-east of Mangaung) is the closest, comprehensive meteorological station to the study site. The climatological information from this station can be summarised as follows:

- Air temperatures range from an average maximum of 30°C in January to an average minimum of 1°C in July;
- Daily temperature range (for both summer and winter averages) is 15°C (Tyson, 1987); and
- Monthly pan-evaporation rates are highest (December = 323 mm) in summer and lowest in winter (July = 85 mm), with an annual average pan-evaporation of approximately 1 750 mm (DWAF, 1986).

4.1.2.3 Geology

The study area is situated on the Beaufort Group of the Karoo Sequence. The regional geology consists of interbedded mudstone, with shale and sandstone being the main rock types (Botha, Verwey, Van der Voort, Vivier, Buys *et al.*, 1998). The geology of the region is illustrated in Figure 4.2. The type of soil upon which the catchment is located, together with amount and type of vegetation cover, determines the wash-off during storms, as well as the on-site drainage capacity associated with water supply and drainage (DWAF, 1999a).

As the catchment consists of both pervious (sandstone) and impervious soils (shale), the following problems are likely to occur:

- Sediment erosion and the delivery of adsorbed contaminants to the receiving waters of the Fontein Spruit. This can create problems, especially in the areas with little cover and where construction activities are taking place in the study area;

- The shale content in the soil can lead to reduction of infiltration, causing increased surface runoff, which exacerbates surface water resource problems.

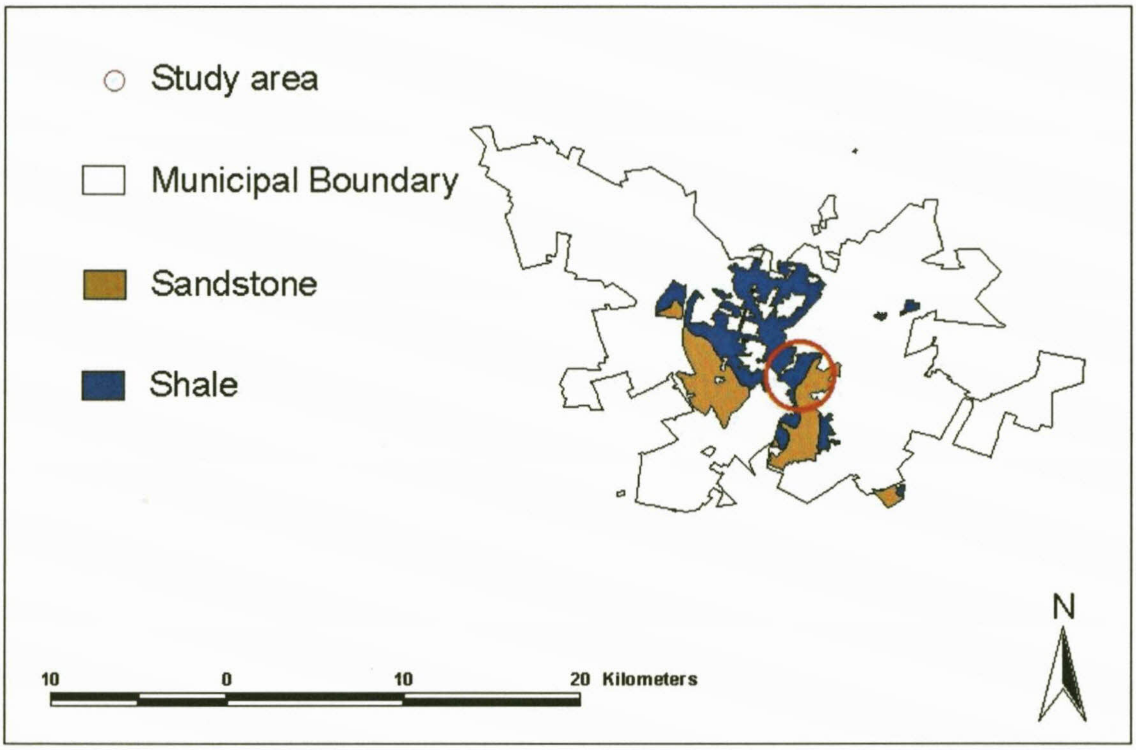


Figure 4.2 The geology of the study area

4.1.2.4 Vegetation

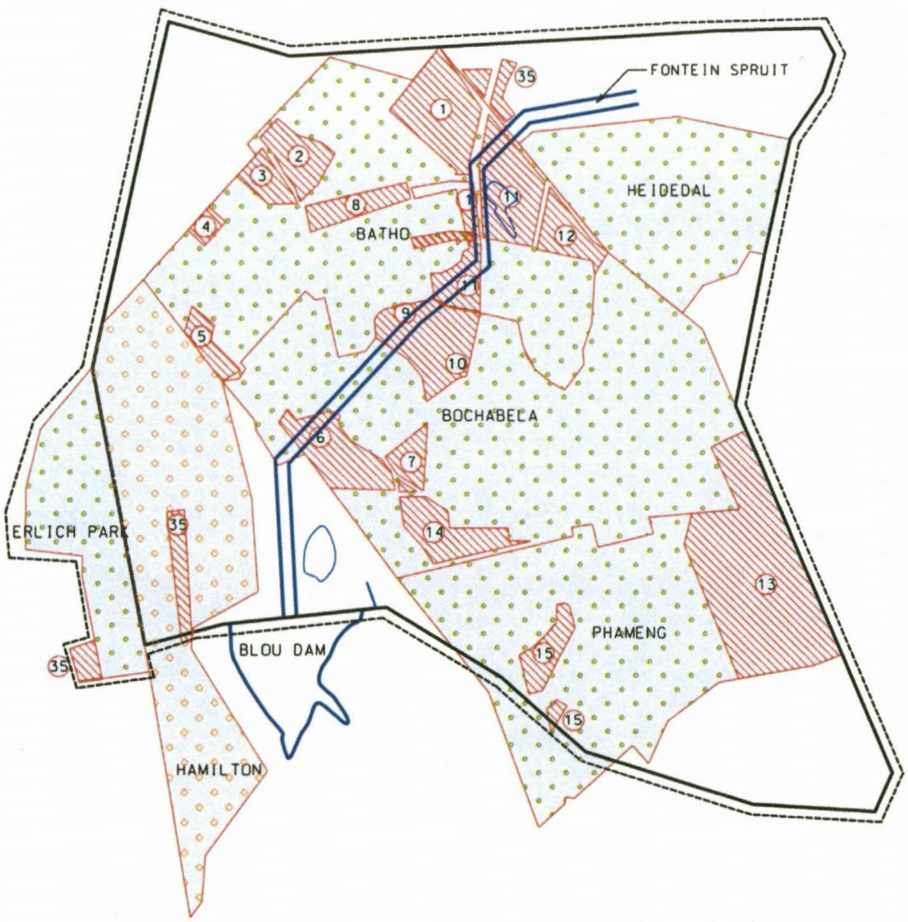
Severe deterioration in the quality of the veldt around Mangaung is evident. Large quantities of grass and sedge have been removed with the result that wide areas of bare soil are exposed. Most of the woody species growing along the Fontein Spruit and near the community have been used for firewood. The riparian vegetation along the Fontein Spruit is composed mainly of the grass species *Themeda triandra* with a variety of other grass, short shrub species and reeds, such as *Phagmites australis*, bulrush and *Typha capensis* (Acocks, 1988).

4.1.2.5 Urban development and land use

After the establishment of Bloemfontein in 1820, the first large scale movement of African people to Bloemfontein occurred after the completion of the Cape-Transvaal railway line (Matiso, 1997), as well as after the Anglo-Boer war in 1902 (Botes, Krige & Wessels, 1991). However, during the nineties, the National Party, according to Swilling (1997), wanted to curtail the growth of the urban African population in urban areas, like Bloemfontein. This resulted in an "urban labour preference policy". Under this policy immigrants who were permitted access to urban employment would be prohibited from settling permanently in the urban area. The African population growth and urbanisation process in Bloemfontein was thus transferred to Thaba Nchu and Botshabelo, approximately 90 km east of Bloemfontein. This canalised urbanisation was put in place from 1960 onwards. According to Krige (1991), the people residing in Mangaung were under pressure because a ban was placed on home-ownership, the building of family housing was ceased and the boundaries of Mangaung were frozen in 1968.

With the abolition of influx control in 1986 Bloemfontein, and especially Mangaung, however, once again became the focus of population growth (Krige, 1991). During the period 1986 to 1994 a variety of informal spatial processes eroded apartheid boundaries, with the most important of these, the process of land invasion (Krige, 1998). It started in February 1990 when families seeking homes in Mangaung were mobilised by the Mangaung Civic Association to settle on adjacent state land and open spaces inside Mangaung (Botes *et al.*, 1991). The first phase of land invasion was pioneered by the landless people in Mangaung, while the follow-up process was characterised by the arrival of people from Botshabelo and other rural or urban areas in the southern Free State (Krige, 1998). This process of land invasion largely accounts for the fact that the number of stands in Mangaung increased from 20 270 in 1990 to more than 46 000 by the end of 1997 (Krige, 1998). High levels of desegregation have also occurred in former low-income white suburbs (*e.g.* Erlich Park) where new low-cost housing projects contributed to the settlements of Africans.

The residential sections of Bloemfontein that are included in the study area are Erlich Park, Heidedal and three subdivisions of Mangaung. The three subdivisions are Batho, Bochabela and Phameng, which all form part of the historically formal Mangaung. The different residential sections included in the study area, as well as the catchment area, are indicated in Figure 4.3, while Table 4.2 illustrates the number of residents, stands and dwelling density in the different residential sections in the study area. From the table it can be seen that the number of stands, at the time of study, in the formal area of Mangaung was 6 240 (Status November 2000). According to Krige (1998), the number of stands in these areas during 1991 where approximately 6000. The increase in formal stands during the period 1990 – 2000 were thus minimal. These formal sectors were also the first to be upgraded and these stands were all fully serviced with water, waterborne sewerage and electricity by the end of 1998.



Zone	Informal Area
1	Thambo 1 & 2
2	Lusaka
3	Maphikela
4	Papi Makotoko
5	Sekhupi 1; 2 & 3
6	Thabo Mbeki 1 & 2
7	Peter Mokhaba
8	Shuping
9	Solomon Mahlanqu
10	Isithwalanwe
11	Codesa 2 & 3
12	Codesa 1
13	Joe Slovo
14	Kagisho
15	Kathrada 1 & 2
35	Unofficial Informal Areas

Scale 1:38750

Figure 4.3 Residential and industrial sections of the study area

Table 4.2 Number of residents, stands and dwelling density in the different residential sections in the study area.

		Demographic detail		
Residential section		Number of stands	Density: dwellings/ha	Number of residents
Heidedal		657	8.1	3 942
Mangaung: Formal areas		6 240	Total	37 440
Batho		2 161	9.6	12 966
Bochabela		2 549	10.0	15 294
Phameng		1 530	8.4	9 180
Mangaung: Informal areas	Zone	2 133	Total	8 620
Thambo 1 & 2	1	280	14.6	1 100
Lusaka	2	91	12.5	373
Maphikela	3	77	18.4	316
Papi Makotoko	4	33	18.1	135
Sekhupi 1; 2 & 3	5	116	29.9	466
Thabo Mbeki 1 & 2	6	114	9.3	467
Peter Mokhaba	7	63	16.4	258
Shuping	8	104	18.3	426
Solomon Mahlanqu	9	46	6.6	188
Isithwalanwe	10	138	14.7	550
Codesa 2 & 3	11	61	11.0	250
Codesa 1	12	70	10.9	287
Joe Slovo	13	635	12.4	2 553
Kagisho	14	159	16.4	652
Kathrada 1 & 2	15	146	22.6	599
Erlich Park		347	7.0	1 194

- Status November 2000. Compiled from official figures from the local municipality.

The road system in these sectors consists mostly of gravel and dirt roads, except for the main connector roads, which are paved. The additional stands in this area of Mangaung, approximately 2 100, were all obtained by means of land invasion and form part of the informal areas in Mangaung (Table 4.2). The housing in the informal sector of Mangaung consists mainly of squatter shacks with a skeleton road system, a limited number of communal water supply points and on-site sanitation. Most of the on-site sanitation systems are in poor state, as they are not maintained. No formal removal of solid waste takes place and these areas are lined with plastic bags and other litter.

As already indicated, Erlich Park consists of low-cost housing, but due to the fact that is was part of the former lower level-income white suburbs, all the normal infrastructure is present and the area is serviced by the local authority. The number of stands forming part of the study area is only 347 and constitutes the higher socio-economic group of the study area. The residential section of Heidedal is very similar to the formal areas of Mangaung. Basic services such as water, waterborne sewerage and electricity are provided and a solid waste management programme is in place. Table 4.3 indicates the level of the municipal services in the different residential sections of the study area.

The different residential areas of the study area comprise approximately 77% of the land use in the study area. The industrial section, Hamilton, constitutes approximately 15% of the land use, while the Fontein Spruit and riparian areas represent about 8% green areas as indicated in Figure 4.3.

Table 4.3 Level of key municipal services in the different residential areas in the study area.

Residential area	Service	Water supply	Sanitation	Electricity	Solid Waste
Heidedal		YC	WB	FG	MR
Mangaung:Formal areas					
Batho		YC	WB	FG	MR
Bochabela		YC	WB	FG	MR
Phameng		YC	WB	FG	MR
Mangaung: Informal areas	Zone				
Thambo 1 & 2	1	RDP	BPL	LC	NO
Lusaka	2	RDP	BPL	LC	NO
Maphikela	3	RDP	BPL	LC	NO
Papi Makotoko	4	RDP	BPL	LC	NO
Sekhupi 1; 2 & 3	5	RDP	BPL	LC	NO
Thabo Mbeki 1 & 2	6	RDP	BPL	LC	NO
Peter Mokhaba	7	RDP	BPL	LC	NO
Shuping	8	RDP	BPL	LC	NO
Solomon Mahlanqu	9	RDP	BPL	LC	NO
Isithwalanwe	10	RDP	BPL	LC	NO
Codesa 2 & 3	11	RDP	BPL	LC	NO
Codesa 1	12	RDP	BPL	LC	NO
Joe Slovo	13	YC	WB	FG	NO
Kagisho	14	RDP	BPL	LC	NO
Kathrada 1 & 2	15	RDP	BPL	LC	NO
Erlich Park		HC	WB	FG	MR

- Status November 2000. Compiled from official figures from the local municipality.

Symbol	Definition	Symbol	Definition
HC	House connection	WB	Waterborne
YC	Yard connection	BPL	Bucket / pit latrine
RDP	Standpipe @ 150 m		
FG	Full grid	MR	Removal by municipality
LC	Low current	NO	No removal

The typical industries in the industrial area include food processing factories, beverage, plastic pipe and pharmaceutical manufacturers and other light industries. Below the Blou Dam and south-west of Bochabela and Phameng is an undeveloped area of natural vegetation up to the point where the Fontein Spruit enters Batho residential section (Figure 4.3). From this point onward the Fontein Spruit is the centre of a green belt of riparian vegetation of approximately 20 m wide with informal shacks lining the perimeter. These green areas are predominantly used for vegetable gardens and livestock grazing, mostly cows, goats and chickens.

4.2 Field monitoring

The preliminary investigations, as discussed in the previous section, resulted in the identification of the study area, namely the Fontein Spruit catchment and the finalisation of the design of the research project. The next assignment, as indicated in the framework (Figure 1.2, Chapter 1), was the field monitoring. The field monitoring consisted of the monitoring and assessment of the water quality in the study area, as well as the identification of the community characteristics with regard to socio-economic conditions in the community. The methodology of these activities is discussed in the next sections.

4.2.1 Water quality assessment

4.2.1.1 Water quality monitoring programme

The primary and foremost purpose of a water quality monitoring programme is to provide an assessment of the water quality conditions in order to determine if the aquatic environment objectives are being achieved and complied with (ECE, 1993). According to Chapman (1992) water quality monitoring activities, including the choice of sampling location and sampling frequency, are highly dependent on the aquatic environment of the drainage basin. The location of sampling sites should coincide with, or be at least near to, stormwater discharge points. In addition, water quality sites should be placed immediately upstream and downstream of confluences and water use regions (Chapman, 1992; O'Keeffe, Van Ginkel, Hughes, Hill & Ashton, 1996). In order to fulfil these requirements a preliminary survey of the Fontein Spruit drainage basin was conducted during the first week of January 1998 to assess stormwater runoff and different types of land use and activities in order to site the water quality monitoring sampling positions. Ten sampling points were identified to be monitored twice a month over an extended period to include seasonal variations. The sampling period was, however, constrained due to several reasons / problems.

The ideal monitoring period would have been from July 1998 to June 1999. This however was impossible due to unavailability of research funds. Application for funds was submitted during September 1997 and even though the application was successful, research funds only became available at the end of March 1998. The first samples were thus taken on 15th April 1998 and the monitoring continued on a bimonthly cycle until 9th December of the same year. Application for funds to extend the monitoring period for another year was unsuccessful. The security problems experienced while conducting the monitoring was another contributing factor which lead to the termination of the monitoring programme. This resulted in a monitoring period not corresponding with the peak rainfall period. However, the programme still permitted the establishment of a dry weather baseline status for the drainage basin.

The location of the water quality sampling sites of the study area are shown in Figure 4.4 and may be summarised as follows:

- FS1 Sampling point in Fontein Spruit, downstream from the Blou Dam reservoir;
- ERL Sampling point outside riverbed, 0.27 km downstream of sampling point FS1. This point represents drainage from Erlich Park residential section;
- FS2 Sampling point in Fontein Spruit, 0.35 km downstream of sampling point FS1;
- IND Sampling point outside riverbed, 0.10 km downstream of sampling point FS2, representing drainage from Hamilton industrial area;
- BCH Sampling point outside riverbed, 1.30 km downstream of sampling point FS2, representing drainage from Bochabela residential section;
- FS3 Sampling point in the Fontein Spruit, 1.45 km downstream of sampling point FS2;
- HMT Sampling point outside riverbed, 0.5 km downstream of sampling point FS3, representing drainage from Hamilton industrial section and several residential sections including Batho residential section;
- FS4 Sampling point in Fontein Spruit, 0.55 km downstream of sampling point FS3;

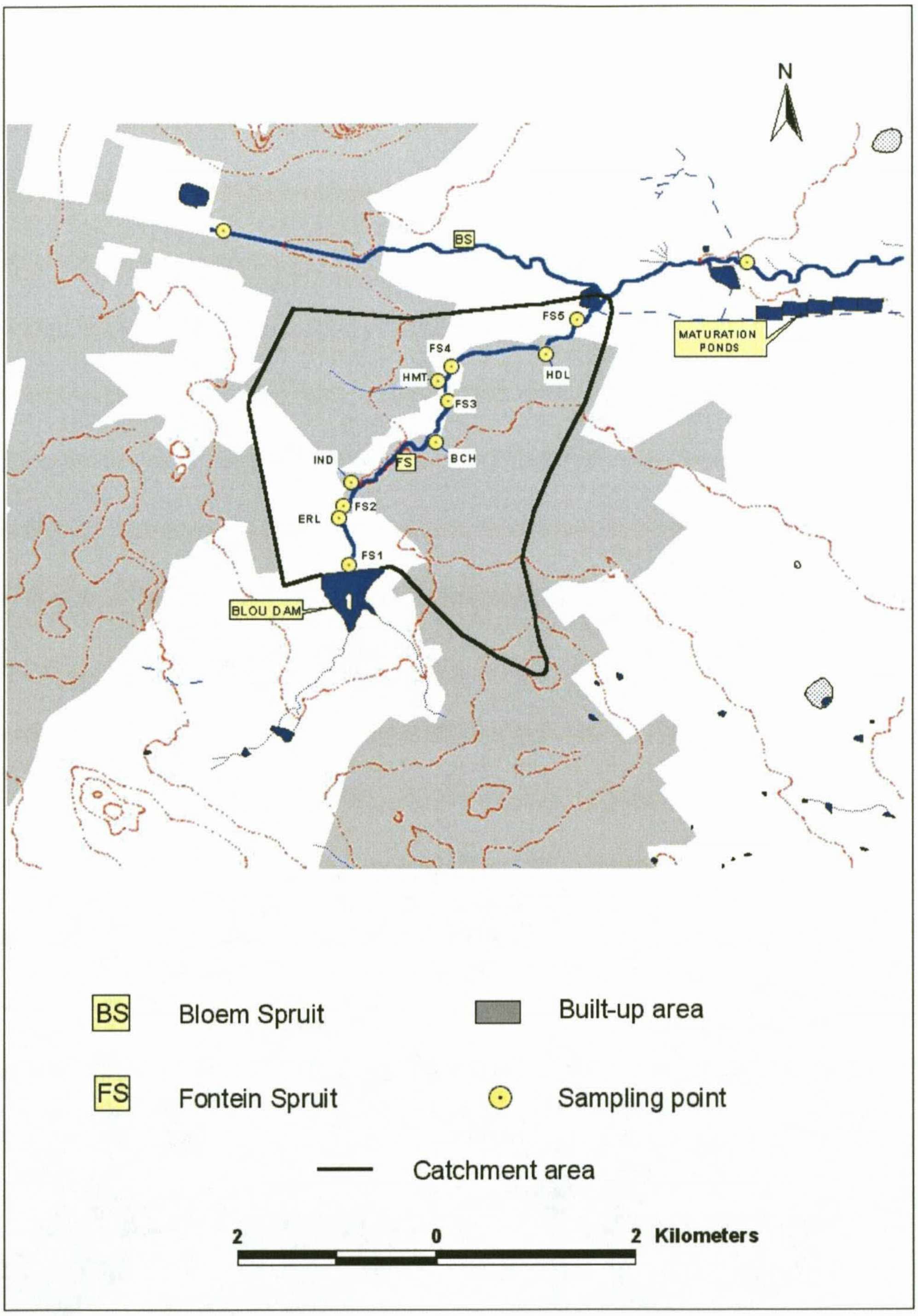


Figure 4.4 The Fontein Spruit catchment, study area and location of water quality sampling sites

- HDL Sampling point outside riverbed, 0.60 km downstream from sampling point FS4, representing drainage from the Heidedal residential section; and
- FS5 Sampling point in Fontein Spruit, 1.05 km downstream of sampling point FS4. This point is 0.35 km upstream of the confluence of the Fontein Spruit and the Bloem Spruit.

4.2.1.2 Water quality criteria

A detailed description of water quality constituents and their occurrence in the aquatic environment are given in Chapter 2 (section 2.4), as part of the theoretical background study. However, the selection of variables to be included in the water quality monitoring programme must be related to the objectives of the research project. Every effort was therefore made to co-ordinate physical, chemical, and biological monitoring to improve understanding of the effect each variable has on the aquatic environment (ECE, 1993). Generally, monitoring programmes can be divided into two categories; use orientated- and impact orientated programmes (Chapman, 1992). Use orientated programmes test whether water quality is satisfactory for specific purposes, such as drinking water supply and industrial use. Impact orientated programmes, as was conducted during this research project, examine the effects of specific activities on water quality, such as urban or rural runoff or accidental pollution incidents (Chapman, 1992; Novotney, 1995; Pegram *et al.*, 1997).

The theoretical background given in Chapter 2 on specific water constituents was used as basis to determine the water quality constituents to be measured in this study. The decision with regard to the physical and chemical variables measured were those that can provide an indication as to the condition of the aquatic environment (conductivity, TDS, DO, COD, nitrate, phosphate and orthophosphate) and also those that can be linked to the survival of micro-organisms (pH, turbidity and temperature). Microbiological analysis in this study was limited to faecal coliforms, *Clostridium perfringens*, and somatic coliphages. Microbiological examination of water to detect the presence of pathogens is the predominant feature of water quality assessment to monitor risks to human health (Tchobanoglous & Schroeder, 1987; Payment & Franco, 1993; Chapra, 1997). The determination of the microbiological safety of water implicated for human contact requires the enumeration of many different species of pathogens, including species of bacteria, viruses and protozoan parasites. The detection of these pathogens entails complex, expensive and time-consuming procedures that render it impractical, and it is therefore standard practice to monitor microbiological water pollution on the basis of indicator organism levels, rather than the pathogens themselves (DWAF, 1996a).

Faecal coliforms were used in this study as the principal indicator group as they represent a selected group of total coliform bacteria that are more specific for faecal or sewage pollution than the wider group of total coliforms (Standard Methods, 1998). Faecal coliforms indicate the possible presence of entero-pathogenic bacterial species such as *Salmonella* and *Shigella*. The principal diseases caused by these species, and as discussed in Chapter 2, are salmonellosis, dysentery, enteric fever and cholera.

Clostridium species, especially their spores, are exceptionally resistant to unfavourable environment conditions. They do, therefore, survive for long periods and are often used as indicators of remote faecal pollution (Cabelli, 1977; Chauret, Armstrong, Fisher, Sharma, Springthorpe *et al.*, 1995). *Clostridium perfringens* were used in the study as it is considered a meaningful indicator of the possible presence of resistant pathogens such as parasitic protozoa, *Giardia* and *Cryptosporidium*, of faecal origin (Payment & Franco, 1993; Chapra, 1997).

Coliphages are model viruses used to indicate the presence of entero-pathogenic human viruses such as Rotavirus (Chapter 2, Table 2.2) and Norwalk. Somatic coliphages include a wide variety of phages and are generally detected in large numbers in sewage-polluted water (Grabouw, 1996). This phage group causes the following clinical symptoms: gastrointestinal syndrome, vomiting, watery diarrhoea and abdominal cramps (Chapter 2, section 2.4.10). The DWAF has included target guideline ranges for somatic coliphage numbers in recreational as well as domestic water in the water quality guidelines (DWAF, 1996a) and this necessitated the inclusion of this phage group in this study. These guidelines are discussed and outlined in Chapter 3.

4.2.1.3 Analysis of water

All samples discussed in this section refer to surface water grab samples taken at depths of less than 250 mm. The routine sampling commenced at 08:00 and was carried out on every second Wednesday for the whole sampling period. Replicate water samples were collected in sterile Whirl packs®, transported at

4-10°C and analysed within 5-12 hours of collection. Laboratory analysis is complex and a specialised activity because it involves the analysis of the different water quality variables using several different techniques. It also includes procedures such as sample handling, quality control and the recording of analytical results. The chemical and physical analysis of the water samples were therefore undertaken by the Institute of Groundwater Studies at the University of the Free State, while the microbiological laboratory of Technikon Free State undertook the microbiological analysis. The methods recommended by Standard Methods (1998) for the examination of water and waste water are used by both laboratories when analysing samples. Both of the laboratories also participate in the SABS Water-Check Proficiency Testing Programme to ensure that the data are reliable and of high standard (Fouche, 2002). The methodology used for microbiological analysis of water samples is given in Appendix 2. The data were set up in Microsoft Excel® spreadsheets and are presented in Appendix 3. The microbiological data were transformed to log10 values prior to doing descriptive statistical analysis such as sample size, range, geometric mean, median, and the 95% confidence intervals of the data. The statistical programme used to present the data was SigmaPlot 2000.

4.2.1.4 <u>Quantitative relationships</u>

For the derivation of quantitative or semi-quantitative relationships an assessment of at least the minimum, maximum and median values for flow concentrations, loads and export coefficients of water quality constituents are required for both low flows and storm flows. Of the more than 50 case studies conducted in South Africa, (Chapter 1, section 1.2), the majority reported mean values whereas flows were seldomly measured simultaneously with water quality. This was due to several difficulties experienced in obtaining sufficient water quantity information from these studies on developing communities. The widespread crime, the virtual absence of security, as well as the often unstable nature of low-cost, high-density urban areas resulted in conditions that made hydrological research extremely difficult (Schoeman *et al.*, 2001). Similar conditions prevailed in the study area where the research was conducted. Therefore it was difficult to measure water quantity during storm events which usually occurred late afternoon-early evening when security could not be arranged at short notice. The velocity of the base flow in the Fontein Spruit could be measured during dry weather conditions with prior arrangement with security. Discharge volumes could only be estimated from data giving averages and therefore accurate values at the required sensitivity level would not be possible. No water quantity data is thus reported in the results. The mean velocity measured at all sampling points in the Fontein Spruit was always less than 0.01 m/s for the duration of the monitoring period and gives an indication of the flow velocity in the Fontein Spruit.

4.2.2 Community characteristics: socio-economic conditions

4.2.2.1 Data capturing form

Questionnaires have a number of limitations as a means of obtaining information (Chambers, 1985; Leedy & Omrod, 2001). Hammond and McCullagh (1978) observe that there is a great likelihood of bias in determining the sampling framework, as it may not truly represent the population under investigation and that any field survey is influenced by the availability of financial resources and time (Moeti, 1996; Leedy & Omrod, 2001). In this study, however, it proved to be the only practical way of obtaining information and input from the community to identify their needs and possible solutions to water quality problems in the community. The socio-economic characteristics of the community with regard to five fundamentals provided the basis for the data capturing form to identify the underlying socio-economic causes of water quality problems in the study area. These attributes, as discussed in Chapter 3, could determine the behaviour of individuals and their impact on the quality of the water. They are:

- environmental awareness;
- political culture;
- payment for services;
- use of services; and
- community demands.

The data capturing form is supplied in Appendix 4. It was pre-coded to facilitate analysis by a computer. Descriptive statistics, in the form of frequency tables, were then drawn up, the statistics were interpreted and tabled and a summary thereof is given in Table 6.1, Chapter 6.

4.2.2.2 Field survey

To assess the socio-economic status of the community, parts of the developed, developing and informal sectors in the study area were included in a field survey. The residential sections included are the developed sector of Erlich Park, the developing sector of Heidedal, as well as three formal and fifteen informal sectors that form part of the developing sector of Mangaung. The different residential sections are illustrated in Figure 4.3. Realising that the households in the community do not vary a great deal in terms of their income, the study was designed to reflect a measure of municipal service differentiation rather than economic differentiation. To this effect, three distinct survey sectors were identified. The developed sector was planned and is maintained and serviced by the local authority. This sector constitutes the higher socio-economic group of the study area. There is less planning and control in the developing sector and even less in the informal sector, where there are virtually no services or control. They are respectively at middle and low socio-economic levels.

To conduct the survey, the developing sector - of which the total number of stands is 6 249 - was divided into 11 blocks of approximately the same number of households. Fifty houses were randomly selected from each block. In order to make provision for residents not available during the field survey, some alternative houses were identified. The fieldworkers incorrectly included this in their survey, which resulted in the fact that a total of 575 households instead of 550 were included in the survey. The total number of stands in the developed sector is 347 and 75 households were interviewed. Information with regard to the number of stands in the informal sector was not available when the field programme was compiled and 50 households were therefore rationally and randomly selected and regarded as a representative sample. The total number of stands in this sector is presently just more than 2000.

The fieldwork was carried out during July 1999 and ten fieldworkers were used to conduct the survey. Residents of the community were recruited as fieldworkers and they attended a training course a week prior to the survey. The fieldworkers interviewed the person of the household responsible for payment of municipal services. Misinterpretation of the technical terms used on the data capturing form was the main problem experienced during the survey. The fieldworkers were able to explain these terms during the interview and proved that the training, which the fieldworkers received, was vital, as incorrect information on the data capturing forms could easily negate the value of the study.

4.3 Sustainable interventions

In the previous sections the methodology to identify the water quality status of the study area and the characterisation of the community with regard to socio-economic issues that may have an impact on the water quality of the Fontein Spruit were outlined. The approach of this part of the research project was to identify appropriate interventions and strategies to protect the receiving waters of the Fontein Spruit as well as the aquatic ecosystem. In South Africa, various university departments and institutes, private organisations, such as the Palmer Development Group, governmental organisations, especially the Department of Water Affairs and Forestry, Department of Environmental Affairs and Tourism, Water Research Commission, several others as well as non-governmental organisations have contributed much knowledge and experience towards interventions and solutions applicable to the South African situation. In this study it was therefore necessary to draw on the national and international lessons learnt and information and experience gained through the successes as well as failures in this field. An analysis of the work and research that has already been undertaken has therefore played a major role in the selection of interventions options for the study area. Possible interventions that can be implemented in the study area are discussed in Chapter 7. Further research, however, will be necessary to determine the applicability and the sustainability of the interventions for this specific community.

4.4 Water quality management plan

The compilation of a Water Quality Management Plan (WQMP) is indicated in the flow diagram in Figure 1.2 as the final assignment of this research project. The WQMP comprises the experience and results acquired during the execution of the research project, which was incorporated into a water management model for the developing community in the study area. The blueprint of the WQMP, as well as it's standing to the National Water Act and catchment management strategies are discussed in Chapter 8. In Chapter 1, the development of a WQMP is indicated as the second objective of this research project, and it also states the extrapolation of results and experiences to catchments with similar land use and human activities. The WQMP, given in Chapter 8, is therefore introduced as a generic management model to direct any local authority or developer in the application of the WQMP, as well as in the selection of the most appropriate methods to address water quality problems in their catchment.

CHAPTER 5 RESULTS: WATER QUALITY

5.1 The water quality profile of the Fontein Spruit

In this study, the microbiological water quality was monitored using the microbiological indicators as parameters of potential risk to human health. The physical and chemical variables measured provided an indication of the condition of the aquatic environment as well as a link to the survival of micro-organisms. A detailed description of the parameters and variables, analysed in this research project, are given in Chapter 4 (section 4.2.1.2) and the location of the monitoring sites is shown in Figure 4.4. To observe trends in the data, the results of the monitoring points in the main water course are presented as line plots, and the monitoring points representing surface runoff as box-and whiskers plots (Figures 5.1; 5.2; 5.4 - 5.8). The median concentrations with the 95% confidence intervals, as well as the minimum and maximum values measured for each sampling point over the sampling period of eight months are given in Tables 5.1 - 5.4, 5.6 and 5.7 and the raw data in Appendix 3. The variations in the number (n-Values) of samples in the tables for the various sampling points are due to several reasons. The dissolved oxygen meter, for example, was calibrated and tested in the laboratory before each field trip. However in the field, it did not function properly most of the time. This resulted in unreliable data that were eventually excluded. On several occasions, even though replicate water samples were taken, analyses could not be done due to leakages of the Whirl Packs®, incorrect handling and problems with delivery to the laboratories on time. These are indicated as 'no analyses' and 'no data' in Appendix 3.

5.1.1 Characteristics of microbiological water resources data

Microbiological water resources data generally have substantial variations, which cause the data not to be normally distributed around the mean for the set (Standard Methods, 1998). According to Helsel and Hirsch (1995), reasons for this is that data analysed by water resources scientists often have the following characteristics:

- A lower bound of zero – no negative values are possible;
- Presence of outliers, observations considerably higher or lower than the most of the data;
- Positive skewness and non-normal distribution of data;
- Seasonal patterns and dependence on other uncontrolled variables; and
- Values strongly co-vary with discharges, rainfall or some other variable.

Microbiological data about populations of indicator organisms formed an important part of this study. Small samples of the water volume were taken and measured in such a way that conclusions about the sample may be extrapolated to the entire target population (Helsel & Hirsch, 1995). These conclusions are estimates of the true population values. The most popular estimate that can generally be made of the true population values is the central value or central tendency.

Central tendency estimates applied for this study were the following:

- **Mean** (or average): This is the sum of all the data in a set divided by the sample size. The mean is sensitive to outlying values in data sets. Since microbiological data may vary greatly (outliers) in the same sample, the mean is generally strongly influenced and the estimate of the target population value may therefore not be realistic;

- **Geometric mean**: To calculate a more realistic estimate based on the mean in a data set that contains outliers, it is best to remove as much of the variance as possible. To do this, the data units are transformed to their logarithms to create data that are more "normally" distributed, although the data will generally not be symmetrical. This is referred to as lognormal data. The mean of these logarithms of data in a set is calculated and then transformed back to its original units. The resultant mean is referred to as the geometric mean. The preferred best estimate of central tendencies of untransformed microbiological data such as obtained in this study, was the geometric mean (Standard Methods, 1998); and
- **Median**: Used with transformed data. The median is only minimally affected by the magnitude of a single observation such as an outlier and will therefore be resistant to the effect of outliers (Helsel & Hirsch, 1995).

5.1.2 Microbiological quality

5.1.2.1 Faecal coliforms

The faecal coliform plots (Figures 5.1 and 5.2), provide an indication of the microbiological pollution in the study area. Faecal coliforms represent a selected group of bacteria that indicate faecal pollution of water (Standard Methods, 1998). The risk for humans that might be infected by microbial pathogens is correlated with the level of faecal coliform contamination of water and the volume of water ingested (DWAF, 1996a). For this study, the faecal coliform target guidelines for *intermediate contact* (DWAF, 1996a) were used, since this type of contact with the water of the Fontein Spruit by residents of the community is common. The criteria for faecal coliforms for intermediate contact are given in Appendix 1. The reference line shown in Figure 5.1, indicates the limit of 1000 faecal coliforms/100 ml, above which health effects may be expected in exposed residents (DWAF, 1996a). From this, it is evident that the water in the Fontein Spruit generally exceeds the lower risk limit. The increase in faecal coliforms counts downstream from sampling point FS3 can be attributed to the drainage from the residential sections of Bochabela (BCH), and Heidedal (HDL), as well as the industrial area of Hamilton (HMT).

Figure 5.2 indicates the log organism numbers/100 ml for faecal coliforms in water sampled at the various sampling points representing the drainage from the different residential sections. The highest organism numbers values were recorded at sampling points BCH, HMT and HDL (the description of the various sampling points are given in section 4.2.1). The medians, 95% confidence intervals as well as the minimum and maximum values of faecal coliforms measured at the different sections of the Fontein Spruit are shown in Table 5.1, while the values for faecal coliforms in the drainage from the different residential sections are presented in Table 5.2. The lowest values recorded in the Fontein Spruit were at sampling points FS1 and FS2 (Table 5.1), just below the Blou Dam, which is an undeveloped part of the study area with natural vegetation (section 4.1.1.5; Figure 4.3).

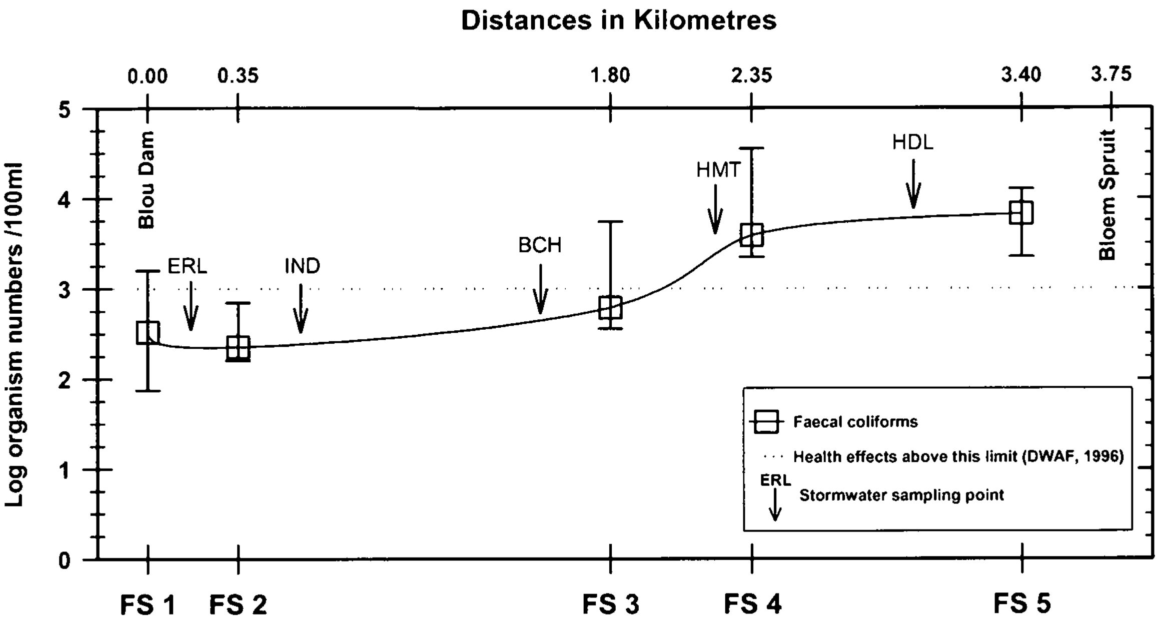


Figure 5.1 Downstream changes in faecal coliform numbers at sampling points in the Fontein Spruit. (Confluence points indicated by arrows)

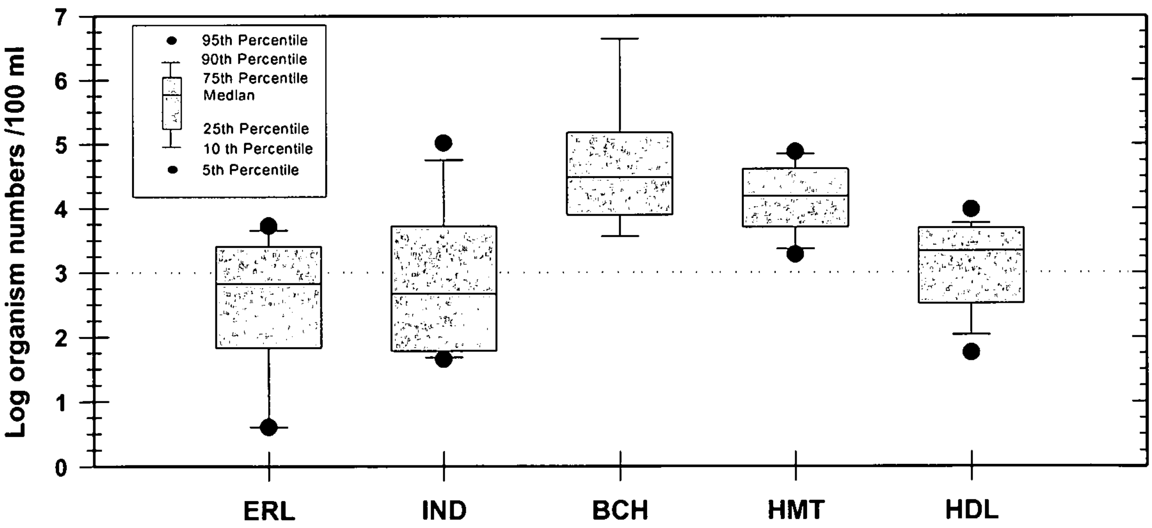


Figure 5.2 Medians and 95% confidence intervals for faecal coliform organism numbers at sampling points representing drainage from the residential and industrial areas in the study area

Table 5.1 n-Values, geometric means, medians, 95% confidence intervals as well as minimum and maximum values for microbiological indicator organisms in the Fontein Spruit (April 1998 – November 1998)

Water quality variable		Sampling sites				
		FS1	FS2	FS3	FS4	FS5
Faecal coliforms (counts / 100ml)	**n-Values**	13	16	17	17	17
	Geometric mean	3.44E+02	3.35E+02	1.40E+03	8.88E+03	5.36E+03
	Log-transformed data					
	Median	2.52E+00	2.36E+00	2.79E+00	3.59E+00	3.83E+00
	95% CI	5.96E-01	2.92E-01	5.48E-01	5.54E-01	3.48E-01
	Min	6.02E-01	1.72E+00	2.25E+00	2.82E+00	2.62E+00
	Max	4.36E+00	3.70E+00	7.28E+00	6.54E+00	4.96E+00
Clostridium perfringens (counts / 100ml)	**n-Values**	10	15	16	17	14
	Geometric mean	1.59E+02	9.80E+01	2.31E+02	2.18E+02	1.89E+02
	Log-transformed data					
	Median	2.21E+00	2.03E+00	2.29E+00	2.38E+00	2.31E+00
	95% CI	3.22E-01	2.36E-01	2.38E-01	3.88E-01	1.98E-01
	Min	1.32E+00	1.01E+00	1.14E+00	1.01E+00	1.49E+00
	Max	3.24E+00	2.71E+00	3.18E+00	4.49E+00	2.90E+00
Somatic coliphages (counts / 100ml)	**n-Values**	5	6	8	9	9
	Geometric mean	9.75E+02	7.29E+02	5.26E+02	2.02E+03	1.98E+03
	Log-transformed data					
	Median	2.90E+00	2.74E+00	2.72E+00	3.04E+00	3.53E+00
	95% CI	4.55E-01	3.99E-01	5.13E-01	3.04E+00	6.58E-01
	Min	2.30E+00	2.30E+00	2.00E+00	2.30E+00	8.45E-01
	Max	3.66E+00	3.58E+00	4.06E+00	4.72E+00	4.11E+00

It is clear from Table 5.1 that the organism numbers of all three microbiological indicator organisms at sampling point FS1, especially somatic coliphages, are high and thus already indicates microbiological pollution. This may be due to impacts from other urban developments as the Blou Dam is situated in the middle of the municipal boundary (Figure 4.1) and is likely to be heavily polluted. FS1 is therefore not an ideal referencing point. However, from Table 5.1 it is clear that the values at FS2 are in all instances lower than FS1 and then increase from FS3 downstream. This might be due to the dense vegetation and reeds (*Phragmites australis*; bulrush and *Typha capensis*), which may act as a filter purifying the water by removing organic matter (COD) and oxidising ammonia, reducing nitrate and removing phosphorous

(Table 5.3). Photograph 5.1 illustrates the vegetation at sampling point FS2 during the winter monitoring period. The vegetation is even denser during the summer months and difficulty to reach this point were experience during these months.

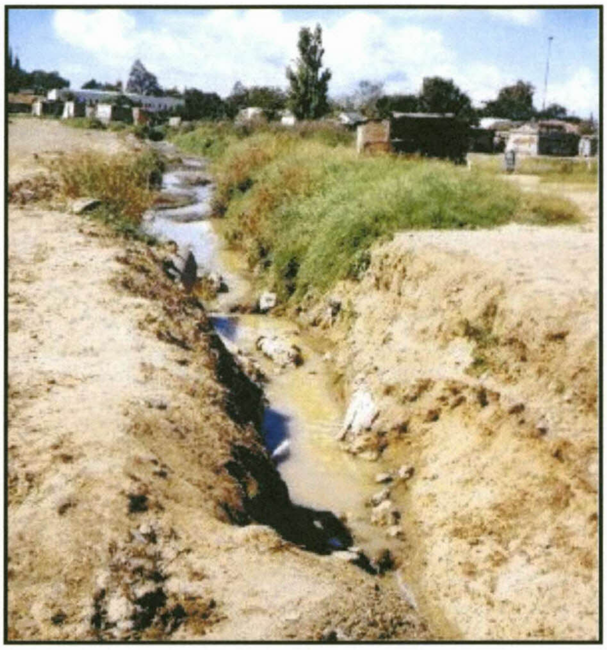
Photograph 5.1 Dense vegetation at sampling point FS2

Due to the reasons given above, FS2 was therefore used as the reference point with regards to determining the impacts of the industrial and residential sections on the Fontein Spruit downstream of sampling point FS1 (Figures 4.3 and 4.4). The lowest values (minimum and maximum) recorded at the sampling points that represented the drainage from the different residential sections was at ERL (Table 5.2).

Table 5.2 n-Values, geometric means, medians, 95% confidence intervals as well as minimum and maximum values for microbiological indicator organisms in stormwater draining from residential and industrial sections (April 1998 - November 1998)

Water quality variable		Sampling sites				
		ERL	**IND**	**BCH**	**HMT**	**HDL**
Faecal coliforms (counts / 100ml)	**n-Values**	15	16	9	14	16
	Geometric mean	3.48E+02	7.31E+02	5.34E+04	1.40E+04	1.25E+03
	Log-transformed data					
	Median	2.83E+00	2.67E+00	4.48E+00	4.19E+00	3.34E+00
	95% CI	5.31E-01	5.89E-01	7.96E-01	2.87E-01	3.64E-01
	Min	6.02E-01	1.64E+00	3.43E+00	3.25E+00	1.64E+00
	Max	3.75E+00	5.12E+00	7.51E+00	4.89E+00	4.07E+00
Clostridium perfringens (counts / 100ml)	**n-Values**	9	16	8	13	16
	Geometric mean	3.51E+01	5.91E+01	3.73E+02	1.82E+02	5.53E+01
	Log-transformed data					
	Median	1.65E+00	1.83E+00	2.57E+00	2.19E+00	1.78E+00
	95% CI	4.00E-01	2.43E-01	5.13E-01	2.67E-01	2.20E-01
	Min	5.38E-01	5.38E-01	1.79E+00	1.54E+00	5.38E-01
	Max	2.50E+00	2.41E+00	3.55E+00	3.45E+00	2.36E+00
Somatic coliphages (counts / 100ml)	**n-Values**	1	4	3	8	7
	Geometric mean	4.00E+02	1.68E+02	1.04E+03	1.41E+03	6.56E+02
	Log-transformed data					
	Median	2.60E+00	2.15E+00	2.85E+00	3.13E+00	3.34E+00
	95% CI		2.82E-01	9.22E-01	2.94E-01	9.02E-01
	Min	2.60E+00	2.00E+00	2.30E+00	2.48E+00	3.01E-01
	Max	2.60E+00	2.60E+00	3.90E+00	3.63E+00	3.96E+00

This can be ascribed to the fact that this residential area is developed at a higher socio-economic level of area. All houses have waterborne sanitation, and the local municipality maintains services. The high values recorded at especially sampling point BCH are reason for concern.During the monitoring phase, when water quality samples were taken at this sampling point, blocked and broken sewerage pipes were frequently observed and raw sewage reached the receiving waters of the Fontein Spruit via surface water runoff. Photograph 5.2 illustrates surface runoff from the Bochabela residential section just before it enters the Fontein Spruit. This photograph was taken during the winter when routine sampling was done and no rainfall was recorded during the preceding days. The water originated mainly from broken and blocked sewerage pipes that were located in the surrounding area.



Photograph 5.2 Drainage from Bochabela residential section

From several other observation studies conducted, it was clear that sewer blockages were a major problem in the study area. For this study, records of the daily rate of sewer blockages in the study area were obtained from the local municipality. Figure 5.3 indicates the number of blockages per day for each month for the monitoring period from June 1998 to January 2000. The average rate of blockages for the monitoring period was approximately six a day. If the month of August 1998 is considered, it was demonstrated that the maximum number of blockages recorded on one day was 16. Ten blockages per day occurred for 23 days (75%) of the month, while for eight days the number recorded was five (10%) per day.

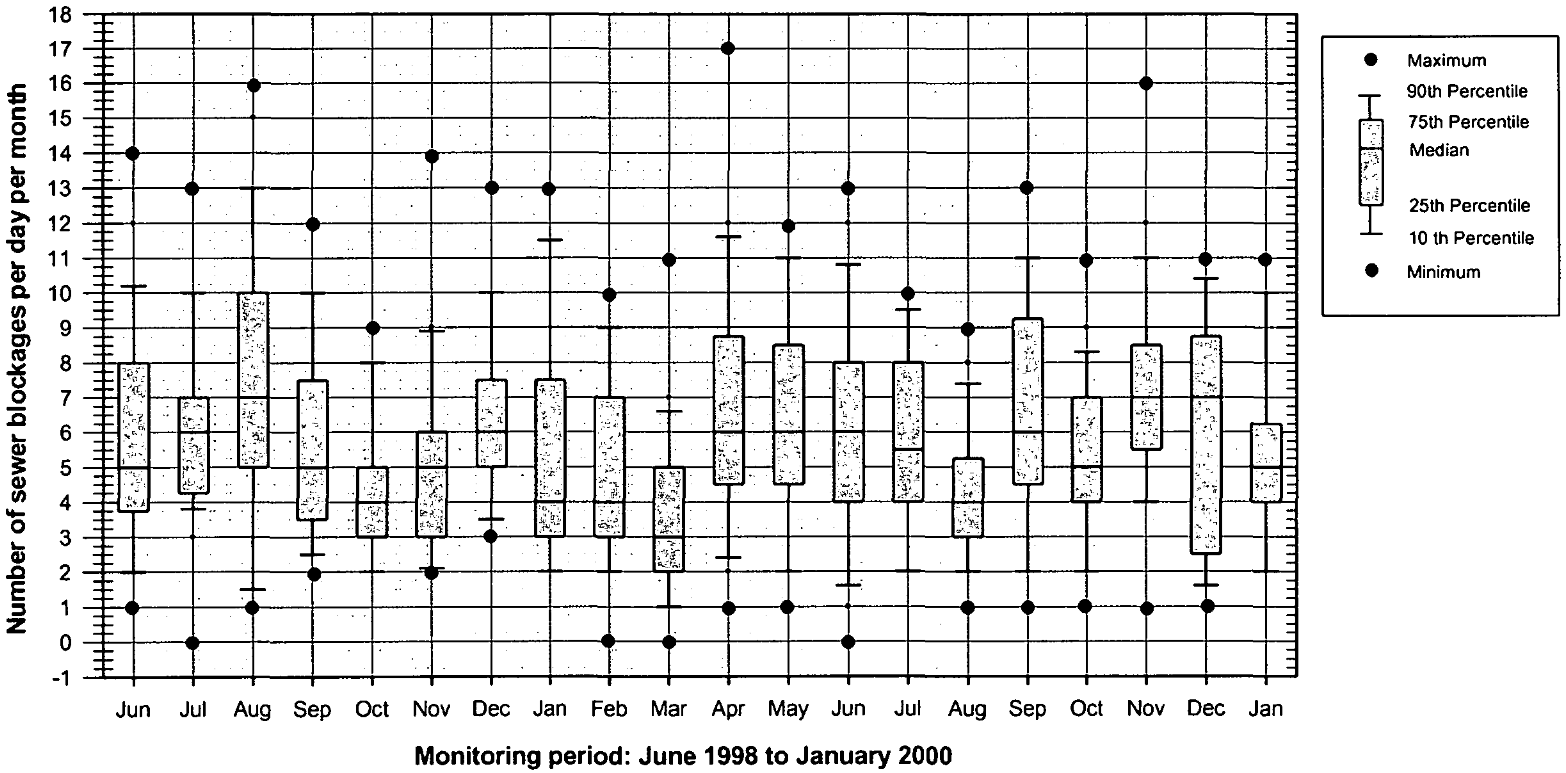


Figure 5.3 Frequency of sewer blockages in the study area for the monitoring period June 1998 to January 2000

The average number of blockages per day that occurred for August 1998 was seven, while the minimum was only one blockage on a specific day.

As indicated in section 4.2.1.2, faecal coliforms were used as the principal indicator for faecal pollution of the water in the area. The high numbers of faecal coliforms recorded (Tables 5.1 and 5.2), were thus a confirmation that there was a major problem with sewage pollution in the study area. As the faecal coliform numbers were high throughout the catchment, the possibility of contracting cholera, as well as other diseases related to gastroenteric illnesses, was very high for the residents of the community. Detailed descriptions of the different diseases, the causative agents and the symptoms of each specific disease, are given in section 2.5.

5.1.2.2 Somatic coliphages

Figure 5.4 shows that somatic coliphages followed the same trend as the faecal coliforms (Figure 5.1). The somatic coliphages target guidelines for *risk free* recreation (DWAF, 1996a) were used and is shown as the reference line on the plot. The full criteria for somatic coliphages for risk free recreation are given in Appendix 1. From this graph, as well as Tables 5.1 and 5.2, it is evident that the somatic coliphage numbers for the Fontein Spruit always exceeded the limits. The high numbers of somatic coliphages in the surface water and water of the Fontein Spruit were primarily due to pollution from sewage, as counts in raw sewage are approximately 103 somatic coliphages/100 ml (DWAF, 1996a). The major factor contributing to this pollution is again the frequency at which sewers were blocked, with raw sewage entering the stormwater system as a result.

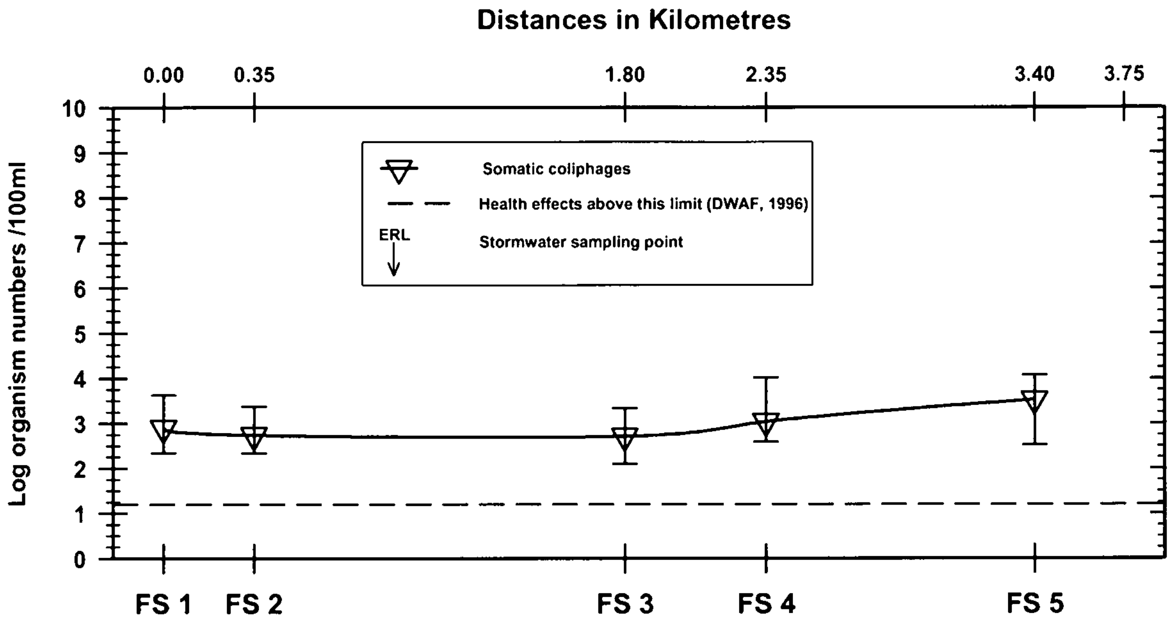


Figure 5.4 Downstream changes in the somatic coliphages organisms at sampling points in the Fontein Spruit.

Coliphages are used as indicators of the potential presence and fate of human viruses in water, particularly the enteric viruses (DWAF, 1996a). Viruses are important causative agents of waterborne diseases and can cause illnesses such as gastroenteritis, hepatitis, poliomyelitis and respiratory illness (section 2.5). The risk of being affected by pathogens also correlates with the level of contamination of the water and the amount of contaminated water consumed. Combined with the fact that the level of contamination of the surface runoff and the water of the Fontein Spruit are high and that viruses have a considerably lower minimum infectious dose than bacteria (and therefore at even low levels of viral pollution a high risk of infection exist), the chances that residents of the study area would contract any of these diseases are very high.

5.1.2.3 Clostridium perfringens

Clostridium species, especially their spores, are exceptionally resistant to unfavourable environment conditions and can survive for long periods. They are therefore often used as indicators of remote faecal pollution (Cabelli, 1977). From the previous sections it was already shown that the stormwater entering the Fontein Spruit are major sources of microbiological pollution. The *C. perfringens* plot in Figure 5.5 is confirmation of this fact.

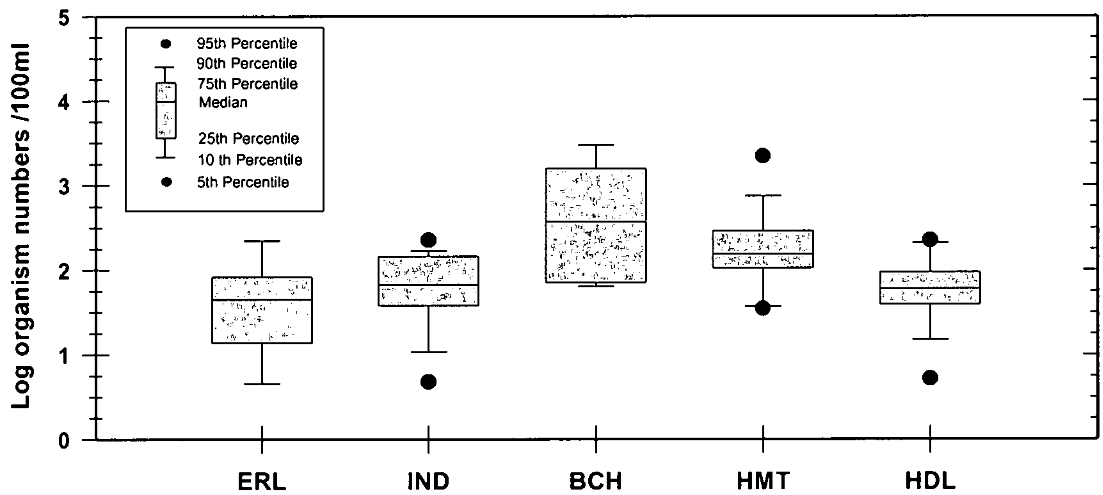


Figure 5.5 Medians and 95% confidence intervals for *Clostridium perfringens* at the sampling points representing drainage from the residential sections.

The graph, however, also indicates the numbers of *C. perfringens* at the various sampling points that represent residential drainage in the study area and therefore gives an indication of the pollution level of the different residential sections and their contribution to the high level of contamination of the Fontein Spruit, through contaminated surface runoff.

Table 5.3 Medians, standard deviations as well as maximum and minimum values of chemical parameters at sampling points in the Fontein Spruit (April 1998-November 1998).

Water quality variable	Sampling sites					
		FS1	FS2	FS3	FS4	FS5
pH	Min	7.0	7.1	7.6	7.5	6.3
	Max	8.8	8.2	9.2	8.4	8.2
	Sdev	0.5	0.3	0.5	0.2	0.5
	Median	7.9	7.8	8.0	7.9	7.9
	n-Values	13	16	17	17	17
DO (mg/l)	Min	1.1	4.3	7.1	1.0	0.5
	Max	16.2	13.2	18.3	17.6	11.9
	Sdev	4.6	3.1	4.3	5.3	3.5
	Median	7.8	8.1	14.2	9.9	7.3
	n-Values	8	11	11	11	12
COD (mg/l)	Min	28.0	14.0	6	10.0	5.0
	Max	67.0	59.0	61	312.0	48.0
	Sdev	13.0	15.5	14.6	78.7	13.2
	Median	46.0	24.0	24.5	24.5	26.0
	n-Values	13	16	17	17	17
NH_4 (mg/l)	Min	0.317	0.159	0.220	0.268	0.256
	Max	5.624	2.855	8.577	35.990	12.481
	Sdev	1.772	0.788	2.036	8.638	2.984
	Median	1.600	0.354	0.512	0.550	0.683
	n-Values	13	16	17	17	17
NH_4-N (mg/l)	Min	0.260	0.130	0.180	0.220	0.210
	Max	4.610	2.340	7.030	29.500	10.230
	Sdev	1.455	0.646	1.669	7.081	2.457
	Median	1.350	0.290	0.420	0.450	0.500
	n-Values	13	16	17	17	17
NO_3 (mg/l)	Min	0.443	1.993	5.136	0.221	3.300
	Max	10.100	10.627	51.630	71.393	71.734
	Sdev	2.711	2.525	14.995	22.343	23.814
	Median	1.640	5.192	22.898	39.500	48.930
	n-Values	13	16	17	17	17
NO_3-N (mg/l)	Min	0.100	0.450	1.160	0.050	0.750
	Max	2.300	2.40	11.660	16.123	16.200
	Sdev	0.617	0.570	3.385	5.024	5.348
	Median	0.370	1.173	5.170	8.900	11.040
	n-Values	13	16	17	17	17
PO_4 (mg/l)	Min	0.083	0.091	0.177	0.267	0.200
	Max	2.400	1.843	2.380	8.740	73.180
	Sdev	0.741	0.544	0.685	2.655	17.545
	Median	0.830	0.415	0.680	0.622	0.549
	n-Values	13	16	17	17	17
PO_4 – P (mg/l)	Min	0.017	0.020	0.058	0.087	0.065
	Max	0.770	0.601	0.777	2.852	24.393
	Sdev	0.241	0.178	0.224	0.684	5.849
	Median	0.271	0.136	0.222	0.203	0.179
	n-Values	13	16	17	17	17

Table 5.4: Medians, standard deviations as well as maximum and minimum values of physical and chemical parameters in the drainage from the residential sections (April 1998-November 1998).

Water quality variable	Sampling sites					
		ERL	IND	BCH	HMT	HDL
PH	Min	7.1	7.5	7.6	6.8	7.5
	Max	8.7	8.6	8.8	8.6	10.6
	Sdev	0.5	0.3	0.4	0.5	0.8
	Median	7.9	7.8	7.9	7.9	8.1
	n-Values	16	17	9	14	16
DO	Min	3.8	1.6	0.1	0.8	3.2
(mg/l)	Max	12.6	12.6	12.8	13.5	11.2
	Sdev	3.3	3.9	4.7	4.1	2.4
	Median	7.7	8.7	8.9	7.9	8.9
	n-Values	11	11	7	8	11
COD	Min	7.0	4.0	8.0	10.0	20.0
(mg/l)	Max	20.0	47.0	803.0	75.0	203.0
	Sdev	3.8	11.9	257.5	18.6	44.1
	Median	11.5	10.0	44.0	21.5	53.0
	n-Values	15	17	9	14	16
NH_4	Min	0.110	0.073	0.488	0.232	0.134
(mg/l)	Max	0.317	2.904	72.346	3.087	1.330
	Sdev	0.062	0.671	23.087	0.803	0.425
	Median	0.134	0.146	3.318	0.427	0.409
	n-Values	15	17	9	14	16
NH_4-N	Min	0.090	0.060	0.400	0.190	0.110
(mg/l)	Max	0.260	2.380	59.300	2.530	1.090
	Sdev	0.051	0.550	18.927	0.657	0.330
	Median	0.110	0.120	2.720	0.350	0.300
	n-Values	15	17	9	14	16
NO_3	Min	0.133	20.457	0.266	0.780	0.602
(mg/l)	Max	2.037	35.500	2.958	6.553	25.700
	Sdev	0.649	3.243	0.918	1.757	8.074
	Median	0.651	29.707	1.993	2.590	8.183
	n-Values	15	17	9	14	16
NO_3-N	Min	0.030	4.620	0.006	0.180	0.014
(mg/l)	Max	0.460	8.000	0.668	1.480	5.800
	Sdev	0.146	0.730	0.219	0.397	1.807
	Median	0.147	6.709	0.450	0.585	2.020
	n-Values	15	17	9	14	16
PO_4	Min	0.230	0.100	0.437	0.113	0.309
(mg/l)	Max	2.790	1.545	81.300	1.800	4.250
	Sdev	0.714	0.385	26.345	0.419	1.040
	Median	0.759	0.520	1.933	0.670	1.290
	n-Values	15	17	9	14	16
PO_4 – P	Min	0.075	0.058	0.143	0.037	0.101
(mg/l)	Max	0.910	0.504	10.212	0.587	1.387
	Sdev	0.233	0.121	3.187	0.137	0.340
	Median	0.248	0.170	0.631	0.220	0.421
	n-Values	15	17	9	14	16

5.1.3 Chemical quality

5.1.3.1 pH

pH is an important variable in water quality assessment, as it influences many biological and chemical processes within a water body and all processes associated with water supply and treatment, as discussed in section 2.4. The pH values measured during the monitoring period were between 6.0 and 8.5, with an average median value of 7.9 (Tables 5.3 and 5.4). The pH values measured were thus mostly alkaline and relatively stable with no definite seasonal variations. Values lower than 6.0 can occur in water high in organic content, and values higher than 8.5 in eutrophic water (Roos & Pieterse, 1994). The water of the Fontein Spruit is eutrophic due to excessive photosynthetic activity of algae (high nutrient values, see Table 5.3), which explain the relatively high pH value of 7.9. Photosynthesis lowers the dissolved CO_2 concentration, as well as carbonic acid, and thus increases the pH (Horne & Goldman, 1994). Low flow, as was experienced during the winter sampling period, is also associated with higher pH values (Roos & Pieterse, 1994).

The different chemical parameters, as indicated in the tables, are all discussed in detail in Chapter 2 (section 2.4), whilst the impact of certain parameters on water quality are discussed in the following sections.

5.1.3.2 Dissolved oxygen

Dissolved oxygen (DO) concentration in a water body is determined by the solubility of oxygen and the DO content is a measure of the ability of surface water to support aquatic life. The Target Water Quality Range (TWQR) for DO is between 80% and 120% of saturation (DWAF, 1996a). Concentrations below 5 mg/l may adversely affect the functioning and survival of biological communities and below 2 mg/l may lead to the death of most fish. In this study the oxygen concentrations were mostly high, almost supersaturated. The solubility of oxygen increases with a decrease in temperature. This is one of the reasons for the high concentration values as the monitoring was mostly done during winter (April 1998 - November 1998). However, the overall high concentrations (>100%) are an indication of algal photosynthesis, as several algal blooms were observed during the monitoring period. The production of the oxygen thus exceeds the diffusion rate of oxygen out of the system by photosynthesis. The low concentrations recorded (<3.0 mg/l; Appendix 3) in the system can either be due to low oxygen production by the algae if washed out with rainfall, or due to high oxygen demand as a result of high organic content in the drainage from residential sections BCH and HMT.

5.1.3.3 Chemical oxygen demand

The chemical oxygen demand (COD) is a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant, such as dichromate. The COD usually includes all, or most, of the BOD (biochemical oxygen demand) as well as some other chemical demands. As discussed in section 2.4.4 the BOD is an approximate measure of the amount of biochemically degradable organic matter present in a water sample. The BOD test is widely used as an indicator of the intensity of municipal- and industrial waste and the measurements are usually lower than COD measurements. The concentration of COD observed in surface water ranges from 20 mg/l O_2 or less in unpolluted water to more than 200 mg/l O_2 in water receiving effluents (Chapman, 1992). In this study the median COD values (Table 5.3 and 5.4) were reasonably low (<30 mg/l), indicating relatively low organic loading. The high concentrations at BCH, HMT and HDL (Table 5.4; Figure 5.6) however, indicate pollution by waste water.

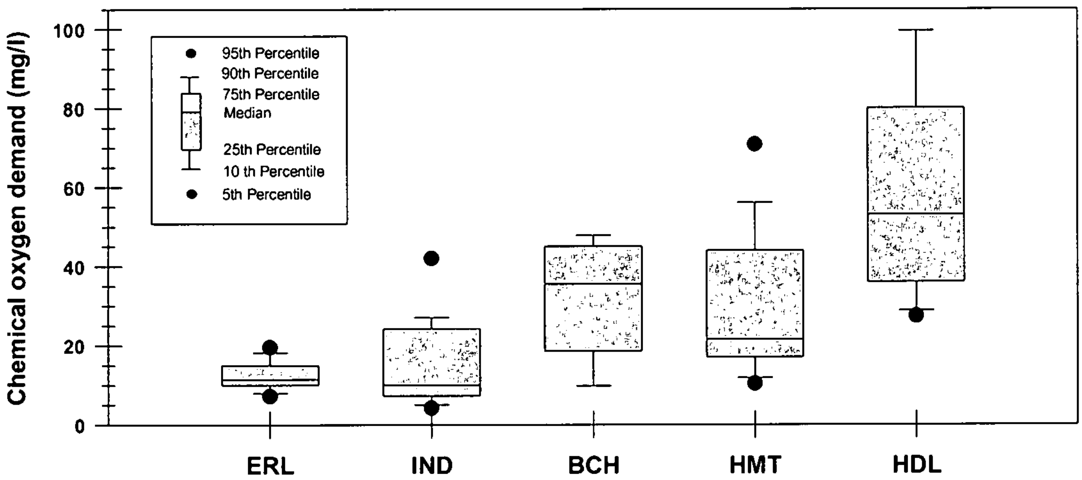


Figure 5.6 Medians and 95% confidence intervals for chemical oxygen demand at the sampling points representing drainage from the residential sections.

The high concentration values were usually associated with low oxygen concentrations and vice versa. The exceptionally high concentration on 25 November 1998 (Appendix 3) at sampling point BCH was due to stormwater contaminated with raw sewage entering the system, which would have had a negative impact on the aquatic ecosystem. The most serious impact is the risk to human health associated with water that contains disease-causing micro-organisms as discussed in section 2.5. Another negative impact is the decreased aesthetic value of the Fontein Spruit, while the general problems are outlined in Table 5.5.

Table 5.5 Major sources and effects of eutrophication on the receiving ecosystem and the problems associated with these effects (compiled from DWAF, 1986; Smith, Tilman & Nekola, 1999; Miller, 2000).

Sources:

- Discharge from municipal sewage treatment works; usually direct point sources;
- Urban stormwater drainage, *e.g.* P from detergents;
- Overflows of combined storm and sanitary sewers;
- Urban runoff from unsewered areas; untreated sewage from informal settlements;
- Waste disposal – *e.g.* pollutants from refuse disposal sites;
- Runoff from abandoned mines;
- Septic tank leachage and runoff from failed septic systems;
- Soil erosion, *e.g.* from cultivation, mining, deforestation, and poor land use;
- Industrial waste water effluents, *e.g.* brewing industry and paper mills;
- Agricultural sources; nutrients runoff from fertilisers on farmland (including return flows from irrigated agriculture), intensive livestock, *e.g.* feedlots; and
- Atmospheric sources; air pollution via rainfall and dry deposition.

Effects:

- Species diversity decreases, thus lower biodiversity;
- Dominant biota change;
- Shifts in phytoplankton species composition to cyanobacteria can have a profound effect on growth and species composition of higher trophic levels;
- High primary productivity;
- Increased biomass of plant and algae; frequent algal blooms;
- Low ecological stability and loss of homeostatic mechanisms;
- Extreme oscillations occur in physical and chemical parameters as well as in the growth of many planktonic organisms - growth in pulses and sudden collapses;
- Habitat loss and significant loss of wildlife;
- Reduced ecosystem integrity; loss of some ecosystem components and functions;
- Turbidity increases; reduced water clarity;
- Rate of sedimentation increases, shortening the life-span of the lake;
- Elevated pH and dissolved oxygen depletion in the water-column; Anoxic conditions may develop in hypolimnion; and
- Increased probability of fish kills.

Problems:

- Treatment of potable water become difficult and costly;
- Potable water supply may have an unacceptable taste or odour;
- Possible health risks in water supplies (*e.g.* toxins by blue green algae; carcinogenic trihalomethanes may be formed when water is chlorinated during purification);
- Decreases in the perceived aesthetic value of the water body (amenity value degraded);
- Increased vegetation may impede water flow in canals (loss of hydraulic capacity);
- The recreational use of water surfaces is adversely affected; and
- Commercially important species (such as trout) may disappear.

5.1.3.4 Nitrate (NO_3-N)

From Table 5.3 it is clear that the nitrate concentration measured in the study area was very high, 11.6 NO_3-N mg/l (max) at FS3 and it increased downstream as indicated in Figure 5.7. Nitrate is normally the most common form of combined inorganic nitrogen in water courses and streams. Inorganic nitrogen is primarily of concern due to its stimulatory effect on aquatic plant and algae, as is discussed in section 2.4.7. Natural concentrations, which seldom exceed 0.1 mg/l NO_3-N, may be enhanced by municipal- and industrial waste water (Chapman, 1992). This is again confirmation of the waste water pollution via the sampling points, which represent the drainage from the different residential sections.

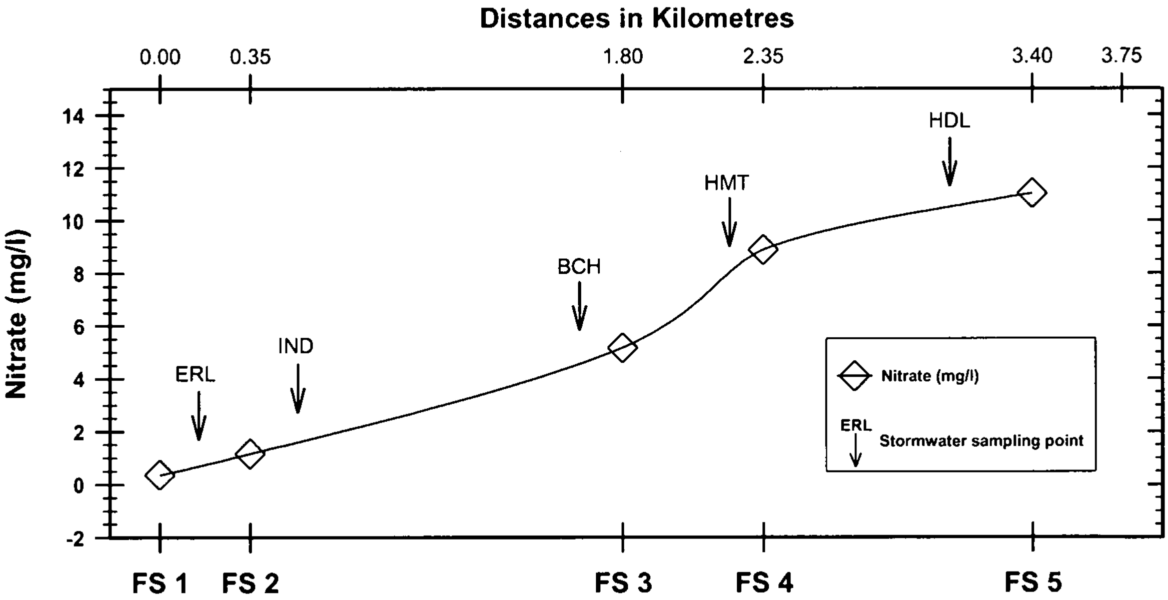


Figure 5.7 Downstream changes in nitrate (NO_3-N) at sampling points in the Fontein Spruit.

5.1.3.5 Ammonium (NH_4)

Ammonia occurs naturally in water bodies arising from the breakdown of nitrogenous organic and inorganic matter in soil and water, excretion by biota and reduction of the nitrogen gas (NH_3) by micro-organisms (Roos & Pieterse, 1994). Unpolluted water contain small amounts of ammonia, usually well below 0.1 mg/l as nitrogen (Chapman, 1992), whilst high ammonia indicates an organic load to the system because NH_3 is generated by heterotrophic bacteria as a primary end product of decomposition of organic matter. The NH_4-N concentration in the Fontein Spruit (Table 5.3) was very high and is much higher than in unpolluted rivers, which average 0.015 mg/l (Roos & Pieterse, 1994). Secondary waste water effluent can contain up to 20-30mg/l NH_4-N and up to 10 mg/l PO_4-P (Horne & Goldman, 1994). Even though the median value at FS1 (NH_4-N; Table 5.3) is higher than any of the other monitoring points in the Fontein Spruit, the maximum value recorded at FS1 was only 4.61 mg/l, compared to the maximum values of 7.03 mg/l, 29.5 mg/l and 10.23 mg/l at FS3, FS4 and FS5 respectively. These high NH_4-N concentrations in the Fontein Spruit (FS3 to FS5) can therefore be attributed to the drainage from the residential sections Bochabela (BCH), Batho (HMT) and Heidedal (HDL). The concentrations measured at sampling point BCH were never lower than 0.4 mg/l. The highest concentration (59.3 mg/l) was recorded on 25 November 1998 (Table 5.4; Appendix 3), due to a rainfall event the preceding day. Stormwater entering the sewer system caused sewers to overflow. The water contaminated with raw sewerage reached the receiving waters of the Fontein Spruit as urban runoff.

5.1.3.6 Phosphate (PO_4)

Phosphorus (PO_4-P) plays a major role in biological metabolism and is seldom present in high concentrations in unpolluted surface water because plants actively take it up. In most natural surface water, PO_4-P ranges from 5-20 µg/l PO_4-P (Chapman, 1992). The most common natural concentration of pristine streams is 10 µg/l (Roos & Pieterse, 1994). The mean PO_4-P concentration, calculated from information on 21 South African impoundments given by Walmsley and Butty (1980), was 60 µg/l.

From Table 5.3 it is clear that the PO_4-P concentration in the Fontein Spruit was very high. The median value at FS2 was 136 µg/l and increased to 222 µg/l at FS3. These high concentrations compare with a hypereutropic system and can be due to PO_4-P discharge by human and animal activity in the study area. Human- and animal wastes contain substantial amounts of PO_4-P and the maximum concentration of 10 212 µg/l at sampling point BCH (Table 5.4; Appendix 3) was once again recorded on 25 November 1998 when raw sewage entered the system. The elevated levels of PO_4-P in the drainage from the residential sections (Table 5.4) can be due to non-point source discharges such as grey water that is dispose directly onto the ground. The impact of the high levels of phosphorous in the Fontein Spruit (Table 5.3) can lead to an increase in the trophic level of the Fontein Spruit, with the result an increase in cyanobacteria (blue-green algae) that can lead to toxic algal blooms and ecological problems in the system, which are discussed in Table 5.5.

5.1.4 Physical quality

5.1.4.1 Total dissolved solids

Total dissolved solids (TDS) are a measure of all the dissolved materials, organic as well as inorganic, in water. The DWAF, (1996a) pointed out that the quality of many water resources in South Africa is declining, primarily because of salination and eutrophication. The total dissolved salts concentration is directly proportional to the electrical conductivity of water and is much easier to measure (DWAF, 1996a). It has therefore become common practice to use the total dissolved salts concentration as a measure for TDS. In this study the median concentration of TDS range from 481-630 mg/l in the Fontein Spruit (Table 5.6; Figure 5.8) and from 238-633 mg/l in the drainage from the residential sections (Table 5.7). This is four times the average of rivers in Africa (Wetzel, 1983). Water with a TDS of >500 mg/l are brackish and can have a negative impact on an aquatic ecosystem.

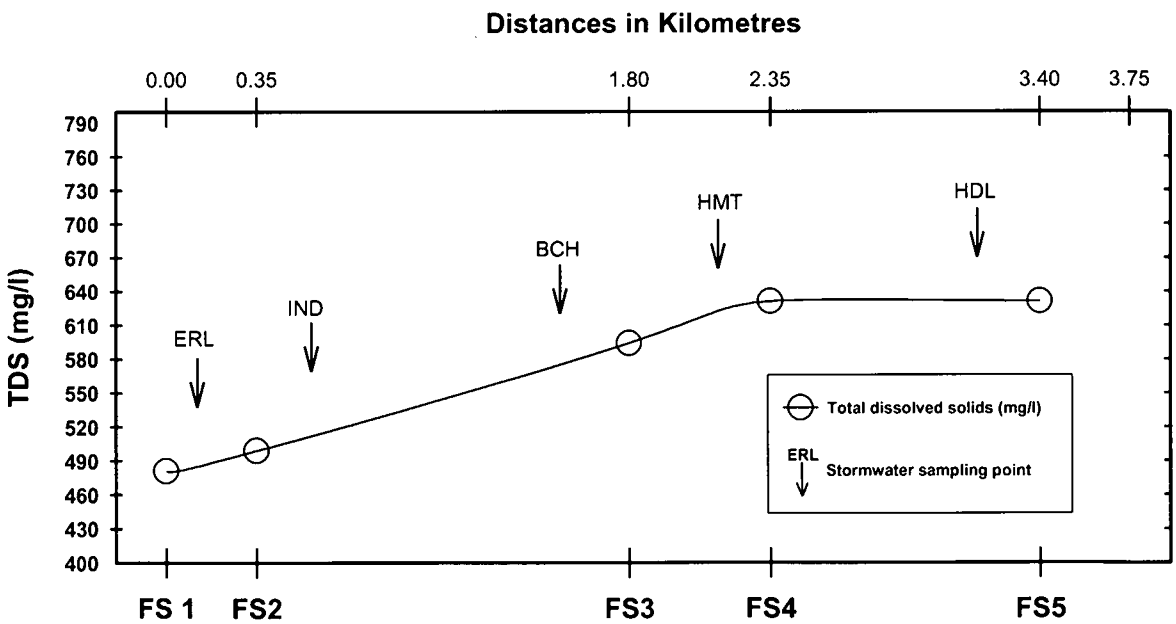


Figure 5.8 Downstream changes in the total dissolved solids at sampling points in the Fontein Spruit.

Table 5.6: Medians, standard deviations as well as maximum and minimum values of physical and chemical parameters at sampling points in the Fontein Spruit (April 1998-November 1998).

Water quality variable	Sampling sites					
		FS1	FS2	FS3	FS4	FS5
Temp	Min	5.3	5.2	5.6	5.0	5.2
(°C)	Max	24.0	21.1	23.0	21.3	18.2
	Sdev	6.0	6.2	6.1	6.2	4.5
	Median	16.5	11.3	12.1	12.1	12.6
	n-Values	11	13	15	15	14
TDS	Min	167.0	213.0	367.0	393.3	85.8
(mg/l)	Max	614.0	618.0	722.0	768.3	810.6
	Sdev	161.4	116.6	97.3	94.2	168.5
	Median	481.7	498.6	595.4	630.5	630.5
	n-Values	13	16	17	17	17
Turbidity	Min	2.6	2.2	2.1	1.6	2.1
NTU	Max	85.8	32.8	14.0	14.4	11.0
	Sdev	24.5	8.4	3.6	3.6	2.6
	Median	8.2	4.0	3.5	3.1	3.8
	n-Values	13	16	17	17	17

Table 5.7 Medians, standard deviations as well as maximum and minimum values of physical parameters in the drainage from the residential section (April 1998–November 1998).

Water quality variable	Sampling sites					
		ERL	IND	BCH	HMT	HDL
Temp	Min	11.3	14.4	10.0	4.6	5.0
(°C)	Max	22.8	21.0	24.0	21.0	23.8
	Sdev	4.1	2.2	5.0	5.2	5.5
	Median	16.5	17.2	16.8	10.0	13.2
	n-Values	13	14	8	13	14
TDS	Min	96.2	177.5	232.1	270.4	310.1
(mg/l)	Max	637.7	671.5	720.2	561.0	1039.4
	Sdev	186.5	119.2	193.3	100.1	194.7
	Median	238.2	622.1	273.7	433.2	509.9
	n-Values	16	17	9	14	16
Turbidity	Min	1.1	1.0	2.0	1.8	1.2
NTU	Max	6.7	77.8	242.0	83.5	10.8
	Sdev	1.5	19.0	79.1	28.3	3.0
	Median	2.5	1.8	3.8	3.8	3.0
	n-Values	16	17	9	14	16

The higher TDS concentrations measured at all sampling points can be due to the fact that the rainfall was low as the water quality monitoring was conducted during winter. High rainfall usually leads to an increase in turbidity and a decrease in TDS (Roos & Pieterse, 1994). From Tables 5.6 and 5.7 it is evident that high TDS values were associated with low turbidity values. TDS also affect the saturation concentrations of DO and influences the ability of a water body to assimilate wastes (section 4.2.2.2). The rate of degradation of organic wastes in the Fontein Spruit will thus be lower than in fresh water due to the high salt content.

5.1.4.2 Turbidity

Suspended clays, silts, organic matter, plankton and other inorganic and organic particles cause turbidity. Turbidity in water courses and streams often increases with rainfall, as particles from surface soils are washed into the river (Roos & Pieterse, 1994; Davies & Day, 1998). The average turbidity in the Fontein Spruit and surface runoff was relatively low (<10 NTU (Nepholometric Turbidity Units); Table 5.6), due to the low rainfall during the winter period. The clear water might be due to the high salt content (previous section) that increases flocculation and precipitation of sludge. Higher concentrations were measured at sampling points FS1 and FS2 (Table 5.6) on 25 November 1998 (Appendix 3). This was due to a rainfall event the previous day resulting in an overflow of the Blou Dam which increased the volume of water entering the Fontein Spruit. According to Davies and Day (1998) further research is needed to establish the extent to which turbidity actually affects the biotas of the aquatic ecosystems.

5.2 The water quality status of the Fontein Spruit

The Fontein Spruit is severely polluted. It is eutrophic with a high salt content and high bacterial counts. The lower sampling values, especially of nitrate and phosphate at sampling point FS2 (Table 5.3), might be due to the dense vegetation and reeds (*Phragmites australis*; bulrush and *Typha capensis*), which may act as a filter. The deterioration in water quality along the river is illustrated by the increase in faecal bacteria, dissolved inorganic nitrogen and total dissolved solids caused by the input of industrial and human effluents. The purpose of this section was to establish the level of pollution and magnitude of microbiological contamination of the Fontein Spruit and its associated health risk. The next chapter will concentrate on the socio-economic issues that can have an impact on water quality, including human behaviour in the production, delivery and transport of the pollutants to the Fontein Spruit.

CHAPTER 6 RESULTS: SOCIO-ECONOMIC ISSUES

The political, economical and social conditions in developing communities are usually the underlying causes of water quality problems as these factors largely determine the behaviour of individuals within communities and the resources available to manage the water quality impacts of the community. As discussed in section 4.2.2.1, the purpose of the socio-economic survey was to identify the characteristics of the community with regard to environmental awareness and political culture; use and functioning of services; payment for services as well as the demands of the community with regard to services, and consequently determine the impact of these characteristics on the water quality of the Fontein Spruit.

6.1 Survey sectors

The survey was conducted in the residential part of the study area as indicated in Chapter 4 (section 4.1.2.5). The methodology regarding the differentiation of survey sectors, identification of households to be included in the survey and the manner in which the fieldwork was carried out, is discussed in detail in section 4.2.2.2.

6.1.1 The developed sector

This area consists of the residential sector of Erlich Park. As indicated in section 4.1.2.5, Erlich Park consists of low-cost housing, but due to the fact that is was part of the former lower level-income white suburbs before the land invasion process in 1986, all infrastructure is in place and the area is serviced by the local authority. The number of stands that form part of the study area are 347 and 75 households were included in the survey. The houses are constructed from bricks, corrugated iron for roofing and cement for flooring. Even though the economic differentiation is not great in comparison to the other areas, this sector represents the higher socio-economic group of the study area.

6.1.2 The developing sector

The developing sector consists of three formal suburbs of Mangaung, as well as a sub-section of Heidedal. A total number of 575 households were interviewed during the survey. The houses in this sector are typical municipal houses which consist of two to four rooms. The residents have made no substantial improvements. Usually the walls are concrete blocks or mud bricks and most of them have corrugated iron roofs and concrete floors. Most of the plots also have backyard houses which were erected for the purpose of renting out to tenants. Many of them are in a relatively poor state of upkeep, especially as most of them have been built with second-hand building material and used corrugated iron. This sector represents the middle socio-economic group of the study area.

6.1.3 The informal sector

This sector represents the people who obtained their stands mainly through land invasion. The total number of informal stands in the study area are approximately 2 100. As this information was not available when the field programme was compiled only 50 houses were randomly selected from the 15 informal sections in the study area (Chapter 4, section 4.2.2.1). The type of housing are mainly 'squatter shacks' which are usually cheap and nonpermanent. It is mostly built with used corrugated iron, and the materials used for roofing are mainly wooden boards and plastic sheets. The shacks have mud floors, consist of only one or two rooms so that the total size of the shack are about 15 m^2. This 'sector' represents the lower socio-economic group of the study area.

6.2 The questionnaire results

The data capturing form that was used in the survey is supplied in Appendix 4. It was pre-coded to facilitate analysis by a computer. The processing and analysis was carried out by the Department of Institutional Research at Technikon Free State. A summary of the data abstracted from the questionnaire results is provided in Table 6.1. The table is divided into three sections, namely housing detail (Table 6.1), municipal services (Table 6.2) and payment for services (Table 6.3) for the three survey sectors under investigation.

6.2.1 Housing detail

From Table 6.1 it is evident that many of the residents in the developing and informal sectors still live in shacks or shelters (traditional dwellings). The lack of ownership is also evident from the table and is also indicated in Figure 6.1. Only 13% (75) of the respondents in the developing sector indicated that they owned their dwellings, while no respondents in the informal sector had title deeds for their properties. It may therefore be argued that the majority of the residents of the community regarded their settlements as temporary. This creates problems concerning the management of municipal services, as people fail to take responsibility in terms of caring and maintaining the services provided. The

DWAF (1999a) underlines this concept by saying that residents of a community may be more receptive to better services or payment for services when they own land.

Table 6.1 Data abstracted from the questionnaire results with regard to housing detail (July 1999).

Housing detail:	Developed sector (n=75) % (n)	Developing sector (n=575) % (n)	Informal sector (n=50) % (n)
Municipal / Concrete	100 (75)	60 (345)	10 (5)
Shack / Shelter	0	40 (230)	90 (45)
Title deed	67 (50)	13 (75)	0
Rent	33 (25)	10 (58)	0
Self-built	0	63 (362)	100 (50)
>6 persons/dwelling	6 (5)	44 (253)	26 (13)
>5 years in dwelling	32 (24)	91 (523)	64 (32)

In the developing sector, 44% (253) of the households had more than six members. From the graph in Figure 6.1 it is clear that this situation occur mostly in the developing area. One of the reasons for this is to increase income by renting out rooms to tenants. This allows for the common practice of back-yard shack development, which puts excessive demand on available facilities. Problems regarding the appropriate use of services are created and blockages and spillages of sanitation systems occur frequently. This, in turn, has a negative impact on the quality of the water. A second characteristic common to most of the dwellings in the study area is that they have less than 2 m^2 per person. In some cases, even small rooms are subdivided to allow multiple occupancy. These crowded conditions, inadequate water supplies, as well as inadequate facilities for preparing and storing food, as can be seen from photograph 6.1, exacerbate the risk of food contamination, and water-related and other diseases could be transmitted from one person to another (McGranahan, 1990).

Photograph 6.1 Typical house in study area indicating the crowded conditions and insufficient work space.

The developing and informal sectors indicated a high degree of stability with 91% (523) and 64% (32) of the respondents respectively indicating that they had been living in their current dwellings for longer than five years (Figure 6.1). According to the DWAF (1998), the ease of characterising water quality problems and their causes is related to the stability of a community. Stable communities are more simple to characterise, and management interventions which are required to improve water quality may be more easily identified (Wood *et al.*, 2001). The implementation of any interventions may, however, be difficult, as the traits of the community may restrict the possibilities. Dynamic or transitional communities are more difficult to characterise, but provide an opportunity to intervene and influence the type of services which are put into place. The fact that most of the respondents have spent more than five years in their current dwelling not only indicates stability, but also suggests that there is a lack of income to improve their situation.

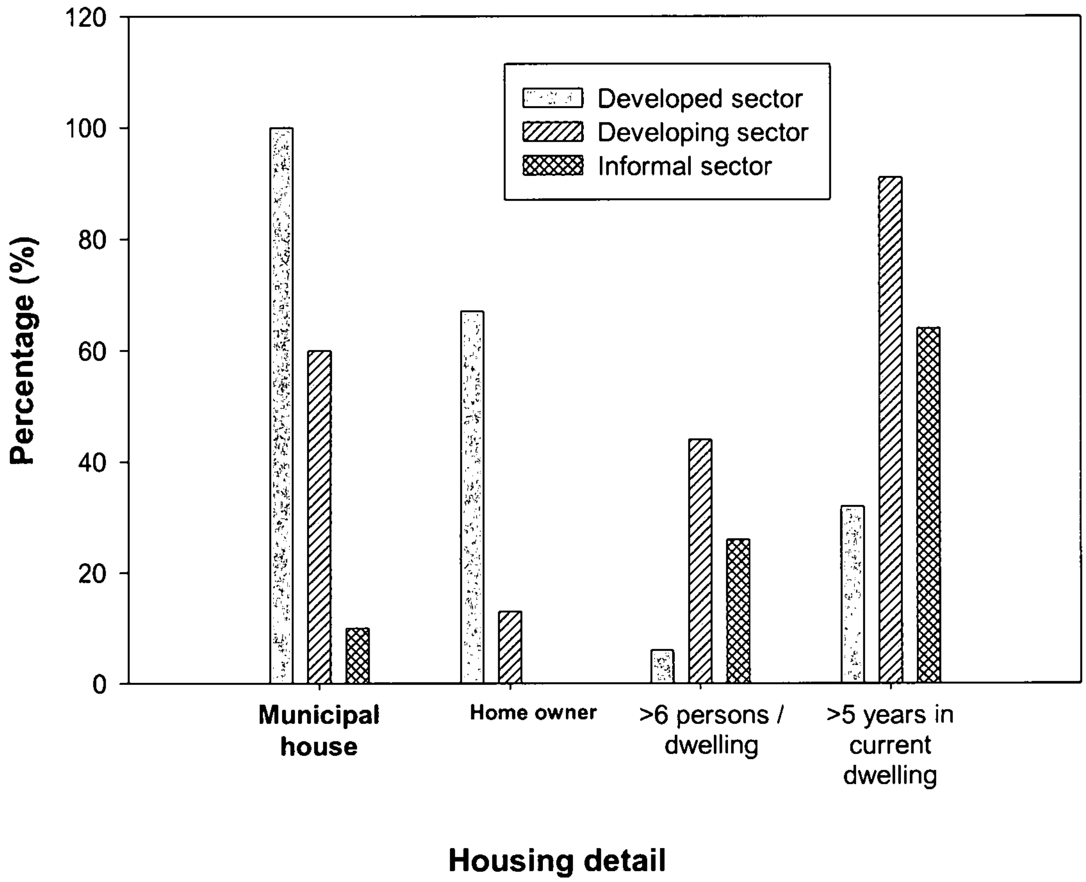


Figure 6.1 The housing detail for the different survey sectors (compiled from data abstracted from questionnaire, July 1999)

6.2.2 Municipal services

6.2.2.1 Water supply

Table 6.2 indicates the level of municipal services available in the different socio-economic sectors as compiled from the questionnaires. Even though 100% (700) of respondents indicated that they had access to water, only 32% (184) in the developing sector and none of the respondents in the informal sector had water in their dwellings. A small minority thus had water piped into their homes, while the rest had to collect water from a yard connection or a communal standpipe. Water is heavy to carry any distance and queuing at a tap or carrying water takes away time that could be better spent. Usually people with a low-income work long hours and are tired when they arrive home. Limited quantities of water are thus collected. This means inadequate supplies for washing and personal hygiene, as well as for washing food, cooking utensils and clothes. Infections – for example eye and ear infections - and diseases are difficult to control without adequate supplies of water (Longergan & Vansickle, 1991). In these cases, the residents are furthermore exposed to the ill effects of water stored in open vessels (Nala, Jagals, Bokako & Genthe, 2000; Photograph 6.1) and, in addition, direct contamination of surface water may be caused as a result of the disposal of the water used at an earlier stage. Although the study was not concerned with a profile of health and waterborne diseases in the community, it endeavoured to ascertain some relationships between water and water related diseases in the community. This, however, was not possible due to fact that the clinic personnel are at present overburdened by the introduction of free health care as well as the fact that typical infections and diarrhoea are not reportable diseases (Seitheisho, 2001).

At communal standpipes and yard connections, water quality problems may occur if there are no grey water drainage facilities. During visits, no such facilities were identified. Observations were, however, made of grey water that had been thrown into nearby storm-water conduits or directly onto the ground. In addition, the residents of the dwellings in the informal sector closest to the Fontein Spruit used the water course to dispose of not only their grey water, but also of litter and other waste. This practice leads to high microbiological contamination by faecal pathogens and high levels of nutrients, mainly nitrogen and phosphorous, in the receiving water. Frequent flooding - especially during the summer months with its high intensity, short duration rainfall – as well as a lack of paved roads, leads to stagnant pools that could convey enteric diseases, and provide breeding grounds for mosquitoes (Longergan & Vansickle, 1991), as can be seen from photograph 6.2.

Photograph 6.2 Stagnant pools of water during summer rainfall period

Table 6.2 Data abstracted from the questionnaire results with regard to municipal services (July 1999).

Municipal services	Developed sector (n=75) % (n)	Developing sector (n=575) % (n)	Informal sector (n=50) % (n)
Water			
House tap	100 (75)	32 (184)	0
Yard tap	0	68 (391)	40 (20)
Standpipe (RDP)	0	0	60 (30)
Sanitation			
Waterborne	100 (75)	100 (575)	28 (14)
Bucket / Pit latrine	0	0	71 (36)
Indoor	100 (75)	18 (104)	0
Outdoor	0	75 (431)	98 (49)
Communal	0	7 (40)	2 (1)
> 5 users / facility	38 (29)	72 (414)	46 (23)
Infant toilet-trained	61 (46)	43 (247)	30 (15)
Solid waste			
Kerb-side collection	100 (75)	94 (540)	32 (16)
Informal dumps	0	6 (35)	68 (34)
Electricity			
Full grid	100 (75)	86 (49)	28 (14)
Low current	0	9 (52)	50 (25)
No electricity	0	3 (17)	20 (10)

6.2.2.2 Sanitation

From Table 6.2, and as indicated in the graph in Figure 6.2, it follows that the local authority succeeded in providing sanitation for all dwellings in the study area, except for the informal sectors. All the households of the developed sector had flush-toilets in their dwellings. Only 18% (104) of the households of the developing sector had indoor sanitation facilities, 75% (431) of households of this group indicated that they had outdoor flush sanitation systems, while the remaining 7% (40) of the respondents of this sector indicated that they had to use communal sanitation facilities. Even though this sanitation system provides a better solution than the bucket and pit latrines (Pretorius, 1996), the higher volume of liquid waste poses a threat of contamination to the water environment.

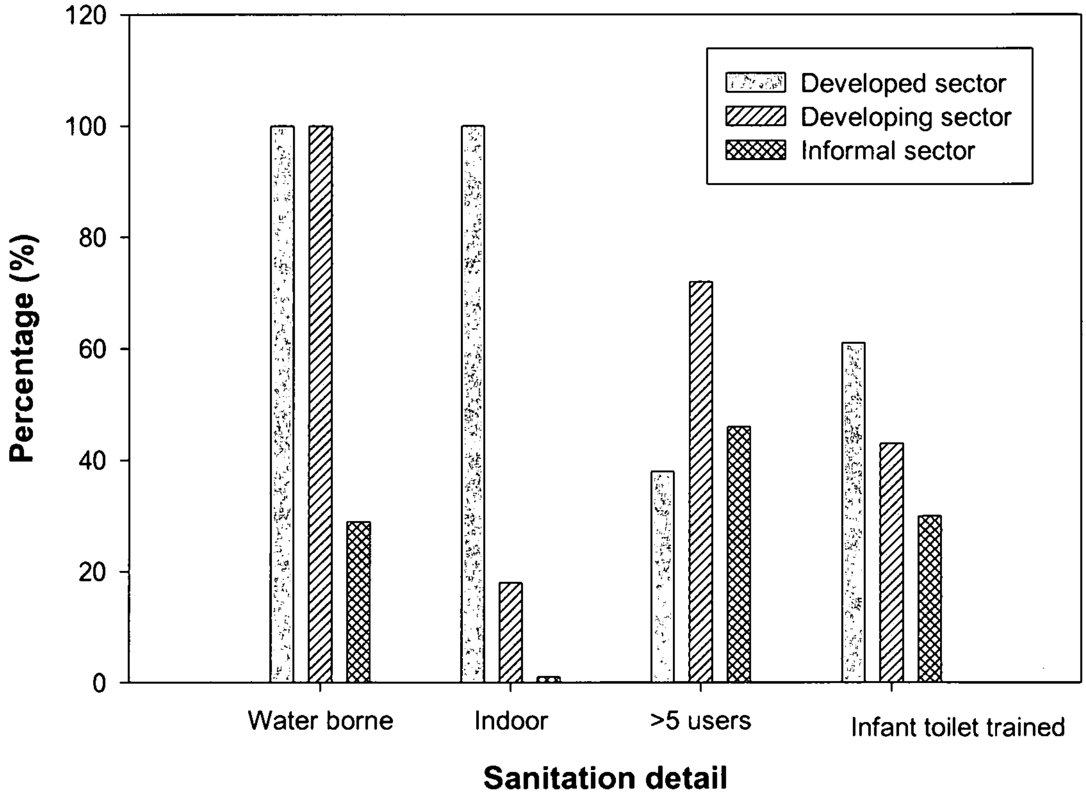


Figure 6.2 The sanitation detail for the different survey sectors (compiled from data abstracted from questionnaire, July 1999)

Full waterborne sanitation requires adequate flow capacity for the housing density and ongoing maintenance to prevent contamination of water resources resulting from blocking, leaking and spilling. While on-site systems pose a threat of groundwater contamination, failing sewer systems present a threat to surface water resources via the storm-water system (De Villiers & Malan, 1985; Du Preez & De Villiers, 1987; Roux, Van Vliet & Van Veelen, 1993).

From observation studies during the monitoring period, it was clear that sewer blockages are a major problem in the study area. Photograph 6.3 indicates several sewer blockages, as well as vandalism of sewer pipes, that occurred in the study area and illustrate the problems and health risks associated with these blockages and deliberate vandalism of sewer pipes.

Photograph 6.3 Blocked and vandalised sewer pipes in the study area.

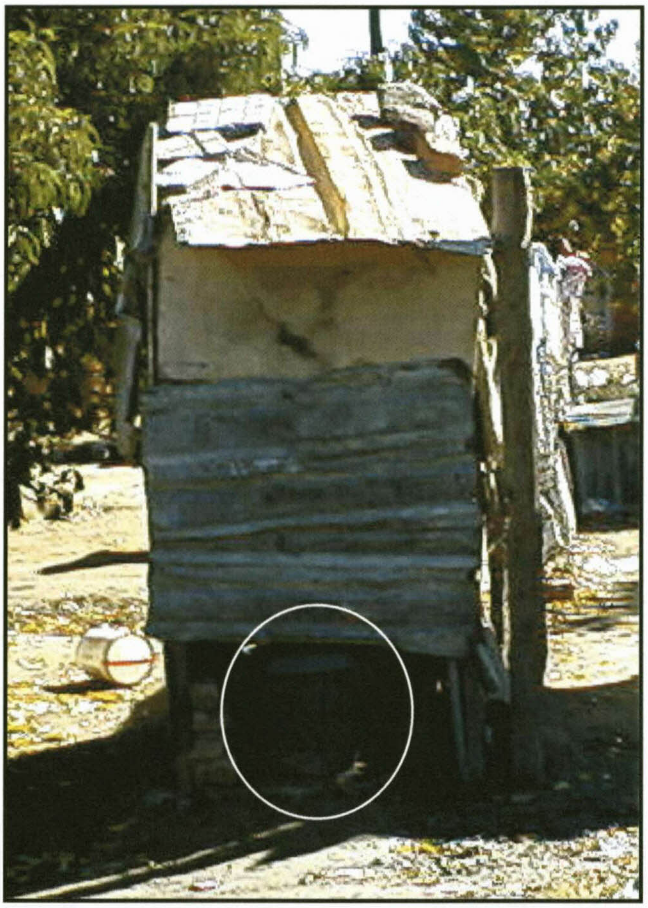
Records with regard to the rate of blockages per day in the study area were obtained from the local Municipality. Figure 5.3 indicates the number of blockages per day for each month for the monitoring period from June 1998 to

January 2000. The average rate of blockages for the monitoring period was around six a day. Reasons recorded by the municipality for these blockages are:

- Rags, cloth, blankets and sanitary towels;
- Silt, rocks, tins, food container bags and plastics;
- Tyres, toys and solid waste; and
- Knives, forks and other cutlery.

During observation visits to the study area and informal discussions held during the field survey, several problems with regard to the blocking of the sewer system were identified. One of the main problems was the removal of the manhole covers and the use of the system for waste disposal. Other problems identified were the fact that cutlery get lost when scraping old or bad food down the toilet, while children, and even adults, were often seen deliberately blocking the system with paper, stones and tyres. This blocking of the sewer system resulted in raw sewage flowing directly into the storm-water conduits or as surface runoff into the receiving water of the Fontein Spruit and constitutes a major heath hazard to the community (Photograph 6.3). The high microbiological pollution recorded in the study area, as discussed in Chapter 5, was mainly due to the blocked and overflowing sewers.

The respondents from the informal sector used either bucket or pit latrines and 46% (23) indicated that there were more than five users per facility (Figure 6.2). The maintenance and cleaning of these toilets are sometimes so poor that their use constitutes a major health hazard. Thus the residents avoid using them. It is also difficult to remove and safely dispose of the human excreta from the bucket latrines, usually at the back through an opening, as indicated in photograph 6.4. The health problems that arise from this are serious, as the high population in the informal sector makes it difficult to protect the residents from contact with excreta. The contamination of the aquatic environment due to overflows and spills is also largely unavoidable, especially after thunderstorms and high intensity rainstorms that occur frequently during the summer period.



Photograph 6.4 Typical example of bucket latrine in study area

In the developing and informal sectors respectively, only 43% (247) and 30% (15) of the respondents indicated that infants (younger than 5 years) were toilet-trained (Figure 6.2). This implies that the majority of the infants in these sectors use the environment for defecation. The children in the study area are therefore particularly at risk as a result of the fact that they may, for instance, contract diarrhoea through ingesting pathogens from faecal matter that contaminates the land or they may come into contact with contaminated water in nearby streams. According to the Water Supply and Sanitation Collaborative Council (WSSCC, 2001), more than 2.5 million children die per year of diarrhoea that could have been prevented by sanitation management. Apart from the fact that faeces transmit diarrhoea, it can also cause schistosomiasis, cholera, typhoid and other infectious diseases. In addition to this toll that ill health takes, the lack of sanitation management is also an environmental threat to the world's water resources and a fundamental stumbling-block in the advancement of human dignity (WSSCC, 2001).

6.2.2.3 Solid waste

From Table 6.2 it is clear that the local municipality does regular kerb-side collection of solid waste as indicated by all the respondents from the developed sector and 94% (540) from the developing sector. Photograph 6.5 shows the containers provided by the municipality, in these areas, and that are emptied on a regular basis. This corresponds with the information received from the municipality that solid waste services are in place in the community, except in the informal areas. Sixty-eight percent (34) of the respondents in the informal sector indicated that they disposed of their refuse by dumping it into the water course, storm-water channels and/or at informal dumpsites. The two main problems resulting from this are the direct water quality impacts of litter and household refuse, coupled with the associated contaminants and the indirect threat by inducing failure of other services such as sanitation and stormwater systems.

Photograph 6.5 Containers provided by municipality in the developing sector for solid waste management (July 1999)

The local municipality regularly services the developed and developing sectors in the study area, but not the informal sector. This sector consists of densely built-up non-paved areas that are difficult or impossible for garbage collection trucks to enter. Waste collection therefore occurs only occasionally. Litter accumulates in open spaces and in tracks until it is either picked up by refuse removal, or is swept into the storm-water system by a downpour. Another problem identified by residents in the informal area was insufficient bags provided by the municipality and that the fact that the refuse collection was collected too few times a week. People do not have storage facilities for their rubbish bags and if they leave them in the streets, dogs tear the bags. Once this has happened, the refuse gets scattered around the street and it creates a negative way of behaving by the residents with regard to littering. Pressend

(1998) agrees with this, as he is of the opinion that "litter begets littering". This implies that the residents in the informal sector have a perceived acceptability of littering, as others have already done so. Photograph 6.6 illustrates the litter problem in the informal sector in the study area. According to Marais (2000), "Keep America Beautiful" – a national litter education and prevention organisation in the United States of America - found that people litter for three reasons:

- They lack a sense of ownership;
- They believe that someone picks up their litter; and
- The area is already littered.

Photograph 6.6 Informal litter dumps in the informal sector in the study area (July 1999).

In South Africa the temptation to litter is exacerbated, as there is a general failure on the side of the authorities to enforce legislation and effective penalties as a deterrent to offenders (Marais, 2000). Educational campaigns and programmes with regard to the impact of solid waste in the Fontein Spruit may help to establish an environmental ethic in the study area to counter the waste problem.

6.2.2.4 Energy

The level of service in the study area can be classified as follows: no electricity supply, low current electricity and full grid electricity. The different levels of electricity supply in the three survey sectors are as indicated in Table 6.2. Only 3% (17) and 20% (10) of the respondents of the developing and informal sectors respectively indicated that they have no electricity supply. Most of the households, however, still burn wood and coal because these energy sources are cheap, accessible and reliable. Some people also prefer using wood for space heating and many have made significant investments in coal-burning stoves, which they cannot afford to replace. The use of wood and coal for heating and cooking, produces atmospheric contaminants as well as ash that is discarded and may be washed into surface water resources.

6.2.3 Payment for services

Table 6.3 indicates the level of payment of municipal services in the different socio-economic sectors as compiled from the questionnaires. From the table, and the graph in Figure 6.3, it is clear that - in the developed and developing sectors - there is a high correlation between willingness to pay and actual payment, as most services are in place. It follows that the availability of services plays an important role in the actual payment of services. In the informal sector there exists a high willingness to pay, but only 4% (2) of respondents indicated that they actually paid for services. Most of the respondents indicated that they did not pay for services, because services were absent or inadequate.

Table 6.3 Data abstracted from the questionnaire results with regard to payment for services (compiled from data abstracted from questionnaire, July 1999).

Payment for services:	Developed sector (n=75) % (n)	Developing sector (n=575) % (n)	Informal sector (n=50) % (n)
Willingness to pay	90 (68)	88 (506)	62 (31)
Regular payer	78 (59)	72 (414)	4 (2)
Should be cheaper	59 (44)	30 (173)	4 (2)
Should be free of charge	32 (24)	53 (305)	14 (7)

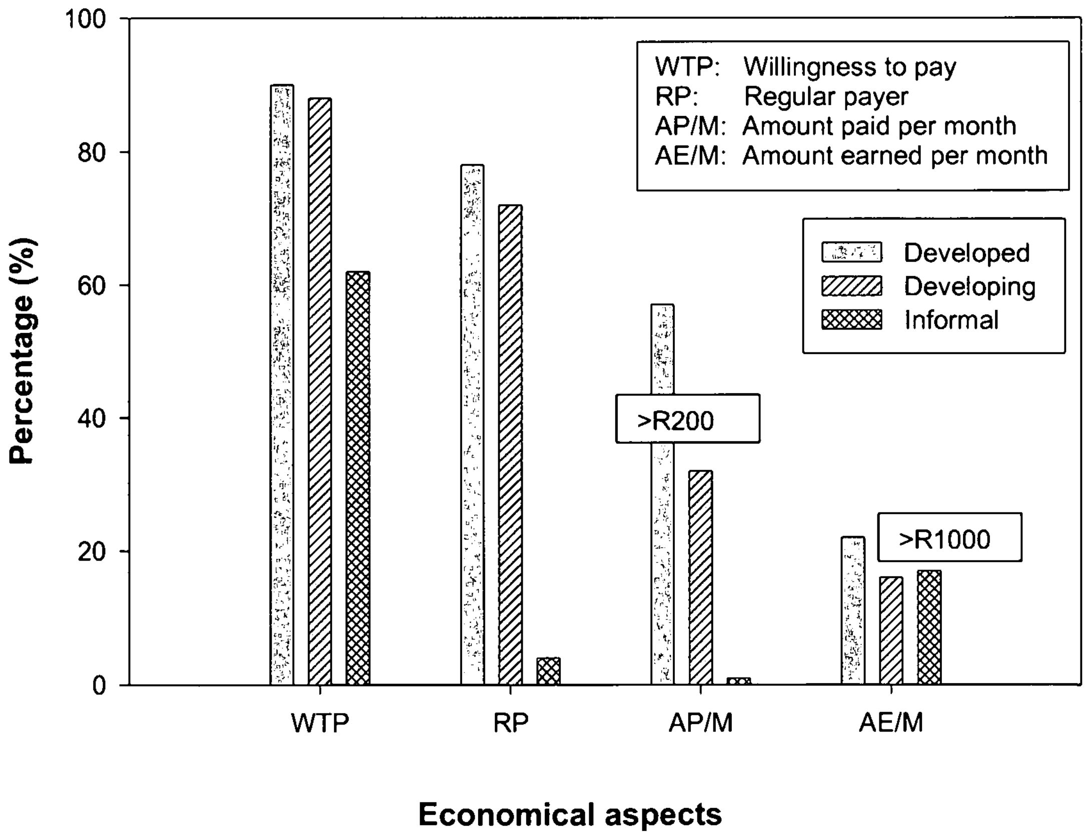


Figure 6.3 The economical aspects with regard to payment for services for the different survey sectors (compiled from data abstracted from questionnaire, July 1999).

From the survey it became evident that unemployment and the low income of the residents of the developing and informal sectors are the major factors influencing the level of payment for services. The majority of these respondents pay out between 5% and 10% of their income to municipal services. Figure 6.4 illustrates the amount (in rand) what the different survey sectors are paying for services. In the informal sector, 20 of the 50 respondents indicated that they pay between R51 to R100 for services. If the amount earned by the respondents in this sector is taken into account (Figure 6.3), the residents do pay approximately 10% or more of their income for services. Hartwick and Olewiler (1998) observe that even though optimal economic pricing of services suggest a marginal cost-based approach to service pricing such an approach may have regressive consequences, resulting in the poor paying a high proportion of their income for a low level of service. This may be one of the reasons for the high percentage of respondents in the developing sector who indicated that the services should be cheaper (30%) and/or free (53%). From informal discussions with respondents and residents while the fieldwork was carried out several other reasons were also highlighted for non-payment of services:

- Pay-points are not accessible;
- Unsatisfactory billing system (*e.g.* billed for what they are not consuming);
- Distrust of the meter readings;
- Not able to read and understand their accounts (unschooled); and
- Lack of transparency on local issues.

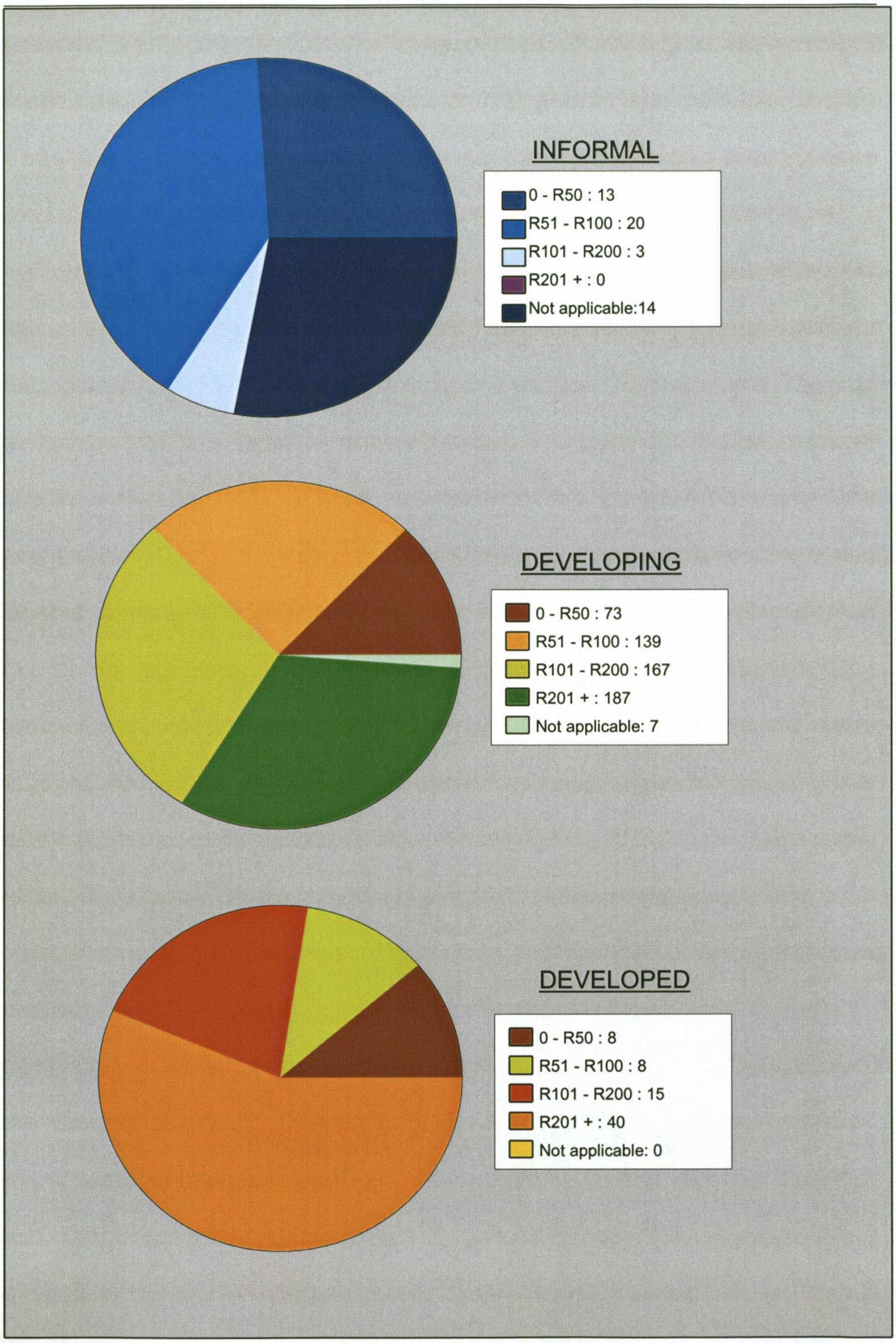


Figure 6.4 Amount paid by respondents (*e.g.* R51-R100 : 20) for services as indicated by the respective survey sectors

6.3 Other factors impacting on the water quality of the Fontein Spruit

This section is a brief overview of other factors that can have an impact on the water quality of the Fontein Spruit which was not addressed in the survey.

6.3.1 Stormwater and road systems

As discussed in section 3.3.2, stormwater management systems must be designed to manage runoff to protect the natural environment by preventing erosion of land and water courses and protecting water resources like rivers and lakes from pollution. Wash-off of accumulated material by stormwater is one of the most significant mechanisms for contaminant delivery from a developing community to surface water resources. Sand and other substances (macro-pollutants) carried by runoff can block drainage systems which result in standing pools of water causing health risks. As roads act as natural stormwater conduits, the two levels of infrastructure in the study area are linked. The stormwater and road systems in the study area can be classified as follows:

- No formal stormwater drainage and dirt roads;
- Open unlined channels and gravel roads; and
- Piped stormwater drainage and paved streets with kerbs.

The areas with piped stormwater drainage and paved streets with kerbs provide the safest stormwater management system in the study area. However, no stormwater detention ponds and litter traps are in place to promote assimilation and to reduce delivery of contaminants that are washed off during storm events. In the other areas, with no formal drainage, open unlined channels and dirt and gravel roads, any rain storm result in soil erosion and formation of gullies, providing conduits for all washed off contaminants. Wash-off of accumulated material, such as litter, sediments, nutrients and microbiological contaminants is one of the most significant mechanisms for contaminant delivery from the study area to the receiving water of the Fontein Spruit.

6.3.2 Land use activities

The management and siting of informal agriculture has an impact on sediment erosion, nutrient loading, microbiological contamination and riparian habitat destruction. A number of informal backyard industries occur throughout the study area and may contribute to water quality problems associated with oils, oxygen demand, metals and hazardous wastes. The lower levels of stormwater drainage and solid waste disposal services exacerbate these impacts. The types of backyard industries that are practised are vehicle mechanics, animal slaughtering and food vendors and are depicted in photographs 6.7 and 6.8.

Photograph 6.7 Vehicle mechanics operating in the study area (July 1999).

Photograph 6.8 Animal slaughtering and food vendors in the study area (July 1999).

Construction sites are frequently overlooked point sources of pollution (Davies & Day, 1998). Numerous materials go into the building of bridges, roads and other structures. Some of these materials, such as paints, bitumen, diesel and wood-treatment compounds, are toxic, while others, like cement and asphalt, leach toxins into aquatic environments (Davies & Day, 1998). Construction material dumped into the Fontein Spruit is illustrated in photograph 6.9.

Photograph 6.9 Construction waste dumped in the Fontein Spruit (July 1999)

6.4 Perceptions and interpretation of survey results

The local authority provides the basic services to the community in the study area. These are looked upon as being inadequate and underdeveloped. This is perceived by the respondents as being due to the Apartheid policies and the community's own non-payment culture. The greatest concern or problem in the study area is broken and blocked sewer pipes. Sewage is seen as being the cause/source of disease in the community by most of the residents. This means that it is of paramount importance to arrange education and training with regards to sewerage systems, the effect of blockages and the health risks involved in overflowing sewers. 'The fork blocking the drains situation', needs to be handled by educating the community members to remove cutlery from plates before washing and not using the toilets to flush down leftovers. Other major causes for pipe blockages are the alternatives that are used for toilet paper. These include telephone directories, newspapers, cardboard, woollen material and sometimes even plastic bags. The use of these alternatives is the result primarily of poverty. A quick fix will be if the municipality supply toilet paper, in much the same way as the refuse removal services provides refuse bags. The parts of the study area that have a refuse service appreciate it. However, the number of informal dumps is unacceptable. The perception is that dumps are formed due to the fact that skips are 'too far' and ' move around a lot', so that people do not use them. They also get full quickly, are to high for children and therefore children taking rubbish to the skip would rather dump it as they are anxious to go and play. Rubbish lying around, whether dumped garbage or litter is the main reason for blocked stormwater drains.

The overall attitude of the community is positive with regard to health and hygiene, as well as water. The largest demand of the community is for improved facilities in terms of water and solid waste and this is matched by the need for education. People are largely willing to pay for services they use. The exception is the extreme poverty cases. People feel that poverty is responsible for all their woes and they experience the real cause for poverty as a lack of education, and industrial or administrative skill.

The survey indicated that a polluted water environment might cause poor community health, which may contribute to poverty. It further indicated that poverty could lead to low payment for services, with the result that services are inadequate or poorly maintained. This may result in inappropriate use of services and polluted water resources. A pollution cycle is formed, which tends to exacerbate the problem over time. The results of the survey suggest that the key to a sustainable management programme to protect the water resources lies in breaking the pollution cycle by addressing the socio-economic issues that have an impact on water quality. From this it follows that a community's attitudes and values are essential components for pollution prevention. This remains a problem in the study area.

A major obstacle when addressing these socio-economic causes of pollution of the water resources in and around developing communities is the belief that the government is responsible for dealing with such issues. However, from informal discussions conducted during the survey it was evident that the community feels a growing need to participate in, and contribute to, decision-making processes with regard to their water resources. Given the rapid urbanisation of South African communities, and the fact that local government funding is limited and has to cover a wide range of services, most local authorities are struggling to manage their water resources (DWAF, 1998). It is therefore critical for the community to be involved in both the planning and management aspects and to take responsibility and accountability for the development, management and protection of its water resources. This concurs with Hill, Motteux, Nel and Papaloizou (2001) that community empowerment by information sharing and education is as important as solving the problem at hand, and to succeed an inter-sectoral approach for engaging people in the process of developing their own community must be taken. In the end, water resources development and management processes need to become more people-orientated, rather than being dominated by technical considerations as in the past (DWAF, 1996b).

CHAPTER 7 IDENTIFICATION OF SOLUTIONS AND INTERVENTIONS

In Chapters 5 and 6 the level of water quality in the study area and the critical issues that have an impact on this water quality were identified. The key causes and effects associated with these issues were highlighted in an attempt to determine *what* to manage. The next step is now to identify and select effective and sustainable management interventions to address the causes and effects of these critical water issues. This process is an attempt to determine *how* to manage. The *how* to manage process can, however, be divided into two phases. The first phase is the identification and implementation of interventions to address the current situation and improve the water quality in the catchment (DWAF, 1996b). The second phase is the development of a Water Quality Management Plan to assist in long-term management and rehabilitation of the aquatic environment. The layout and discussion of the plan is given in Chapter 8.

From the results, as summarised in Chapters 5 and 6, it is evident that the misuse or abuse of services stems from a lack of awareness about the negative impacts, a belief that the appropriate use is too difficult or inconvenient, or the perception that there are no alternatives. Research done by the DWAF (1999b) has indicated that awareness creation and user education programmes provide the most effective method for addressing water quality problems in developing communities. The transfer of technical knowledge and technical skills creates opportunities for solving key water quality problems and for transforming the lives prospects of masses of poor people. As such, the communication of and transfer of technical knowledge forms an essential component of development initiatives, such as upgrading of services, in developing communities. Experience elsewhere in South Africa has shown the vital importance of communication in all community projects (Duncker, 2000). It forms both the vehicle for obtaining community participation as well as essential mechanisms for promoting management at local level.

Despite the essential nature of participation, this concept frequently remains ill defined and loosely structured in its application (Duncker, 2000). While local participation is not seen as a universal remedy, it is firmly believed that effective sharing of the process is an essential requisite for the success of community projects on an ongoing basis. Capacity building is aimed at ensuring that the individuals and the communities are trained and prepared to take over the responsibility of owning and operating municipal service projects. This will include the ability to take informed and rational decisions concerning the level of service and the reasons and need for cost recovery. Education and awareness programmes thus form an essential part of capacity building initiatives. The overall institutional capacity building objective is therefore to create within the community the skills, the ability, confidence and capacity to take ownership and responsibility for the implementation, management and long-term sustainability of service schemes and to ensure an enabling environment for health. Capacity building also forms an essential component of an empowered agenda and has a social objective and is seen as functional learning and skills development. Learning needs to be promoted as a life long process that seeks to impart motivation and skills allowing individuals a competency base to raise their general standard of living and improve their quality of life.

The needs of communities offer a logical and basic point of departure for co-operation between all stakeholders to allow effective upgrading and development of municipal services, as well as the ongoing management thereof. Communities are heterogeneous in their nature, setting and situations. For this reason it is impossible to compile standardised guidelines for management of services that are identical for all communities. However, the provision or upgrading of basic services in developing communities' needs to be a bottom up process that will enhance the capacity of the communities. The communities should be in a position to take the decisions affecting the level of the service and the final form of the scheme. They should accordingly be empowered to take decisions. The process however depends on the extent to which the parties can communicate effectively. It requires the community to be informed in a manner that will enable them to understand the technical choices and the consequences of selecting any of the options. It requires the local authority and the planners, engineers to comprehend the needs and aspirations of the communities and to react to satisfy these needs.

From Chapter 6 it is evident that the waste streams contributing to the water quality problem in the study area, if ranked from high impact to low impact, are:

- Sewerage;
- Stormwater and surface runoff;
- Solid waste; and

- Grey water.

The complexity and interrelated nature of the waste streams and their impact on the water quality requires the problem to be addressed holistically. A combination of interrelated and self-supporting interventions directed at the key physical, social and institutional issues would be more effective than isolated remedies trying to address the breakdown of the waste streams. The interventions must address these issues on various levels, ranging from the resident, through the dwelling and household, the community itself, the local authority and even the broader region. This requires the identification and selection of a set of interventions that address the water quality in an integrated manner. The effectiveness and sustainability of these interventions will depend upon the acceptance and support of the community and institutional role players and the solutions must therefore involve these groups. The fact that there are limited human and financial resources available for water quality management purposes in the study area will also necessitate the selection of interventions that have the least resource requirements.

In South Africa, various university departments and institutes, private organisations, such as the Palmer Development Group, governmental organisations, especially the Department of Water Affairs and Forestry, Department of Environmental Affairs and Tourism, Water Research Commission, several others as well as non-governmental organisations have contributed much knowledge and experience towards interventions and solutions applicable to the South African situation. In this study it was therefore necessary to draw on the national and international lessons learnt and information and experience gained through the successes as well as failures in this field. An analysis of the work and research that has already been undertaken has therefore played a major role in the selection of interventions for the study area and are as follows:

7.1 Sanitation interventions

7.1.1 Sanitation systems

Providing safe and environmentally suitable sanitation systems is necessary to reduce the risk of diseases such as gastroenteritis, and to dispose of waste without harming the environment. It is clear that the municipality has come a long way in providing waterborne sanitation to all sectors, except for the informal sectors (Chapter 4). As a temporary sanitation measure in these informal sectors the improved bucket system can be considered. This system is currently being developed in South Africa and involves using enzymes to convert faeces into a dry flaky product, which can be used as fertiliser (Sowman & Urquhart, 1998). The system is better than standard bucket systems as there is very little odour and it does not attract flies. Both initial costs and cost of enzymes are very low. As sewerage is recycled into useful fertiliser at household level, there is also no need for collection services. Sanitation upgrading is an ongoing process and depends on the household's economic position, the value placed on a better level of sanitation and willingness to pay for it. It is therefore necessary to ensure ongoing community involvement and consultation to be able to upgrade the sanitation systems in the informal sectors in the future. Other sanitation options that can be considered, together with the advantages and disadvantages of each option, are given in Table 7.1.

Table 7.1 General sanitation management options (Adapted from Sowman & Urquhart, 1998; Wood *et al.*, 2001)

Option	Advantage	Disadvantage
Ventilated improved pit latrine (VIP)	Easy to built, cheap and hygienic as a basic system; Improved ability ventilate odour nuisance; Minimise insect nuisance.	Unsuitable with high groundwater table or rocky ground; Security problem if used at night; Expensive to empty or replace.
Aqua-Privy	Relatively cheap and easy to install; Various structures and capacities available; Can be upgraded to full-bore sewerage system; Small amount of water is used for flushing.	Requires frequent emptying; Water has to be carried to flushing tank if no piped water supply; Ground conditions must be suitable or else the soak-aways will not work properly, resulting in surface water pollution.
Enviro-loo	Waterless system and odour free; Fertiliser is produced.	Higher initial cost than VIP.

7.1.2 Sewage system

Durban Metro Waste Water Management has designed an easy to follow pamphlet to highlight how residents can help to keep the sewers free from blockages and also make the community healthier. A similar pamphlet can be designed and distributed in the Fontein Spruit catchment. The role that education has to play is paramount, as 'old habits die hard'. Changing attitudes and improving the responsibility level of people can however be accomplished with proper training.

7.2 Stormwater management

In Table 7.2 general options for stormwater management in developing communities are given. The advantages and disadvantages of each option are also indicated in the table. Management options specific for the study area are discussed in the next sections.

7.2.1 Construction sites

Soil erosion from construction sites and community development areas produces high sediment loads during storm events. Erosion and sediment control programmes should therefore be adopted during and after any large-scale development projects planned within the community and study area. This is particularly important to areas located near the riparian zone of the Fontein Spruit and with regard to road construction, as this exposes large areas of soil. The costs of the stormwater management programme may be implemented at a percentage of the total project cost and can also be further reduced where the stormwater management system for the construction site is linked with the stormwater system of the community.

7.2.2 Stormwater litter traps

Litter and household refuse that is scattered throughout the community tends to be washed into the stormwater system and streams during storm runoff events. A number of structures for removing litter from the stormwater system have been proposed and tested in South Africa and internationally, and seven have been recommended for use in South Africa (Armitage & Rooseboom, 2000). These may be grouped into:

- In-line screens, including grids, mesh nets and catch pit traps through which stormwater flows;
- Self-cleaning screens, which use water forces to continually remove debris and prevent blocking;
- Booms and baffles, which float on a water surface;
- Dry or wet detention ponds; and
- Vortex devices, which increase the rate of settling solids.

Litter traps are most effective in a formal stormwater system. The major problems with litter in the study area are, however, that the litter is delivered to the Fontein Spruit by runoff where erosion gullies and unlined channels act as conduits. A different approach will therefore be necessary and relevant research must be conducted to determine the structures that will be suitable for the specific conditions in the study area. The required efficiency, reliability, ease of maintenance and cost effectiveness would also influence the selection of such a device. An important aspect that should also be taken into consideration is the fact that these structures are relatively expensive, requires ongoing maintenance and are not substitutes for solid waste management.

Table 7.2 General stormwater management options (adapted from Sowman & Urquhart, 1998; Wood *et al.*, 2001)

Option	Advantage	Disadvantage
On-site stormwater management	Effective management of stormwater qualities and quantities; Integration with grey water management for pollution control and environmental protection; Encouragement of community responsibility for stormwater management; Maximising use of resources and environmental protection.	Tendency to be used for disposal of overnight sanitation buckets and waste; Open areas to service drainage channels tend to encourage shack erection; Expensive to implement, service and maintain; Utilises land that community may wish to use for residential development; Requires high level of community support to mitigate increased risk of problems if technologies are abused; Requires education of the technologies and uses of stormwater.
Off-site stormwater management	Maximises opportunities for pollution control and environmental potential; Maximises potential for beneficial use of stormwater; Upgradeable as settlement develops	Decentralises stormwater management and to a large extent environmental protection from the community; Expensive to implement and operate; Requires extensive management and servicing to ensure off-site facilities are utilised effectively.
Drainage of roads	Protection of roads	Tendency to be used as waste disposal sites; Increases rapidity and extent of pollution delivered to receiving waters.

7.2.3 Riparian zone protection

The poor management of riparian zones has been identified as an important area of concern by Bosch, Hubbard, West and Lowrance (1994) and the DWAF (1999b). Informal development and building of squatter houses take place on a regular basis in the study area. Possible interventions that can be implemented in the study area are as follows:

- The planting of indigenous plants along the stretches of the Fontein Spruit;
- The landscaping of the riparian area, as well as adjacent areas as to create a slope that reduces the flow of pollutants and erosion material;
- The development of an appropriate vegetated buffer strip that should be as wide as possible, to act as a filter strip;
- The development of recreational utilities along the river bank to allow for community usage;
- The introduction of a management system to reduce activities that might degrade the river banks or increases pollutants access to the river; and
- The introduction of an education and awareness campaign to promote the value and benefits of a healthy riparian zone.

7.3 Solid waste management

Well-organised solid waste management is critical for the well being of the community in the study area, both in terms of controlling the contamination of the surface water and the Fontein Spruit with litter, and to ensure the effective functioning of the sanitation and stormwater systems. To address the problem of litter in the informal sectors, where no solid waste management is in place, communal skips can be considered. The skips, large open metal containers, must be located at various points throughout the informal sector, in order for the resident to discard of household refuse. These skips should, however, be regularly removed and emptied at the official landfill site.

Transfer of household refuse from the dwelling to the skip may be the responsibility of the household or, alternatively, a local contractor may be appointed by the local authority to collect the refuse from households and transfer it by hand, bicycle or cart. The appointed person must also be responsible for maintaining and cleaning the area around the skip. The critical factors for the success of the system are (DWAF, 1999b):

- Reliable and regular removal of the skips;
- Maintenance and cleaning of the area around the skip;
- A good distribution of skips, with every household being close to a skip;
- A desire by the community to keep the community clean.

The advantages and disadvantages of the above mentioned management option as well as several other general options are given in Table 7.3.

The Tidy Town Programme, an initiative of the organisation 'Keep South Africa Beautiful' can also be considered for implementation in the study area. The Tidy Town Programme offers a systematic community driven educational and awareness creation approach to changing the attitudes, perceptions and practices of communities regarding the way they handle their waste. The key objectives are to encourage, educate and empower members of the community to participate in the effective handling of waste in the community. The programme makes optimal use of local resources with an emphasis on capacity building that will enable a community, in association with its local authority, to raise environmental awareness levels to such an extent that the community can effectively deal with their local environmental problems through volunteer community participation.

Table 7.3 General solid waste management options (adapted from Sowman & Urquhart, 1998; Wood *et al.*, 2001)

Option	**Advantage**	**Disadvantage**
Communal skips	Provides basic collection unit to minimise littering; Reduce pollution and health risks; Induces behaviour changes.	Cost of service not necessarily recoverable from community; Waste has to be carried to skip; Uncontrolled scavenging; Inadequate units lead to overflowing of skips.
Communal waste site	Location for community to dispose of waste; Reduce pollution, litter and health risk; Encourage behaviour changes.	Severe pollution and health risk; Encourages scavenging; Encourages pests and rodents, insects, odours and fire hazard.
Street waste bay	Localisation of waste; Encourage household/street responsibility for waste management; Reduce street pollution & litter and health risk.	Requires regular servicing; Requires provision of waste bags to household for optimal effectiveness; Requires community participation.

7.4 Grey water drainage interventions

The desperate need to provide water supply in South Africa often leads to inappropriately designed water supply points (DWAF, 1999b). As indicated in Chapter 6, lack of drainage at the standpipes is one of the major problems of grey water generation in developing communities. According to Wood *et al.*

(2001), grey water management is severely limited in the majority of informal settlements, and streams of contaminated water are the predominant character arising from the general provision of standpipe water supplies. The water quality problems that occur in the study area with regard to communal and yard supply points can be dealt with by addressing the design of the standpipe. The standpipes should be robust to prevent leakage and abuse, have a facility to ensure the water is switched off after use and prevent access by animals. Another option to be considered is to restrict the amount of water that taps can discharge to 15 – 20 litres per minute to reduce water wastage if taps are left open. At the communal washbasins it is essential to provide non-removable plugs to prevent taps from continually running while washing takes place. Similarly, the area surrounding the standpipe should prevent water from collecting in puddles or making the area muddy. Sufficient drainage for the water wastage is therefore important. General options for the management of grey water in developing communities are given in Table 7.4.

Table 7.4 General grey water management options (adapted from Sowman & Urquhart, 1998; Wood *et al.*, 2001)

Option	**Advantage**	**Disadvantage**
On-site grey water management	Effective management of grey water quantities and qualities; Potential for beneficial use of grey water; Integration with grey water management for pollution control and environmental protection.	Expensive to implement, service and maintain; Requires high level of community support to mitigate increased risk of problems if technologies are abused; Requires education of the technologies and uses of grey water.

Table 7.4 (Continue)

Off-site grey water management	Pollution control and environmental protection; Upgradeable as settlement develops.	Decentralise grey water management and environmental protection from the community; Requires extensive infrastructure to ensure effective utilisation.
On-site re-use	Use of grey water within household and community; Minimise off-site pollution and human health risks; Behaviour changing.	Contamination of crops (requires care and education in handling and preparation of food).
Off-site re-use	Encourage small business development and community participation.	Limited volume and variable quality of grey water may need supplementation; Requires high level of technical and financial support.
Combined grey water / sewer system	Minimise on-site and off-site stormwater management technologies requirements; Removes contaminated water for integration into local sewerage system; Captures point and non-point source of pollution; Reduce health risk and enhance living standards.	Significantly increases hydraulic load on sewage treatment plant capacity; Decentralise management from community; Requires provision of full-bore sewerage system; Requires community participation.

7.5 Cost recovery

Cost recovery is a key element in the sustainability of service provision. It involves the concrete processes of costing ongoing operations and maintenance, measuring consumption, billing and collection tariffs (DWAF, 1999b). The research, however, showed that intrinsic cost recovery factors are willingness as well as the ability to pay, the provision of acceptable and affordable levels of service as well as customer satisfaction with service provision. South Africa has an extremely poor developed culture of consumerism. There has been a history of unequal service provision, marginalisation of poor communities, politically as well as pragmatically induced boycotts of services as well as payments and ineffective cost recovery initiatives. There is also an inherent tension in the Constitutional Right of access to basic services such as water and sanitation for all and the imperative that such services must be paid for. In addition the imperative to accelerate service delivery to previously disadvantaged communities holds the danger that the measure of success will be the number of persons supplied with services rather than the number of people who are satisfied customers. As the implementation of cost recovery in communities is a far more complex task than ensuring that operations and maintenance takes place or billing gets done, it needs an approach that will ensure an understanding of the principles of cost recovery amongst all role players, the provision of infrastructure and services on a participative basis and the promotion of a culture of consumerism.

As indicated at the beginning of Chapter 7, the interventions that was highlighted in this chapter must be seen as interim measures which can help to improve the water quality of the Fontein Spruit. A longer term solution is given in the next chapter with the blueprint of the Water Quality Management Plan.

CHAPTER 8 WATER QUALITY MANAGEMENT PLAN

8.1 Catchment Management in South Africa

Chapter 3 reviews the legislative review process that was initiated in 1995 with regard to water resources management in South Africa. The result of this process was the culmination in 1997 of the *White Paper on a National Water Policy for South Africa* and the National Water Act (Act 36 of 98). As indicated in Chapter 3, the ultimate objective of the National Water Policy and National Water Act (NWA) is to provide for the management of the nation's water resources to ensure equity, sustainability and efficiency of water use (Pegram & Palmer, 2001). The White Paper states that the National Government is "custodian of the nation's water resources and its powers in this will be exercised as a public trust" (DWAF, 1997). The DWAF is the primary agency responsible for water resources management and in exercising its mandate, the DWAF must reconcile, integrate and co-ordinate diverse and often conflicting interests of different stakeholders, within the framework of sustainable and equitable utilisation of South Africa's water resources (DWAF, 1999c; Pegram & Palmer, 2001). The Minister must establish water management institutions to support the DWAF in exercising its mandate as the NWA provides for the phased establishment of Catchment Management Agencies (CMA). The role of the CMAs will be to undertake water resource management in defined water management areas (Pegram & Palmer, 2001) and they will be responsible for implementing the statutory provisions of the Act, as well as developing Catchment Management Strategies (CMS) in their Water Management Area (WMA). The NWA requires the progressive development and establishment of a number of strategies to provide the framework for water resources management at the national and catchment level. The National Water Resources Strategy (NWRS) gives effect to the need for integrated water resource management at a national level, by providing a framework for water resources management between and within management areas (NWA, Section 5; Pegram & Palmer, 2001). The management of the water resource at catchment scale, with input from all stakeholders, led to the requirement CMS to be formulated and established by law (NWA, Section 8; Pegram & Palmer, 2001). These strategies should outline a framework for water resource protection, use, development, conservation, management and control within a WMA and must be consistent with the NWRS (DWAF, 1999c; Pegram & Palmer, 2001). As the NWRS is established in law, it may consist of a number of functional strategies, such as the strategy to manage the water quality effects of settlements (DWAF, 1999a; DWAF 1999b). The Policy, however, also promotes a participatory approach to water resource management, including water quality management. This implies that responsibility for water quality management is shared among national, provincial and local governments, public sector agencies, private sector organisations, community based organisations and non-governmental organisations (DWAF, 1999c). To facilitate this shared responsibility, the implementation of CMS may thus furthermore be assisted by the development of action plans (*e.g.* Water Quality Management Plan). Figure 8.1 outlines the framework of the NWRS and indicate the interrelationship of the catchment management strategy and the action plan (DWAF, 1999c).

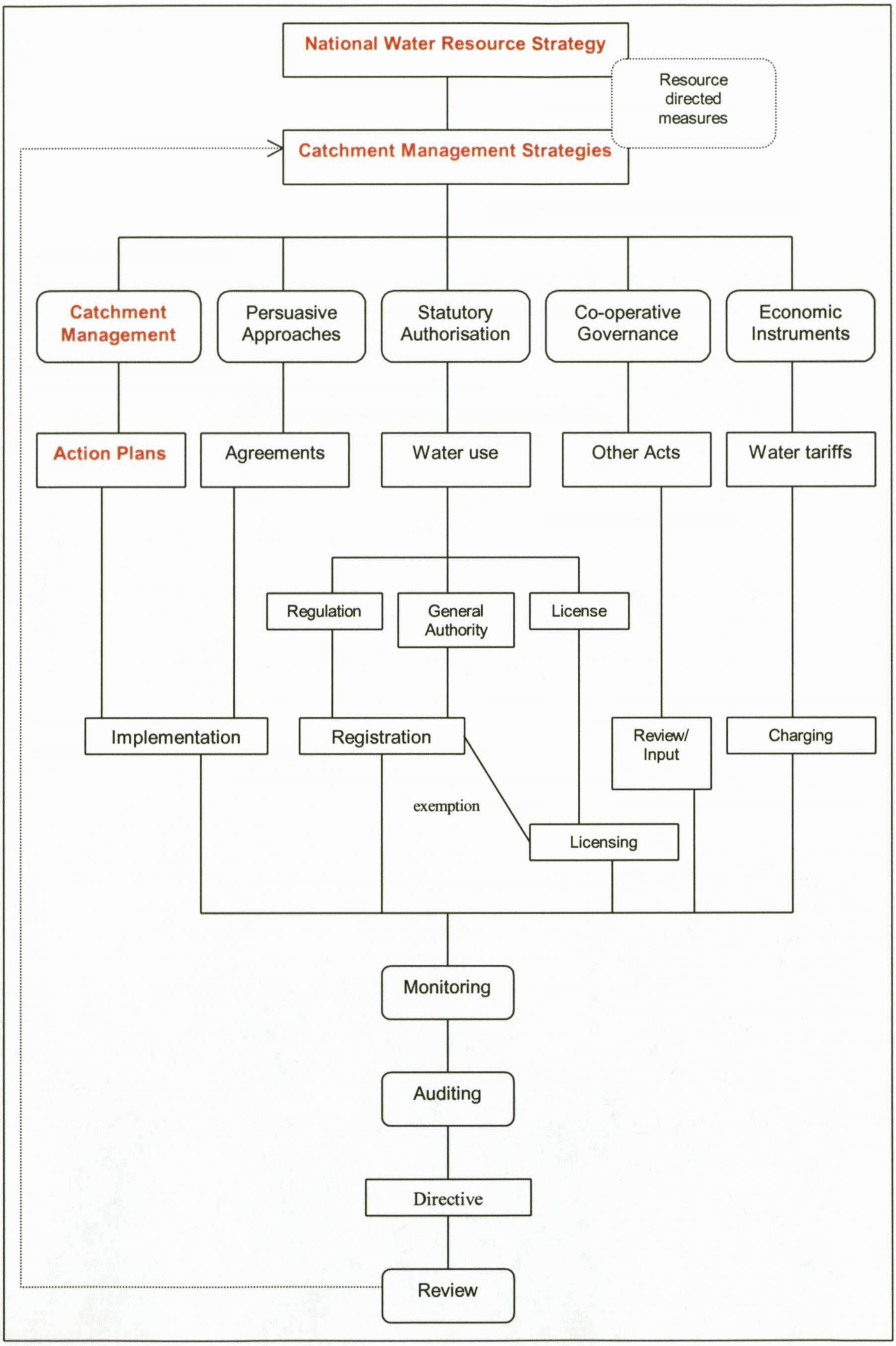


Figure 8.1 Framework of the National Water Resources Strategy (DWAF, 1999b)

The framework, as indicated in Figure 8.1, illustrates that in the medium to long term, the NWRS will be used to identify those water management areas where pollution from developing communities creates significant water quality problems. CMS would in turn be used to identify specific areas or sub-catchments where attention should be given to pollution from developing communities. The CMS would also identify those areas where community development holds particular risks for the water resource. The CMS should then develop action plans or water quality management plans in order to address the problems as experienced in their WMA. Figure 8.2 illustrates the process of identifying priority areas as part of the NWRS.

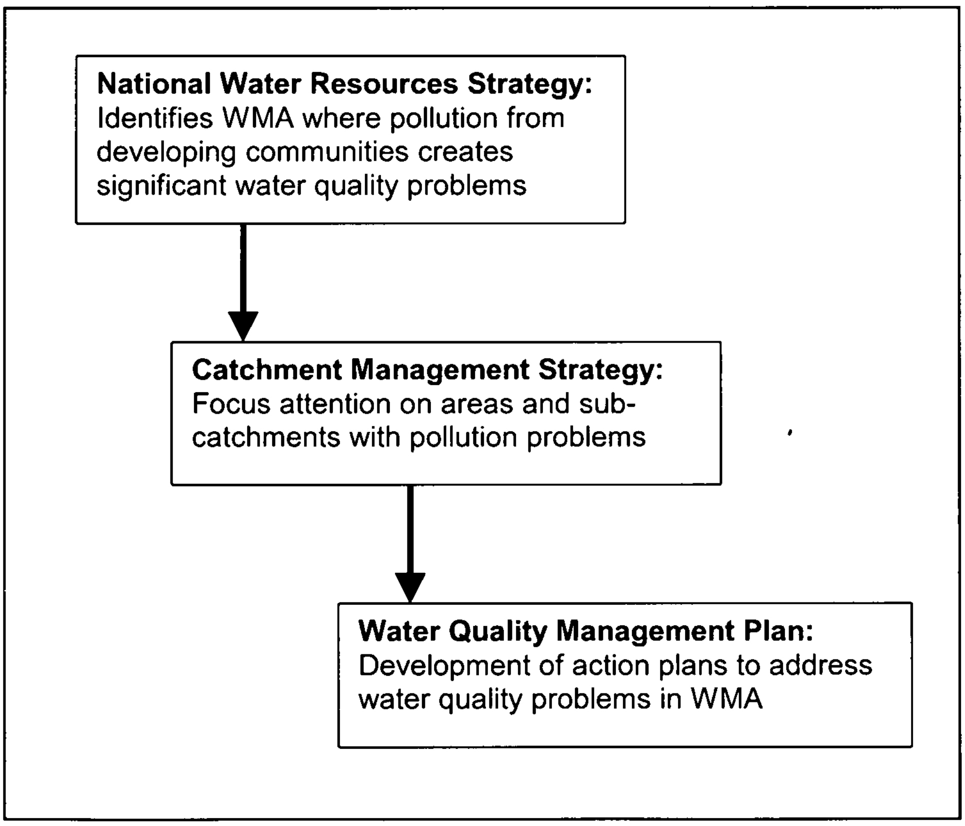


Figure 8.2 The process of identifying priority areas and development of action plans as part of the National Water Resource Strategy (adapted from DWAF, 2001b)

8.2 Water Services Development Plan

The relationship between the NWA and the Water Services Act (Act 108 of 1997) can be explained as follows: while the Water Services Act (WSA) legislate the municipal function of providing water services, the NWA legislate the way that water resources are to be protected, used, developed, conserved, managed and controlled. It is in terms of the NWA that municipalities obtain use of water that they require to provide water services to their customers. This Act also governs how municipalities may return effluent and other waste water back to the water resource. The WSA also requires local authorities to develop Water Services Development Plans (WSDP), outlining the planned development and provision of water supply and sanitation services within their area of jurisdiction (DWAF, 2001a). These plans should be consistent with the relevant CMS, in terms of the impact of these services on the water resources, including water availability and water quality (DWAF, 1999c).

The purpose of a WSDP is to progressively ensure efficient, affordable, economical and sustainable access to water services (DWAF, 2001a). It is the product of the water services development planning process and deals with socio-economic, technical, financial, institutional and environmental issues as they pertain to water services. It also functions as a management tool in ensuring the provision of total, effective and sustainable water services. The WSDP is a critical part of planning for integrated sustainable development where above mentioned issues are addressed. The relation of the WSDP to the CMS as well as the action plan, or Water Quality Management Plan (WQMP) is explained in the next section.

8.3 Relationship between the Water Services Development Plan and the Catchment Management Strategy

There is both a planning and an institutional relationship between Catchment Management Agencies and the Water Services Authority. The catchment management strategy of a CMA is in terms of the NWA required to "take into account relevant national or regional plans prepared in terms of any other law, including any development plan adopted in terms of the Water Services Act" (DWAF, 2001a). Thus when a CMA prepares its catchment management strategy, the CMA needs to take into account the water requirements of the water services authorities as outlined in their WSDPs. Likewise, when preparing the WSDP, the Water Service Authority must refer to the catchment management strategy to determine whether there is sufficient water available to support the proposed water services targets. The institutional relationship between Water Services Authorities and CMAs is provided for in the National Water Act, which indicates that relevant local authorities are to be represented on the governing board of a CMA (DWAF, 2001a). From the point of view of a Water Service Authority the CMA would deal with the limitations on the amount of water, which can be abstracted, from a resource and how this should be returned – thus managing water services from an environmental point of view. The catchment management strategy identifies limits to how much water can be abstracted and the quantity or concentration of particular pollutants, which can be returned to the catchment (DWAF, 2001a). Since Water Service Authorities facilitate water use and impact upon water resources, they are a key role player within water resource management. The WSDP of a Water Service Authority must therefore serve as a mechanism to integrate water services planning of the municipality with catchment management and water resources planning of the CMA. Figure 8.3 illustrates the relationship between a WSDP and a Catchment Management Strategy. Figure 8.3 also illustrates the relationship of the WQMP with regard to the NWA and the Water Services Act (WSA) (section 8.4).

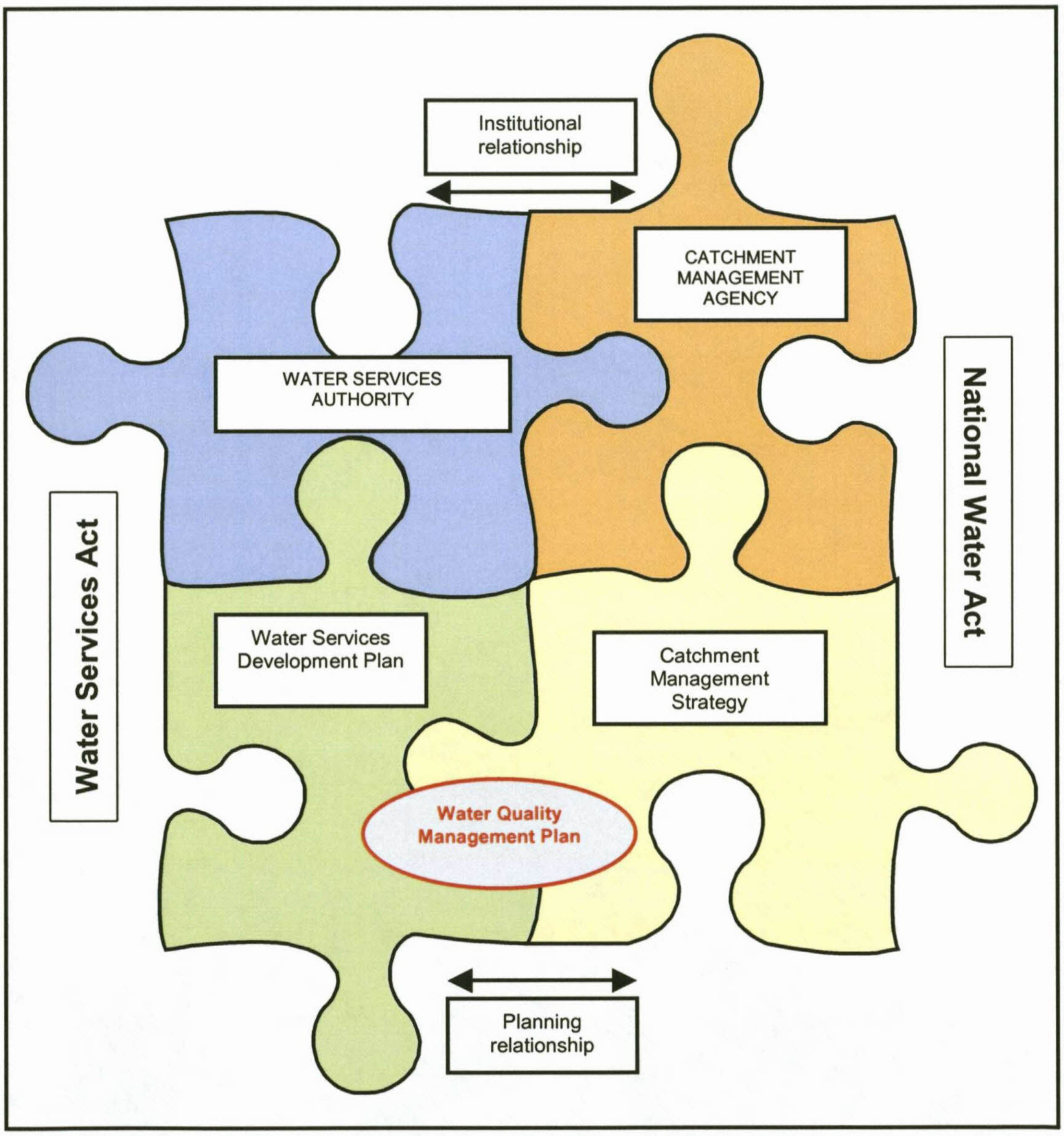


Figure 8.3 Relationship between the National Water Act and the Water Services Act.

8.4 Water Quality Management Plan

The interrelationship between the National Water Strategy, the Catchment Management Agencies and the Water Services Authorities was discussed in the previous section in order to explain the role of the Water Quality Management Plan (WQMP) in catchment management. The rationale of the WQMP, as mentioned in Chapter 1, is to introduce management guidelines to direct both authorities and developers in the selection of the most appropriate method to address water quality problems in their catchment to ensure the protection of the ecosystem. The WQMP is thus in agreement with the National Water Act, the National Water Resources Strategy and can be used as an action plan to assist with the implementation of catchment management strategies.

The results of the study as discussed in Chapters 5 and 6, highlight the impact of socio-economic and human behavioural factors on water quality. This once again accentuates the need for an integrated management plan to address the water quality impacts from developing communities. Water quality impacts, according to the DWAF (1999c) that have their roots in the social and institutional environment are less suitable for statutory authorisation, and should rather be the focus of other non-point source management approaches, such as the national strategy to manage the water quality effects of settlements (DWAF, 1999a & 1999b). However, from the results it is clear that contamination from residential areas stem from a number of causes, which is largely associated with the level and operation of municipal services. It is therefore not only necessary to integrate water services planning of the municipality into the catchment management and water resources planning of the CMA, but also into the WQMP. Figure 8.3 thus also depicts the interaction between the National Water Act, the Water Services Act and the WQMP with regards to catchment management.

8.4.1 Objectives of the WQMP

The Water Quality Management Plan is an integrated plan attempting to address the management of water quality in developing communities. The key objective of the WQMP is the integration of environmental, physical, social and economical issues relevant to the effective management of water quality in consultation with internal and external stakeholders to achieve sustainability of the aquatic environment. In other words, the WQMP integrates the results of environmental and socio-economic assessments into management interventions and strategies and prioritises actions that:

- Assist long term management and rehabilitation of the water courses and lead to cost effective and practical solutions;
- Ensure provision of adequate source control and regional management measures in a balanced way to manage water quality and quantity in the catchment;
- Provide opportunities for active participation of the community and relevant stakeholders to protect water course values;
- Promote environmentally sustainable development in the catchment with water sensitive urban design practices; and
- Minimise impacts from future developments by identifying infrastructure requirements for infill areas earmarked for future development.

8.4.2 Stages in preparing a Water Quality Management Plan

There are six stages involved in preparing a WQMP. Figure 8.4 outlines the tasks involved in each stage, while the discussion and methodology of the tasks are given in the next section.

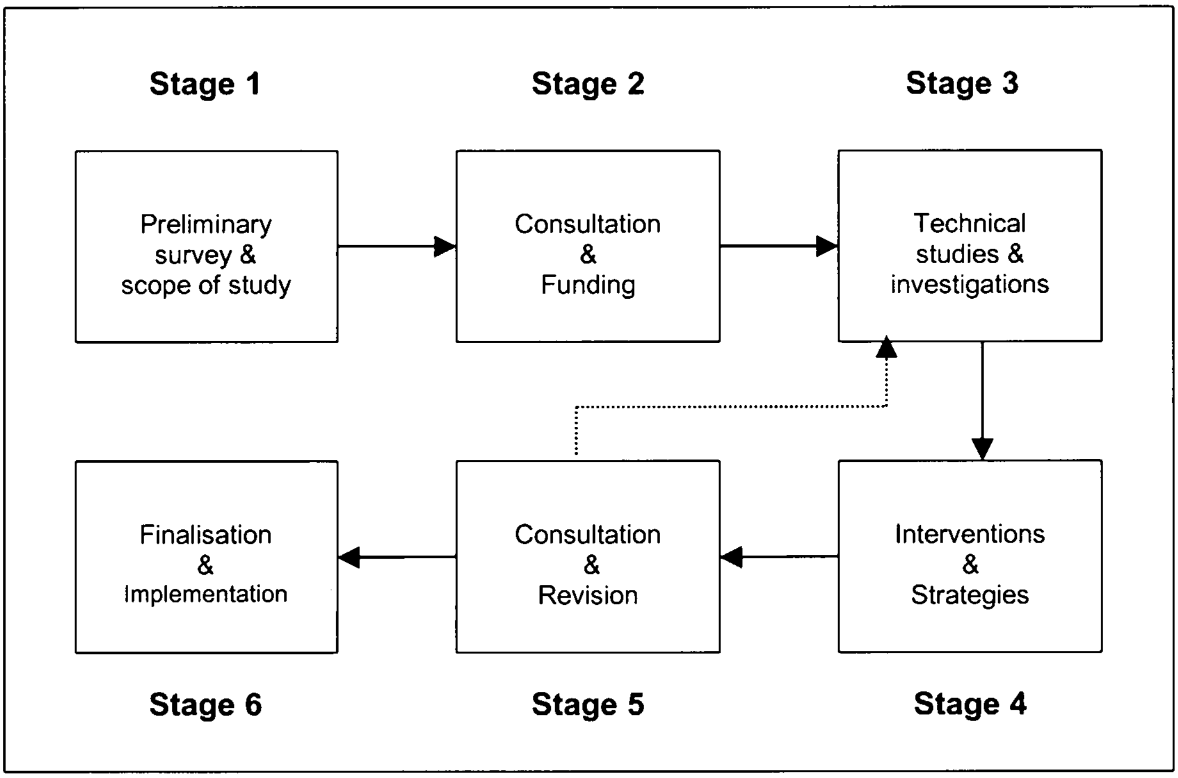


Figure 8.4 The stages of a Water Quality Management Plan (Revised from Rahman & Taylor, 2000)

8.4.2.1 <u>Stage 1: Preliminary survey and scope of study</u>

The main objective of the preliminary survey is to identify and map the catchment to establish the current state of water quality and to identify relevant issues associated with water quality of the catchment. The second objective is to identify current or potential problems with regard to water quality in the catchment.

8.4.2.1.1 Catchment identification

The key sub tasks of Stage 1 are:

- Identify and map the catchment, include smaller water bodies and specific sites needing attention because of development or other special circumstances;
- Locate wetlands and other critical areas;
- Identify vegetation strips and other areas that can control pollution of urban runoff;
- Map the drainage pattern, overland flow and flood lines;
- Map the location of groundwater aquifers;
- Map and calculate the number of hectares within the catchment for each type of land use. Categories can be defined as residential, commercial, industrial, agricultural and open spaces;
- Collect geographical data (*e.g.* geographical location; relief and soil types);
- Collect existing water quality data (*e.g.* physical, chemical and biological);
- Establish the infrastructure and municipal services available (*e.g.* water supply, sanitation, solid waste management); and
- Identify critical management issues (*e.g.* institutional resources, environmental sensitivity, capacity building, awareness creation and education).

Central to Stage 1, and all other phases of development of the WQMP, is involving the public. Contrary to traditional approaches, the aim of the WQMP is to make the community the centre of the WQMP. The identification and selection of internal and external stakeholders are thus very important aspects to be addressed during the first stage as it can have a bearing on the success of development of the WQMP.

8.4.2.1.2 Identification of key stakeholders (internal and external)

Collaboration between all stakeholders is required to achieve synergy of action. This requires dialogue, planning, budgeting and commitment and strategies leading to joint action plans. Collaboration is needed both vertically, between all levels from local communities to national and international authorities, and horizontally, between agencies, departments, NGOs, activists and between the public and the private sector. A framework of collaboration to guide relationships involving people, authorities and sector professionals must be established, as effective water quality management requires working with all stakeholders at catchment and ultimately at river basin level. All forms of land and water use that affect the freshwater ecosystem, and thus the ability to provide sustainable municipal services, need to be planned. Collaboration is also essential between the water, sanitation and hygiene sectors and related sectors of health, education, environment, community development and agriculture. This holds an enormous potential of combining the strengths of specific approaches and skills which each of these partners have in preserving the quality of the water resources and thus the natural environment.

Particularly important is collaboration between government and civil society, because *"governments do not solve problems, people do"* (UNESCO, 1999). The application of people's own energies and local-decision making control is essential for sustainable human development and are therefore the core of the WQMP. Empowerment, achieved through self-reliance, is fundamental to the WQMP. Such empowerment enables individuals and communities to understand their options for change, to choose from among them, to assume the responsibility that these choices imply, and then to act to realise as well as sustain their choices. Facilitating the required social and political processes to make this empowerment possible is therefore a precondition of the WQMP. These processes will need to create the opportunity for self-empowerment through capacity building and awareness creation and demands that the needs of the poor be accepted as a priority. The use of participatory approaches is thus essential for the implementation of the WQMP. Individual and community initiatives need to be supported where possible. The development of civil society and community representation must balance local government and private sector interests.

8.4.2.1.3 Outcomes of Stage 1

The outcomes of the first stage is to prepare a draft document containing the following:

- Description of catchment and an assessment of issues that may potentially affect the water quality and other amenity values of the catchment;
- Assessment of the ecological character of the catchment that identifies those aspects that are unique to the catchment;
- Identification of data gaps and development of strategies to collect the data; and

- Identification of all participants, stakeholders and their objectives.

8.4.2.2 Stage 2: Consultation and funding

Following the preliminary survey, the first consultation process must be carried out to present the findings of Stage 1 with internal as well as external stakeholders. As discussed in the previous section a wide variety of stakeholders may influence the implementation of the WQMP. The capacities of these stakeholders as well as the awareness of the problems in the catchment will to a large extent determine the ease of implementing the WQMP. Similarly, effective interaction between these stakeholders will facilitate the implementation of the WQMP. It is therefore recommended that joint committees be established with key stakeholders, and that active capacity building and training programmes be instituted at an early stage to develop a common understanding and approach to managing the water quality impacts from the catchment. The following key issues need, however, to be considered during the consultation process in order to support a community-sustained approach to the development of the WQMP:

- The complexity of the project in general;
- The size of the project;
- The resources available to the community;
- Community needs and objectives in respect to water quality;
- Community awareness of and demand for a water quality management project;
- The degree and nature of community involvement in critical functions;
- Community willingness to pay for certain aspects of the WQMP;

- Capacity to understand and manage the WQMP in the community;
- Capacity to take responsibility for operations and maintenance in the community, when appropriate;
- Principles that the community regard as criteria to determine the success;
- How the community will check to see if objectives are being achieved; and
- How, if at all, the community will intervene to correct things that have gone wrong.

Successful and sustainable implementation of the WQMP requires an individual (*e.g.* community leader) or group to take responsibility for it, and requires the allocation of adequate financial and human resources for its implementation and operation. The responsibility for the implementation of the WQMP should therefore be allocated during the consultation process with the relevant stakeholders. All funding options must be investigated and a selection of those that best suit the community must be identified and considered for financial support. It is, however, essential that the local authority endorse the WQMP in order to ensure budget allocation and facilitation of partnerships with development industries and the community at large to sustain the intended outcomes in the long run. The finances available must also be considered during the selection of the suite of interventions during Stage 4. Where there are no or inadequate resources, that intervention should not be selected. This may require additional interventions to be identified.

8.4.2.2.1 Outcomes of Stage 2

The outcomes of Stage 2 that must be documented are:

- A preliminary work plan that describes the necessary actions and the person / group responsible thereof;
- A detailed methodology of the technical studies and investigations to be carried out during Stage 3;
- A 'vision' for the catchment to reflect those values that are considered important within the catchment with regard to water quality and quantity.

8.4.2.3 Stage 3: Technical studies and investigations

The scope and focus of Stage 3 are determined during Stage 1 and 2 and will depend on the size and complexity of the catchment and the aquatic environment, as well as the range of issues with regards to water quality identified by the internal and external stakeholders. Likely factors to be investigated are:

8.4.2.3.1 Ambient monitoring

In order to evaluate the state of the catchment with regard to water quality, high quality data is required. This sub task seeks to provide necessary data by assessing a wide range of indicators in dry weather (ambient) while the second sub task will provide data assessed in wet weather (event-based). Appropriate sampling locations should be selected to determine and evaluate the impact of the catchment on the water quality of the aquatic environment. Parameters that are typically monitored include:

- *Water quality:* Physical-chemical: pH, electrical conductivity, dissolved oxygen, temperature, turbidity, suspended solids, dissolved phosphate, ammonia, nitrogen; and microbiological: faecal coliforms;
- *Water quantity assessment:* physical instruments and /or hydraulic models;
- *Sediments:* total nitrogen and total phosphorus and metallic elements (As, Cd, Cr, Co, Cu, Ni, Pb and Zn);
- *Litter:* the quantity and make-up of litter located within 50 m radius of each sampling point; and
- *In-stream habitat:* Presence of bank erosion and bank instability, presence or absence of man-made and engineering structures, and presence, absence and diversity of natural habitat.

8.4.2.3.2 Event monitoring

Monitoring of the same suite of parameters as the ambient programme and at the same sampling locations. At least two rainfall/runoff events must be monitored to assess the effect of stormwater loads on ambient water quality levels and to allow the calibration of water quality models where necessary.

8.4.2.3.3 Water quality modelling

Water quality modelling is typically undertaken for either the whole catchment or part thereof, to determine the ultimate impact of changes in land use on the water quality and to identify and evaluate potential management measures to address those impacts. Up to date hydrological modelling in developing communities in South Africa could not be performed satisfactory (Wright *et al.*, 1992; Schoeman *et al.,* 2001). With the changing political and social climate, such studies may become possible in the future.

8.4.2.3.4 Land use

The scope of this sub task is determined during Stage 1 where land use categories were defined broadly. Further subdivision may be necessary during Stage 3. For example, a low-density residential area has a different impact on water quality than a high-density residential area, while different type of industries also have different impacts on water quality. Identification of other land use activities, such as informal agriculture, informal backyard industries (*e.g.* food vendors) and construction and structural maintenance activities are also pertinent because these activities have an impact on sediment erosion, nutrient loading, microbiological contamination and habitat destruction. Other water quality problems associated with these activities are oxygen demand, oils, metals and hazardous waste.

8.4.2.3.5 Municipal services

The level and functioning of the municipal services, both bulk and connector infrastructure, determine the production and delivery pathways of pollutants to surface and ground water resources. Low level of services can therefore have a negative impact on the aquatic environment. Information with regard to this can be gathered through the following:

- 'Community walk' observation. Fieldworkers can make visual observations regarding the different facilities and services available, as well as the condition of these facilities and services;

- Interviews with household or individual. Semi-structured / informal interviewing of individuals with regard to the level and functioning of the services;
- Household questionnaire. This is a pure quantitative technique to obtain the information as mentioned above; and
- Use of census data and municipal records.

8.4.2.3.6 Socio-economic factors

The possibility of managing the water quality problems in a catchment is largely influenced by the socio-economic conditions in the catchment. The socio-economic factors largely determine the behaviour of individuals within the catchment and the resources available to manage the water quality impacts of the catchment, as well as social upliftment. This information can be gathered using the following techniques:

- 'Community walk' observation. Fieldworkers can make visual observations regarding the location of the different facilities and services available, the use of these facilities and services, the behaviour and interaction of people as they go about their daily activities, as well as local customs and social rules;
- Interviews with household or individual. Semi-structured / informal interviewing of individuals with regard to the use of the services, their perception on the level of services and problems experienced within the community with regard to water quality;

- Household questionnaire. This is a pure quantitative technique to obtain information regarding, for example, household size, age of respondent, level of income and level of education; and
- Use of census data.

8.4.2.4 Stage 4: Identification of interventions and strategies

The findings and results of the technical studies must be analysed and evaluated before possible solutions and interventions are identified. A cost-benefit analysis must be done and implementation options must be considered, as the objective of the actions derived are meant to protect and enhance the aquatic environment of the catchment. Strategies and educational and awareness campaigns must be identified and undertaken within the industrial, residential and commercial sectors of the catchment in an endeavour to educate the community about water quality related issues. Possible interventions and strategies to be considered are given in Table 8.1.

Table 8.1 Different management interventions and strategies to be considered for implementation (From DWAF, 1999b)

▪ **Sanitation interventions:** * On-plot sanitation options * Ventilated improved pit-latrines * Settled sewerage systems * Simplified and swallow sewer systems * Decentralised non-mechanised sewerage treatment * Waste stabilisation ponds	▪ **Solid waste management interventions:** * National waste management strategy * Tidy town programme * Public-private partnership for solid waste management * Communal skip collection systems * Community solid waste management

Table 8.1 (Continue)

▪ **Grey water drainage interventions:** * Drainage design for public standpipes * On-site soakaways	▪ **Stormwater and roads interventions:** * Stormwater management for construction sites * Structural stormwater management practices * Vegetated swales * Stormwater litter traps * Wet and dry detention ponds * Low-cost road surfacing with stormwater drainage
▪ **Community-orientated interventions:** * Community-based problem analysis * Community consultation approaches * Community education and awareness programme * Implementing cost recovery in communities ▪ **Community planning interventions:** * Integrated development planning * Water services development plans * Integrated environmental management * Non-structural watershed management measures	▪ **Institutional interventions:** * Capacity building for intermediate technologies * Sustainable operation and maintenance of services * Developing local public-private partnerships * Developing a customer services approach

8.4.2.5 Stage 5: Consultation and revision

The second consultation process must be undertaken with the internal and external stakeholders to review the outcomes of the technical studies and evaluate the proposed actions and interventions to be implemented. The following sub tasks must be conducted:

8.4.2.5.1 Focus of the WQMP

After analysing the data collected, re-establish the focus of the WQMP. The goals of the WQMP will be driven either by the need to take immediate action or to achieve community support for a long-term preventive program or a combination of both. The basic steps in settling realistic goals are based on setting priorities and matching them with available resources:

- Identify and list the most serious problems;
- List all other problems, both immediate and potential;
- Rank all problems for immediate, medium-range and long-term action; and
- Establish a series of objectives and timeframe for achieving each goal.

8.4.2.5.2 Development of work plan

After redefining the focus and goals of the WQMP, a work plan must be developed. The work plan should express the community's goals in definite terms, yet be broad and flexible in their execution. The work plan should include specific measurable objectives to meet community goals and for the successful implementation thereof, it is crucial that achievable targets are set. The plan should complement existing plans, translating local goals, priorities and resources into action. The work plan should be adopted by the community's governing body and it is therefore important that community ownership of the management practices and interventions are promoted during this stage to ensure a commitment to the WQMP. The interventions must also be prioritised and time frames must be determined. If certain interventions prove difficult and/or costly to implement revisions must be considered (See Figure 8.4).

8.4.2.6 Stage 6: Finalisation and implementation

After the revision stage all the issues raised by the parties must be taken into account and be consolidated. Conflicting issues must be sorted out through workshops in order to reach consensus. The generation of 'winners' and 'losers' must be prevented at all cost as this may result in poor implementation and management of interventions and strategies. Figure 8.5 illustrates the importance and role of the community in the whole development of the WQMP.

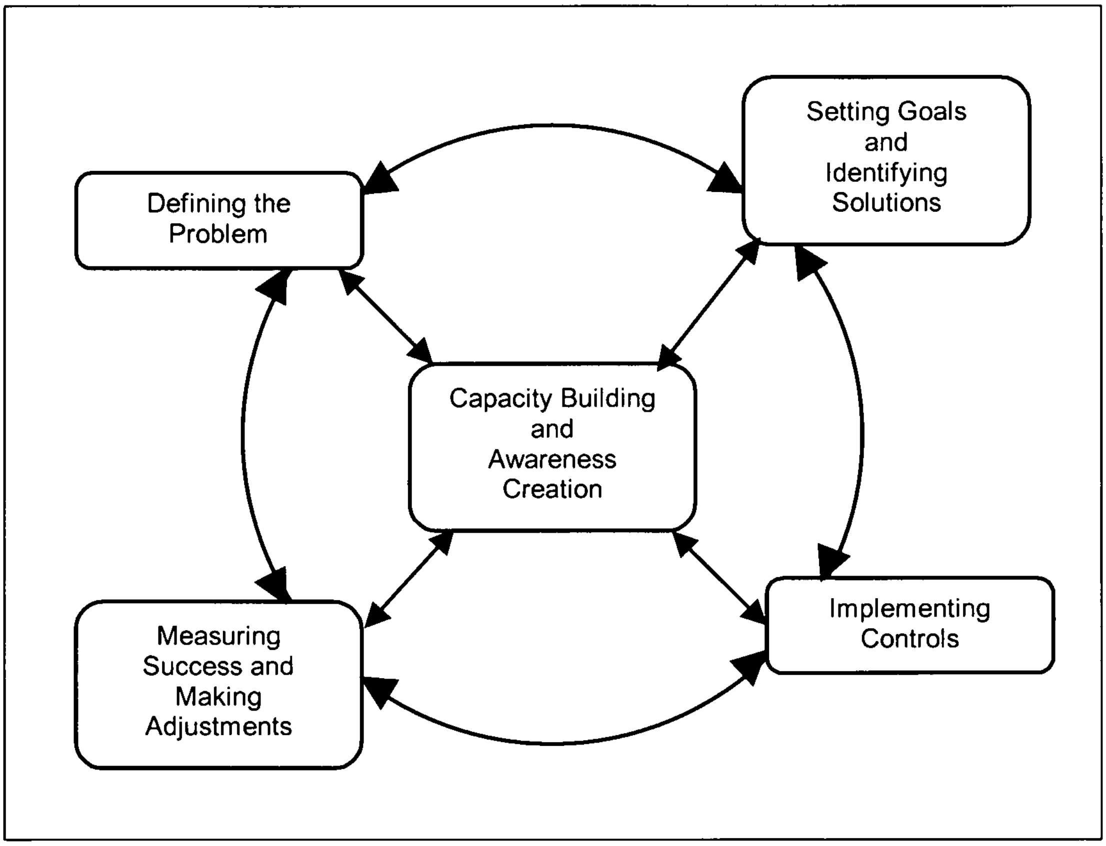


Figure 8.5 Elements of a successful Water Quality Management Plan

After local adoption, an implementation plan must be established. Actions must be scheduled by time period and group and responsibility agency. Costs must be related to the general budget. Needs for training, and public participation must be described as the support from the community are vital for the WQMP to succeed. The WQMP should ultimately be a practical, easy-to-use guide to decision making over the long term. After implementation of the WQMP it is vital that all actions and interventions are checked via monitoring and auditing to determine the success of the WQMP.

8.5 A new concept in water quality management

The water quality situation, which varies greatly in developing countries, reflects different levels of development and requirements for water quality management programmes. The conventional paradigm of water quality monitoring is not suitable for many developing countries and is severely curtailed by some developing countries as being too expensive, inefficient and/or ineffective. However, most international agencies and donors promote this approach. There is, therefore, an opportunity to establish a new concept that is more cost-effective and sustainable, which must start with an explicit integration of water quality into national water policies so that priorities based upon social and economic benefits are established (Ongley, 2001). In South Africa, this concept is one of the fundamental principles of the new National Water Act (Act no 36 of 1998). According to the National Water Act, water is a national resource, owned by the people of South Africa and held in custodianship by the state. This principle allows the state to have total control over the utilisation of the resource. It also permits mechanisms to be put in place to manage water resources using a more holistic, ecologically based approach, taking into account the entire water cycle. As already mentioned, the National Water Act furthermore provides for Catchment Management Agencies to be created and each agency must draw up a Management Strategy for the catchment. The implementation of the Catchment Management Strategy can be facilitated by the development of action plans for the water management area, outlining responsibilities and time frames for implementation. The WQMP is in essence an action plan that was developed to facilitate the implementation of the management process of water quality in developing communities. The WQMP addresses environmental, physical and socio-economic issues relevant to the effective management of water quality in consultation with internal and external stakeholders. The WQMP allows the addition of more detail as further knowledge and experience is gained and a comprehensive WQMP for the applicable water management area can be developed, which reinforces societal and political goals as well as quality of life.

CHAPTER 9 CONCLUSIONS AND SYNTHESIS

9.1 Consolidation of aims and objectives

This chapter aims at consolidating the conclusions reached in the previous chapters with a special focus on their relationship to the problems addressed by the study. It is therefore appropriate to restate the objectives of the study in order to relate them to the conclusions.

The formulation of the first objective of the study can be stated as follows:

> *To integrate socio-economic, human behavioural, environmental and technical aspects at planning level when designing water quality management options.*

The second objective of the research project, and complementary to the first objective was:

> *To develop a water quality management model that will permit the extrapolation of results and experiences to catchments with similar land use and human activities, locally as well as regionally.*

The formulation of the hypotheses was based on the objectives of the study and stated that:

> *Water quality problems arising from developing communities can be managed using an integrated approach to ensure that the receiving water environmental objectives can be met on a sustainable basis.*

In addition, but secondary to the first hypothesis, it stated that:

The management practices and interventions to deal with pollution problems from developing communities can be sustained by addressing the socio-economic and human behavioural factors contributing to the problems.

The third hypothesis stated that:

A water management model that address water quality problems in catchments in a holistic manner can be developed when an integrated approach, addressing the socio-economic and human behavioural factors impacting negatively on water quality, is taken.

The research was thus an attempt to find answers to the following specific questions:

- What are the underlying causes of pollution in developing communities?
- What role does the community play?
- What role does the level of service play?
- What is the role of non-payment?
- What is the role of poverty?
- What is the role of local government?
- What is the role of the environment?

The following sections deal with the findings of the study regarding these questions.

9.1.1 The underlying causes of pollution in the study area

Pollution from the developing community in the study area is caused by the following factors: the way in which the community discards waste, uses waste services and the way in which these services are provided and maintained by the service provider. The waste may be sewage waste from failing or non-existent sanitation systems, solid waste and/or grey water. The community thus impacts on the water quality when the waste that is generated as part of the day-to-day activities in the community reaches the water resource. Stormwater may wash faecal matter, waste and/or sediment into the receiving waters, which also impact on the quality of the water resource. Pollution by the community is therefore a complex interaction of attributes, including socio-economical, technical, environmental and human behavioural factors.

9.1.2 The role of the community

The way in which the community discards waste and uses or misuses the municipal services contributes to pollution in the study area. Littering and the deliberate dumping of household refuse are rife in most parts of the study area, despite the fact that solid waste removal services have been supplied. A lack of awareness also leads to the inappropriate use of the sanitation services. This happens when the sewer system is used to dispose of solid waste, which causes frequent blockages of the system. Deliberate or unintentional vandalism of services, such as waste bins used for other purposes, or deliberate destruction of the sewage system, also occurs frequently in study area. Misuse of services is most of the time related to political or social issues. South Africa's political history has left a legacy of social problems that are difficult to address.

Civil unrest, which was used as a form of protest, together with oppressive attitudes in past local government structures has resulted in a lack of trust and poor communication between communities and service provider. Communities are also reluctant to accept the social causes of pollution, preferring to put the blame on the authority (DWAF, 2001b).

9.1.3 The role of the level of municipal services

High level of services, such as full waterborne sewerage or house-to-house collection of refuse, that are in place in the greater part of the study area, offer greater opportunities to collect and safely dispose of waste generated in the community. High level of services come, however at a greater risk. They are more expensive to operate and require greater organisational and technical capacity within the service provider. High level of sanitation services require that faecal matter be transportable in water, which increase the risks of it to reach the water resource when the system fails, as frequently happens in the study area. There are, however, political and social pressure to install higher levels of services, irrespective of the capacity to manage these systems and the ability of the community to pay for these services (DWAF, 2001b).

9.1.4 The role of non-payment

A polluted environment, as in the study area, demoralises the community and encourages further pollution, or limits the effectiveness of those services which are provided. Where large amounts of wastes are left in the community, the community is less likely to take care when disposing of waste, to report breakdowns and to pay for services. The non-payment problem is also deeply rooted in South Africa as a consequence of a long history of suppression, deprivation and dependency (DWAF, 2001b). The non-payment rate in the study area of 30% limits the income of the Local Authority, who curtails spending money on operation and maintenance of the services, particularly in the areas where non-payment is occurring. Non-payment thus robs local government of capacity and hence contributes to the pollution problem.

9.1.5 The role of poverty

The social causes of water quality problems in the study area are all closely linked to poverty. A poor community not only struggle to afford to pay the full operation and maintenance costs of high level of services, but a lack of awareness and poor education also contributes to the misuse of services. The unemployed youth are also more likely to vandalise services.

9.1.6 The role of local government

Many of the institutional causes of pollution are associated with the resources allocated to operation and maintenance of the municipal services. The local government budgeting process determines the resources that are made available for operation and maintenance and hence can contribute to pollution.

9.1.7 The role of the environment

The interaction between environmental factors and pollution from the community is largely related to the way in which waste services and layout of the community are planned. High rainfall, such as in the summer months in the study area, increases the risks of waste generated in the community being washed into the nearby streams and stormwater conduits. Waste generated on steep slopes is also more likely to be carried to the water resource once it rains. Settlements and houses close to the streams and conduits are more likely to pollute the water resource.

9.2 Acceptance of hypotheses

From the previous discussion it is apparent that the various factors underlying pollution from developing communities are inter-dependant and a holistic approach to identify and address these problems, as well as their impact on a water resource, is necessary. The proposed objective, therefore, of integrating technical, environmental, socio-economic and human behavioural aspects at planning level when designing water quality management options are not only necessary but also non-negotiable if the implementation of management options are to lead to sustainability of the water resource. The approach adopted in this study is an attempt to investigate solutions to water quality management problems in developing communities in a holistic fashion. The investigation of the technical, environmental socio-economic and human behavioural aspects in the study area led to the identification of management options which formed the basis for the development of the Water Quality Management Plan (WQMP). The second objective of applying the WQMP as a model that will permit the extrapolation of results and experiences to catchments with similar land use and human activities, locally as well as regionally, is unlimited in the sense that the problems contributing to pollution in a specific community are common, but site-specific approaches may however be necessary in order to successfully implement the WQMP in these catchments. It is therefore believed that the study has the potential to influence the course of water quality management in developing communities. The hypotheses of the study are thus accepted on the following basis: Ideas such as the WQMP and community awareness for tackling water quality problems are not in themselves solutions to the problems but merely tools. The management options identified in Chapter 8 and therefore the WQMP need to be translated into action to genuinely start to address the water quality problems in developing communities.

9.3 Recommendations and further research

> 'People's participation is becoming the central issue of our time. The democratic transition in many developing countries, the collapse of many socialist regimes, and the worldwide emergence of people's organisations, these are all part of a historic change - not just isolated events.'
>
> Human Development Report, 1993 (cf. UNESCO 1999)

During the study all known aspects of relevance have been investigated and the interrelationships were emphasised from a geographical perspective. The study therefore recommends that the role of government regulations in water quality management be reduced and that the role of awareness creation and community participation be maximised. It is quite clear from international literature consulted in this study that the developed world, when examining the root causes of diffuse pollution and the serious difficulties in controlling it, still argues that pollution generally is an economic externality not taken care by normal market processes. Even though the developed world accepts the role of non-government community initiatives, it still considers the role of regulatory authorities and economic instruments (incentives, subsidies, taxation, pricing) to be much more important, even critical. A greater dependence on economic instruments to go along with the market-culture, currently invading all issues on a global basis, is proposed by the developed world. Figure 9.1 pictures water quality management and the different pollution-control-strategies as a triangle.

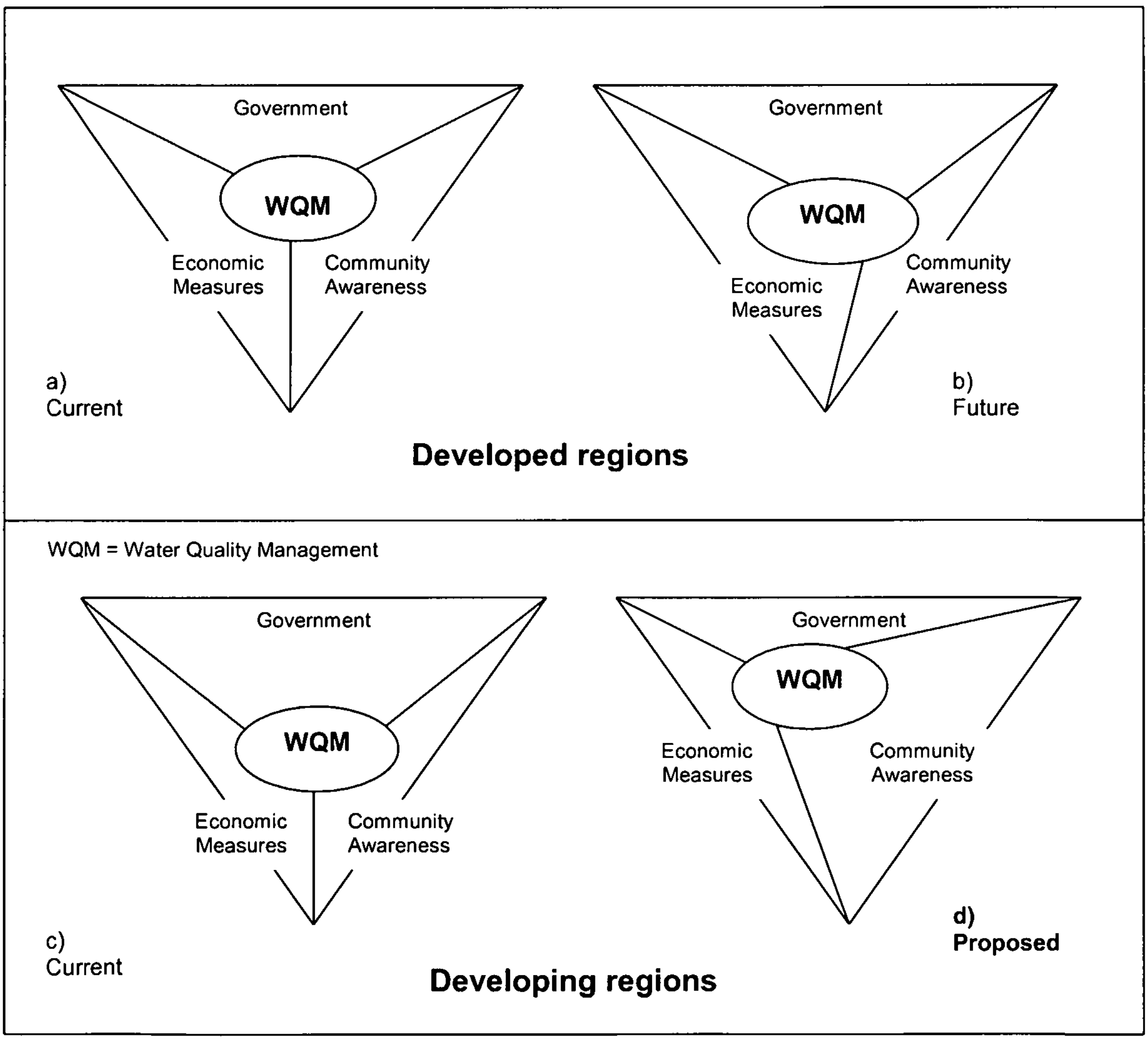


Figure 9.1 Current, future and proposed trends of water quality management in developed and developing countries (Revised from Agrawal, 2000)

The developed world places regulatory measures at the top in its indicative triangle and also makes it slightly larger area than the other two (Figure 9.1a). If one were to move towards greater dependence on government intervention and economic measures, as the developed world proposes, the balance of the three parts of the triangle may shift to be as in second triangle (Figure 9.1b). The political and institutional instability, combined with financial restraint and poor domestic scientific capacity, of developing countries means that *western* approaches to water quality management are often inappropriate. The end-result of such a shift in developing countries, as proposed in Figure 9.1(b), would be unsustainable water quality management. The success of voluntary groups in managing the stream reaches taken up by them, without any government support or financial resources, as documented in UNESCO (1999) points the triangle in the direction of maximising community awareness as illustrated in Figure 9.1(d).

Future research needs and priorities

The general scarcity of appropriate quantitative information on the characteristics of urban runoff hampers the selection of suitable management options that can be deployed to reduce or ameliorate the impacts of this runoff. Consequently, it is essential that carefully targeted research should be conducted to fill these information gaps. The most important information gaps are as follows:

- The extent to which groundwater contamination has occurred as a result of low-cost, high-density types of urbanisation;

- The appropriate use of groundwater as a water supply for informal settlements and the most suitable management options to prevent its contamination (Wright *et al.*, 1992);
- The extent to which geographic information systems (GIS) can be used with appropriate management and communications technologies to quantify urban runoff, select appropriate management strategies and to communications choices to the communities concerned; and
- Low-cost, high density type of urbanisation, with its informal housing and shack areas, is an inescapable part of South Africa and will continue to play a major role in this country for many years to come. Therefore, it is vitally important to study these urban catchments and to develop new and innovative ways of dealing with the problems associated with urban runoff.

The wide range of adverse impacts that low-cost, high density urban land uses have on catchments and their water resources warrants serious and urgent attention. The development and installation of appropriate sanitation and waste disposal for both existing and peri-urban areas will require fundamentally new management approaches. Therefore, it is imperative that carefully focused research is conducted in these priority areas to ensure the long-term protection of South Africa's limited water resources.

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APPENDICES

APPENDIX 1

1.1 Selected water quality guidelines of various water user groups

Selected water quality guidelines of various water user groups

Water quality parameter	Units	**Water User Groups** (Target Water Quality Range)				
		Domestic	**Recreation contact**	**Industry**	**Irrigation**	**Aquatic life**
Conductivity	(mS/m at 20°C)	70	-	100	40	-
Total Dissolved Solids	mg/l	476	-	680	272	-
Chemical Oxygen Demand	mg/l	-	-	30	-	-
Dissolved Oxygen Demand	mg/l	5	-	-	-	-
Dissolved Oxygen	% saturation	70	-	-	-	-
PH	PH units	6-9	6.5-8.5	7-9	6.5-8.4	6-9
Temperature	(°C)	<25	-	-	-	-
Turbidity	(NTU)	1	5	-	-	-
Total Nitrogen	mg/l	-	-	-	5	-
Ortho-phosphate	mg/l	-	0.5	-	-	-
Total Phosphorous	mg/l	-	0.08	-	-	-

- Compiled from DWAF, 1996

1.2 Guideline for faecal coliforms to be used for intermediate contact recreation

Faecal coliform range	EFFECTS
Target guideline range (counts/100 ml)	
0 – 1000	Health effects are indicated for intermediate contact with recreational water. If water contact is extensive, such as may occur for novice water-skiing or novice windsurfing and if full body immersion is likely to occur, the more stringent guidelines proposed for full contact recreation might be more appropriate.
1000 – 4000	It may be expected that limited contact with water of this quality is associated with a slight risk of gastrointestinal illness. The upper limit of this range corresponds to the limit recommended by the Australian guidelines for at least four out of five samples collected over 30 days.
> 4000	Intermediate recreational contact with water can be expected to carry an increasing risk of gastro-intestinal illness as faecal coliform levels increase.

- Compiled from DWAF, 1996

1.3 Guideline for faecal coliforms to be used for full contact recreation

Faecal coliform range	EFFECTS
Target guideline range (counts/100 ml)	
0 – 150	Negligible risk of gastro-intestinal effects is expected. It should, however, be noted that while the presence of faecal indicators indicates a possible risk to health, the absence of indicators does not guarantee the absence of risk. *The postulated range should not be exceeded by the geometric mean or median count over a period of three months. Whenever possible, this three-month period should coincide with seasons to allow detection of seasonal variation in water quality.*
150 – 600	A slight risk of gastro-intestinal illness is indicated at faecal coliform levels that occasionally fall in this range. The risk increases if geometric mean or median levels are consistently in this range. *This range should not be exceeded by the geometric mean or median of fortnightly samples collected over a three-month period.*
600 – 2000	Noticeable gastro-intestinal health effects may be expected in the population of swimmers and bathers. Some health risk exists if single samples fall in this range, particularly if such events occur frequently.
> 2000	As the faecal coliform level increases above this limit, the risk of contracting gastrointestinal illness as a result of full contact recreation increases. The volume of water which needs to be ingested in order to cause adverse effects decreases as the faecal coliform density increases.

- Compiled from DWAF, 1996

1.4 Guideline for somatic coliphages to be used for full contact recreation

Coliphages range	EFFECTS
Target guideline range (counts/100 ml)	
0 – 20	Negligible risks of sewage pollution and of enteric virus infection are indicated. It should be noted that, as for all indicators, the absence of the indicator does not necessarily guarantee the absence of indicated pathogens. This range should not be exceeded by the geometric mean or median of fortnightly samples collected over a period of three months. Preferably this three-month period should coincide with seasons to allow detection of seasonal variation in water quality.
20 – 100	A slight risk of sewage pollution and of virus infection is indicated. The risk is increased if geometric mean or median levels frequently fall in this range but is probably minimal if only isolated instances are recorded. This range should not be exceeded by the geometric mean or median of fortnightly samples collected over a three-month period.
> 100	Significant sewage pollution and health risks may be expected if geometric mean or median coliphage levels commonly exceed this limit. Risks increase as occurrences of high coliphage levels increase in frequency and extent.

- Compiled from DWAF, 1996

APPENDIX 2

2.1 Bacteriological indicator analysis

Faecal coliforms

Enumeration by means of M-FC agar: Faecal coliforms were enumerated with the membrane filter technique using M-FC Agar in triplicate on 90-mm petri dishes.

M-FC agar (Difco®):52 g of the powder was suspended in 1 litre of distilled water. The mixture was boiled until the powder was totally dissolved. The liquid was poured into 90-mm petri dishes, 5 mm in depth. 10 ml of a 1 % rosolic acid (in 0.2 N NaOH) solution was added if a batch was to be used for heavily polluted stormwater flush after long dry periods. This medium did not require autoclaving. Fresh plates were stored in the dark in sealed plastic bags (for moisture retention) at < 8°C. Unused plates were discarded after 3 months.

Incubation:	The plates were inverted and incubated in glass beakers placed inside waterbaths at 44.5°C ± 0.2°C for 24 hours ± 2 hours.
Identification:	Faecal coliform colonies appeared in various shades of blue or partial blue (Millipore Corporation, 1992; Standard Methods, 1995).
Confirmation:	API® 10S and 20E (bioMérieux®) (Appendix D)

Clostridium perfringes

Clostridium perfringens was enumerated with the membrane filtration technique using supplemented Perfringens (OPSP) Agar (Oxoid, 1990). Enumeration was done in triplicate on 90-mm petri dishes.

Perfringens (OPSP) agar (Oxoid, 1990): 22.8 g of the powder was added to 500 ml-distilled water, the mixture was boiled gently to dissolve the powder. The mixture was then autoclaved at 121°C for 15 min. After cooling to 50°C, rehydrated supplements A (SR76) and B (SR77) were added. The mixture was mixed well and then poured into 90-mm diameter petri dishes, 5 mm in depth.

After cooling, the plates were stored in darkness in plastic bags (to maintain moisture content) at < 8°C. Unused plates were discarded after 2 weeks.

Pasteurisation: Samples (presumably containing C perfringens spores) were pasteurised in a water bath at 75°C for 10 minutes (Oxoid, 1990; Ashbolt et al.,1993; Ferguson et al., 1996)).

Incubation: The plates were inverted and incubated anaerobically in an incubator at 37°C for 48 hours. Oxoid gas generating kits producing atmospheres of 95% hydrogen and 5% carbon dioxide were used.

Identification: Clostridium perfringens colonies appeared as partially or fully discoloured dark brown to black colonies.

Confirmation: Cultured isolates confirmed on Rapid ID® 32A galleries (bioMérieux®) (Appendix D).

2.2 Phage analysis

Somatic coliphages

Somatic coliphages were enumerated, using the Plaque Assay method for Somatic Coliphages using Small Petri Dishes with Double Agar Layer (SP-DL) (ISO, 1995c; Grabow et al., 1997a). The method is based on conventional plaque assays for somatic coliphages (Grabow et al., 1993) in small volumes of water (generally 1.0 mL) using small petri dishes (90-mm diameter).

Growth medium for the host culture (Nutrient broth)

Prepare ordinary nutrient broth (Difco® or equivalent) according to the manufacturer's instructions, heat to dissolve, dispense in convenient containers - i.e., 100 mL quantities in 200-mL medical flats, autoclave, store at about 4°C for not longer than 30 days.

Phage bottom agar

Bacto agar	14.0 g
Tryptone	13.0 g
NaCl	8.0 g
Glucose	1.5 g

Distilled water	1000 mL

Heat to dissolve agar, and autoclave. Pour about 20 mL in 90-mm diameter petri dishes. Store at 4°C for a maximum 10 days.

Phage top agar

Bacto agar	8.0 g
Tryptone	10.0 g
NaCl	8.0 g
Glucose	3.0 g
Na_2CO_3 solution	5.0 mL
$MgCl_2$ solution	1.0 mL
Distilled water	1000 mL

Autoclave and cool to 55-60°C. Add naladixic acid solution if considered necessary (1.0 mL/100 mL). Distribute 2.5-mL aliquots into test tubes with caps. Store at 4°C for a maximum 30 days.

Host culture

Escherichia coli strain C (ATCC 13706) = WG4

Naladixic acid resistant mutant of WG4 = WG5

Test sample

Water (e.g. drinking water, wastewater, river water, seawater) or liquid suspension (e.g. suspension of faecal material). Make tenfold dilution in peptone saline solution as necessary.

Naladixic acid solution

Dissolve 0.5 g of naladixic acid in 4 mL of 1 M NaOH. Add 16 mL of sterile water and mix well. Decontaminate by membrane filtration, e.g. syringe filter, 0.22 µm membrane. Store at 4°C for a maximum 4 weeks.

$MgCl_2$ solution

Prepare 4 M stock solution by dissolving 820 g of $MgCl_2.6H_2O$ crystals in 1000 mL of water; sterilise by autoclaving; store at room temp in the dark.

$CaCl_2$ solution

Prepare 1 M stock solution by dissolving 147 g of $CaCl_2.2H_2O$ in 1000 mL water by gentle heating. Decontaminate by membrane filtration, e.g. syringe filter, 0.22 µm membrane. Store at 4°C for a maximum 6 months.

Peptone saline solution

Dissolve 1 g peptone and 8.5 g sodium chloride in 950 mL water by boiling. Adjust pH to 7.0±0.1 using 1 M NaOH or HCl. Make up to 1000 mL with water, and dispense in convenient volumes. Autoclave. Store at 4°C for a maximum 6 months.

Test procedure

1. Steam the required number of test tubes with top agar to liquefy agar and adjust to 48°C in a heating block.
2. Add 0.5 mL of the host culture (grown overnight in stored volume of growth medium at 35-37°C) to the top agar.
3. Add 1 mL of the test sample, or an appropriate dilution of the test sample, to the top agar in each test tube.
4. Mix gently and pour the top agar mixture with minimum delay onto the bottom agar layer in a 90-mm phage agar plate.
5. Repeat the above in tenfold to obtain counts per 10 mL. If tenfold dilutions are required, three plates should preferably be used for each dilution to obtain meaningful results.
6. Incubate inverted plates overnight at 35-37°C and count plaques of somatic coliphages.

Notes

1. Tests were carried out according to basic principles outlined in:
   Grabow W O K, Holtzhausen C S and de Villiers C J (1993) Research on Bacteriophages as Indicators of Water Quality. WRC Report No 321/1/93. Water Research Commission, Pretoria. 147 pp.
2. ISO/CD 10705-2:1995. Water Quality - Detection and Enumeration of Bacteriophages. Part 2: Enumeration of somatic coliphages. International Organisation for Standardisation, Geneva. 15 pp.
3. In the case of heavily contaminated test samples (e.g. wastewater), interfering microbial growth may be suppressed by the addition of 1 mL of the naladixic acid solution to 100 mL of molten phage top agar. Final concentration of naladixic acid in phage top agar = 250 g/mL. The resistant mutant WG5 must be used as host in these assays (Naladixic acid is generally not necessary for testing treated drinking water).

4. A heating block should be used for tubes with top agar instead of a water bath if possible in order to avoid contamination by phages in water bath water.

2.3 Analytical quality control

General quality control procedures

Accuracy of results obtained from the analyses done for this project was of paramount importance. An effective quality assurance programme was established. According to Standard Methods (1998), it is especially important that laboratories performing only a limited amount of microbiological testing exercise strict quality control. The guidelines for minimal quality control programmes recommended by Standard Methods (1998) were followed during this study. For membrane filter tests, the sterility of media, filters, dilution and rinse water, glassware and equipment was checked with sterile water as a sample during each sample series analyses. Each lot of medium was checked by testing for known positive and negative control cultures for the indicator organism group under test.

Control cultures for the selected microbiological tests

Faecal coliforms: Stock cultures of *Escherichia coli* (positive control - culture acquired from SABS) and *Enterobacter aerogenes* (negative control - culture acquired from SABS) were made up (Standard Methods, 1998; Merck, 1996; bioMérieux, 1996).

Clostridium perfringens: Stock cultures of *C perfringens* (positive control - culture acquired from SABS) and *C bifermentans* (negative control - culture acquired from SABS) were made up (Oxoid, 1990).

Procedures for medium check

Volume units of 1-ml of the solution were filtered through membranes and the membranes placed on petri dishes containing the various selective growth media. Parallel analyses were done at least once a month for the duration of the project. The specific colony colour identification and distinction was standardised by the analyst group (making sure everyone see and understand the same colour – including the various nuances / shades) and used to identify the various indicators tested for on the various media.

Method precision

Precision was calculated with duplicate for each different water type. The test laboratory is continually involved in surface and drinking water quality testing and has a set precision criterion based on 3.272 (Standard Methods, 1998). This criterion is updated every 3 months, using the 15 most recently set of duplicate results. Duplicate testing of at least 10% of all samples is a monthly routine and includes duplicates for each analyst involved. Results are transformed and the range calculated. Results from a series that show excessive variability will not be accepted. The analytical problem will be identified and resolved.

Colony verification

The actual selectivity / specificity of the various selective growth media has been found in many reports to be inconsistent (Dionisio and Borrego, 1995; Figueras et al., 1996). Various reasons are given for this. Probably one of the most common reasons is the vast array of species and sub-species often to be found in a single indicator organism group or species as well as in the multitude of non-indicator groups. Amongst these variants one will inevitably find non-indicator organisms that find the selectivity of a specific medium accommodating and may even manifest in the colours prescribed to the analyst for identification. To establish the accuracy of detected indicator levels as well as the selectivity of the various media for detecting the selected indicators, a verification programme was designed and followed according to Standard Methods (1998). Representative selections of colonies were made of various bacterial pollution-indicator organisms detected in water samples from the target catchment. Standard Methods (1998) recommends at least 10 colonies picked randomly per month from known positive samples and verified. Because this study critically examined the specificity of the various media selective for the various selected indicator groups, this number of verifications was increased.

Preparation of colonies for verification

Selections were made only from colonies that could be counted as the actual indicator on the various selective growth media. These counts would be based on various colour-related identifications (counting the specific coloured colonies) as prescribed by the relevant authoritative manual such as Standard Methods and guidelines from manufacturers. Between 12% and 40 % of all the colonies cultured on the various media were randomly selected. Before verification began with multi-test identification system galleries such as the API® and RAPID ID® by bioMérieux®, the coloured selected colonies was first stripped of the coloration that facilitated the selectivity of the growth medium. This was to eliminate all possible interference with the functions of the Identification System Galleries.

The principle of Identification System Galleries

Selections were made from the plates where the particular dilution yielded growth of between 20 and 80 colonies. Of this, a constant percentage exceeding 10% of the identified coloured colonies were selected and processed (Section 3.1 above) for transfer to the various types of confirmation galleries. The various identification systems (confirmation galleries) consisted of strips with a characteristic number of micro-tubes containing dehydrated substrates. These substrates support specific enzymatic activity or fermentation of sugars. Each micro-tube is inoculated with a dense bacterial suspension made up of the original selected colony, which at the same time reconstitutes the substrates. Metabolic end-products are produced during incubation which produces spontaneous colour changes or revealed colours afterwards by the addition of reagents. The various reactions are then coded and read into a Reading Table. The identification is obtained from an Identification Table or a computerised Analytical Profile Index.

APPENDIX 3

3.1 Concentrations of microbiological organisms at sampling points in the Fontein Spruit : April 1998 – November 1998

FS1	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98	4.29E+03	3.63E+00	2.14E+02	2.33E+00	8.00E+02	2.90E+00
29-Apr-98	4.80E+02	2.68E+00	1.48E+02	2.17E+00		
13-May-98	4.96E+02	2.70E+00	2.42E+02	2.38E+00	4.60E+03	3.66E+00
27-May-98	1.48E+02	2.17E+00	4.14E+01	1.62E+00		
10-Jun-98	4.00E+00	6.02E-01	1.76E+02	2.25E+00	2.00E+02	2.30E+00
24-Jun-98	3.32E+02	2.52E+00	3.76E+02	2.58E+00		
08-Jul-98	4.00E+00	6.02E-01				
22-Jul-98						
19-Aug-98	4.51E+03	3.65E+00	2.07E+01	1.32E+00		
02-Sep-98	1.20E+02	2.08E+00				
16-Sep-98	2.12E+02	2.33E+00			6.00E+02	2.78E+00
30-Sep-98						
14-Oct-98	2.28E+03	3.36E+00	1.73E+03	3.24E+00		
28-Oct-98	2.00E+02	2.30E+00	1.38E+02	2.14E+00		
11-Nov-98						
25-Nov-98	2.28E+04	4.36E+00	1.00E+02	2.00E+00	2.00E+03	3.30E+00
09-Dec-98						
n VALUES	13	13	10	10	5	5
MIN	4.00E+00	6.02E-01	2.07E+01	1.32E+00	2.00E+02	2.30E+00
MAX	2.28E+04	4.36E+00	1.73E+03	3.24E+00	4.60E+03	3.66E+00
STDDEV	6.23E+03	1.10E+00	5.05E+02	5.20E-01	1.79E+03	5.19E-01
95% CI	3.39E+03	5.96E-01	3.13E+02	3.22E-01	1.57E+03	4.55E-01
MEDIAN	3.32E+02	2.52E+00	1.62E+02	2.21E+00	8.00E+02	2.90E+00
MEAN		2.54E+00		2.20E+00		2.99E+00
GEOMEAN	3.44E+02		1.59E+02		9.75E+02	

SAMPLES NOT SENT (29-Apr-98 SC/SC LOG: no analyses; 24-Jun-98 SC/SC LOG: samples not sent)

NO ANALYSES

NO DATA

FS2	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98						
29-Apr-98	1.20E+02	2.08E+00	1.00E+02	2.00E+00		
13-May-98	3.32E+02	2.52E+00	1.21E+02	2.08E+00	3.80E+03	3.58E+00
27-May-98	2.20E+02	2.34E+00	2.42E+01	1.38E+00		
10-Jun-98	4.97E+03	3.70E+00	3.11E+01	1.49E+00	6.00E+02	2.78E+00
24-Jun-98	1.08E+02	2.03E+00	5.11E+02	2.71E+00		
08-Jul-98	5.20E+01	1.72E+00	5.18E+01	1.71E+00	3.00E+02	2.48E+00
22-Jul-98	1.04E+02	2.02E+00	6.21E+01	1.79E+00		
19-Aug-98	2.48E+03	3.40E+00	5.87E+01	1.77E+00		
02-Sep-98	1.60E+02	2.20E+00	2.31E+02	2.36E+00		
16-Sep-98	1.64E+02	2.21E+00			5.00E+02	2.70E+00
30-Sep-98	8.40E+01	1.92E+00	1.69E+02	2.23E+00	2.00E+02	2.30E+00
14-Oct-98	6.00E+02	2.78E+00	2.76E+02	2.44E+00		
28-Oct-98	4.00E+02	2.60E+00	2.10E+02	2.32E+00		
11-Nov-98	2.36E+02	2.37E+00	1.07E+02	2.03E+00		
25-Nov-98	2.88E+03	3.46E+00	3.35E+02	2.52E+00	2.20E+03	3.34E+00
09-Dec-98	1.12E+03	3.05E+00	1.04E+01	1.01E+00		
n VALUES	16	16	15	15	6	6
MIN	5.20E+01	1.72E+00	1.04E+01	1.01E+00	2.00E+02	2.30E+00
MAX	4.97E+03	3.70E+00	5.11E+02	2.71E+00	3.80E+03	3.58E+00
STDDEV	1.39E+03	5.95E-01	1.39E+02	4.67E-01	1.44E+03	4.98E-01
95% CI	6.80E+02	2.92E-01	7.04E+01	2.36E-01	1.15E+03	3.99E-01
MEDIAN	2.28E+02	2.36E+00	1.07E+02	2.03E+00	5.50E+02	2.74E+00
MEAN		2.53E+00		1.99E+00		2.86E+00
GEOMEAN	3.35E+02		9.80E+01		7.29E+02	

SAMPLES NOT SENT
NO ANALYSES
NO DATA

FS3	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98	4.72E+03	3.67E+00	1.45E+02	2.16E+00	1.16E+04	4.06E+00
29-Apr-98	3.00E+03	3.48E+00	2.55E+02	2.41E+00		
13-May-98	4.80E+02	2.68E+00	1.52E+03	3.18E+00	1.70E+03	3.23E+00
27-May-98	1.55E+03	3.19E+00	9.66E+01	1.98E+00		
10-Jun-98	3.72E+02	2.57E+00	1.97E+02	2.29E+00	9.00E+02	2.95E+00
24-Jun-98	6.16E+02	2.79E+00	7.07E+02	2.85E+00		
08-Jul-98	6.76E+03	3.83E+00	1.24E+02	2.09E+00	1.10E+03	3.04E+00
22-Jul-98	6.08E+02	2.78E+00	1.97E+02	2.29E+00		
19-Aug-98	6.36E+02	2.80E+00	1.97E+02	2.29E+00		
02-Sep-98	7.20E+02	2.86E+00	1.10E+03	3.04E+00	1.00E+02	2.00E+00
16-Sep-98	3.52E+02	2.55E+00	2.83E+02	2.45E+00	3.00E+02	2.48E+00
30-Sep-98	1.84E+02	2.26E+00	3.11E+02	2.49E+00		
14-Oct-98	6.00E+02	2.78E+00	7.25E+02	2.86E+00		
28-Oct-98	4.80E+02	2.68E+00	1.76E+02	2.25E+00		
11-Nov-98	1.76E+02	2.25E+00			1.00E+02	2.00E+00
25-Nov-98	1.90E+07	7.28E+00	1.04E+02	2.01E+00		
09-Dec-98	1.12E+03	3.05E+00	1.38E+01	1.14E+00	1.00E+02	2.00E+00
n VALUES	17	17	16	16	8	8
MIN	1.76E+02	2.25E+00	1.38E+01	1.14E+00	1.00E+02	2.00E+00
MAX	1.90E+07	7.28E+00	1.52E+03	3.18E+00	1.16E+04	4.06E+00
STDDEV	4.61E+06	1.15E+00	4.19E+02	4.86E-01	3.93E+03	7.41E-01
95% CI	2.19E+06	5.48E-01	2.05E+02	2.38E-01	2.72E+03	5.13E-01
MEDIAN	6.16E+02	2.79E+00	1.97E+02	2.29E+00	6.00E+02	2.72E+00
MEAN		3.15E+00		2.36E+00		2.72E+00
GEOMEAN	1.40E+03		2.31E+02		5.26E+02	

SAMPLES NOT SENT
NO ANALYSES
NO DATA

FS4	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98	3.89E+03	3.59E+00	2.14E+02	2.33E+00	8.50E+03	3.93E+00
29-Apr-98	4.00E+03	3.60E+00	2.90E+02	2.46E+00		
13-May-98	6.56E+02	2.82E+00	2.83E+02	2.45E+00	2.30E+03	3.36E+00
27-May-98	1.32E+03	3.12E+00	5.87E+01	1.77E+00		
10-Jun-98	8.65E+03	3.94E+00	5.00E+02	2.70E+00	2.00E+02	2.30E+00
24-Jun-98	8.40E+02	2.92E+00	1.04E+01	1.01E+00		
08-Jul-98	3.84E+03	3.58E+00	7.94E+01	1.90E+00	1.10E+03	3.04E+00
22-Jul-98	1.26E+03	3.10E+00	2.66E+02	2.42E+00		
19-Aug-98	9.94E+03	4.00E+00	3.93E+02	2.59E+00		
02-Sep-98	1.60E+03	3.20E+00	1.07E+03	3.03E+00	2.00E+02	2.30E+00
16-Sep-98	2.84E+03	3.45E+00	4.14E+01	1.62E+00	5.00E+02	2.70E+00
30-Sep-98	3.50E+06	6.54E+00	3.09E+04	4.49E+00	5.20E+04	4.72E+00
14-Oct-98	1.72E+06	6.24E+00	2.04E+03	3.31E+00		
28-Oct-98	4.00E+03	3.60E+00	2.14E+02	2.33E+00		
11-Nov-98	1.96E+03	3.29E+00	5.18E+01	1.71E+00		
25-Nov-98	1.04E+06	6.02E+00	2.42E+02	2.38E+00	4.15E+04	4.62E+00
09-Dec-98	1.28E+04	4.11E+00	1.73E+01	1.24E+00	6.00E+02	2.78E+00
n VALUES	17	17	17	17	9	9
MIN	6.56E+02	2.82E+00	1.04E+01	1.01E+00	2.00E+02	2.30E+00
MAX	3.50E+06	6.54E+00	3.09E+04	4.49E+00	5.20E+04	4.72E+00
STDDEV	9.33E+05	1.17E+00	7.44E+03	8.17E-01	2.01E+04	9.25E-01
95% CI	4.43E+05	5.54E-01	3.53E+03	3.88E-01	1.31E+04	6.04E-01
MEDIAN	3.89E+03	3.59E+00	2.42E+02	2.38E+00	1.10E+03	3.04E+00
MEAN		3.95E+00		2.34E+00		3.31E+00
GEOMEAN	8.88E+03		2.18E+02		2.02E+03	

SAMPLES NOT SENT
NO ANALYSES
NO DATA

FS5	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98	2.48E+04	4.39E+00				
29-Apr-98	1.72E+03	3.24E+00	1.50E+02	2.18E+00		
13-May-98	3.56E+04	4.55E+00	2.19E+02	2.34E+00	1.16E+04	4.06E+00
27-May-98	7.36E+02	2.87E+00				
10-Jun-98	6.72E+03	3.83E+00	3.11E+01	1.49E+00	3.40E+03	3.53E+00
24-Jun-98	1.62E+04	4.21E+00	3.66E+02	2.56E+00		
08-Jul-98	7.40E+03	3.87E+00	2.07E+02	2.32E+00	7.70E+03	3.89E+00
22-Jul-98	9.44E+02	2.97E+00	2.73E+02	2.44E+00		
19-Aug-98	4.24E+02	2.63E+00	2.00E+02	2.30E+00		
02-Sep-98	4.16E+02	2.62E+00			2.40E+03	3.38E+00
16-Sep-98	4.51E+04	4.65E+00	1.04E+02	2.01E+00	6.30E+03	3.80E+00
30-Sep-98	7.88E+03	3.90E+00	4.83E+02	2.68E+00	1.30E+04	4.11E+00
14-Oct-98	2.36E+04	4.37E+00	7.94E+02	2.90E+00		
28-Oct-98	5.20E+03	3.72E+00	6.90E+01	1.84E+00		
11-Nov-98	2.60E+03	3.41E+00	9.32E+01	1.97E+00	7.00E+00	8.45E-01
25-Nov-98	9.20E+04	4.96E+00	5.18E+02	2.71E+00	1.40E+03	3.15E+00
09-Dec-98	1.60E+03	3.20E+00	1.38E+02	2.14E+00	8.00E+02	2.90E+00
n VALUES	17	17	14	14	9	9
MIN	4.16E+02	2.62E+00	3.11E+01	1.49E+00	7.00E+00	8.45E-01
MAX	9.20E+04	4.96E+00	7.94E+02	2.90E+00	1.30E+04	4.11E+00
STDDEV	2.37E+04	7.32E-01	2.13E+02	3.78E-01	4.76E+03	1.01E+00
95%CI	1.13E+04	3.48E-01	1.11E+02	1.98E-01	3.11E+03	6.58E-01
MEDIAN	6.72E+03	3.83E+00	2.04E+02	2.31E+00	3.40E+03	3.53E+00
MEAN		3.73E+00		2.28E+00		3.30E+00
GEOMEAN	5.36E+03		1.89E+02		1.98E+03	

SAMPLES NOT SENT

NO ANALYSES

NO DATA

ERL	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98	2.32E+03	3.37E+00	5.31E+01	1.73E+00		
29-Apr-98	4.60E+03	3.66E+00	2.76E+01	1.44E+00		
13-May-98	4.92E+02	2.69E+00				
27-May-98	4.00E+00	6.02E-01				
10-Jun-98	6.00E+01	1.78E+00				
24-Jun-98						
08-Jul-98	9.60E+01	1.98E+00	4.49E+01	1.65E+00		
22-Jul-98	2.40E+01	1.38E+00	6.90E+00	8.39E-01		
19-Aug-98	4.00E+00	6.02E-01	7.11E+01	1.85E+00		
02-Sep-98	1.18E+03	3.07E+00				
16-Sep-98	3.64E+02	2.56E+00				
30-Sep-98	2.64E+03	3.42E+00	3.17E+02	2.50E+00		
14-Oct-98	5.56E+03	3.75E+00	1.73E+01	1.24E+00		
28-Oct-98	8.40E+02	2.92E+00	1.31E+02	2.12E+00		
11-Nov-98	3.24E+03	3.51E+00	3.45E+00	5.38E-01		
25-Nov-98	6.80E+02	2.83E+00			4.00E+02	2.60E+00
09-Dec-98						
n VALUES	15	15	9	9	1	1
MIN	4.00E+00	6.02E-01	3.45E+00	5.38E-01	4.00E+02	2.60E+00
MAX	5.56E+03	3.75E+00	3.17E+02	2.50E+00	4.00E+02	2.60E+00
STDDEV	1.80E+03	1.05E+00	9.92E+01	6.12E-01		
95% CI	9.10E+02	5.31E-01	6.48E+01	4.00E-01		
MEDIAN	6.80E+02	2.83E+00	4.49E+01	1.65E+00	4.00E+02	2.60E+00
MEAN		2.54E+00		1.54E+00		2.60E+00
GEOMEAN	3.48E+02		3.51E+01		4.00E+02	

SAMPLES NOT SENT

NO ANALYSES

NO DATA

IND	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98	4.80E+02	2.68E+00	3.45E+01	1.54E+00		
29-Apr-98	1.72E+03	3.24E+00	5.52E+01	1.74E+00		
13-May-98	5.60E+01	1.75E+00	1.86E+01	1.27E+00		
27-May-98	1.56E+02	2.19E+00	1.04E+01	1.01E+00		
10-Jun-98	4.80E+01	1.68E+00	5.52E+01	1.74E+00		
24-Jun-98	1.32E+05	5.12E+00	2.59E+02	2.41E+00		
08-Jul-98	6.80E+01	1.83E+00	4.14E+01	1.62E+00		
22-Jul-98	6.40E+01	1.81E+00	3.45E+00	5.38E-01		
19-Aug-98	4.40E+01	1.64E+00	1.48E+02	2.17E+00		
02-Sep-98	4.80E+01	1.68E+00	1.64E+02	2.22E+00		
16-Sep-98	1.06E+03	3.03E+00			4.00E+02	2.60E+00
30-Sep-98	4.56E+02	2.66E+00	1.71E+02	2.23E+00	1.00E+02	2.00E+00
14-Oct-98	1.04E+03	3.02E+00	1.46E+02	2.16E+00		
28-Oct-98	5.98E+04	4.78E+00	1.21E+02	2.08E+00		
11-Nov-98			8.97E+01	1.95E+00		
25-Nov-98	3.20E+04	4.51E+00	6.90E+01	1.84E+00	1.00E+02	2.00E+00
09-Dec-98	1.64E+04	4.21E+00	6.56E+01	1.82E+00	2.00E+02	2.30E+00
n VALUES	16	16	16	16	4	4
MIN	4.40E+01	1.64E+00	3.45E+00	5.38E-01	1.00E+02	2.00E+00
MAX	1.32E+05	5.12E+00	2.59E+02	2.41E+00	4.00E+02	2.60E+00
STDDEV	3.53E+04	1.20E+00	7.11E+01	4.96E-01	1.41E+02	2.88E-01
95% CI	1.73E+04	5.89E-01	3.48E+01	2.43E-01	1.39E+02	2.82E-01
MEDIAN	4.68E+02	2.67E+00	6.73E+01	1.83E+00	1.50E+02	2.15E+00
MEAN		2.86E+00		1.77E+00		2.23E+00
GEOMEAN	7.31E+02		5.91E+01		1.68E+02	

(green)	SAMPLES NOT SENT
(yellow)	NO ANALYSES
(orange)	NO DATA

BCH	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98						
29-Apr-98						
13-May-98						
27-May-98						
10-Jun-98						
24-Jun-98						
08-Jul-98	6.16E+04	4.79E+00	6.90E+01	1.84E+00		
22-Jul-98	1.52E+04	4.18E+00	2.01E+03	3.30E+00		
19-Aug-98	3.00E+04	4.48E+00	6.21E+01	1.79E+00		
02-Sep-98	1.34E+05	5.13E+00	1.07E+03	3.03E+00	8.00E+03	3.90E+00
16-Sep-98	8.80E+03	3.94E+00	7.25E+01	1.86E+00	2.00E+02	2.30E+00
30-Sep-98	2.72E+03	3.43E+00	3.52E+03	3.55E+00	7.00E+02	2.85E+00
14-Oct-98	5.56E+03	3.75E+00	1.28E+02	2.11E+00		
28-Oct-98	2.21E+05	5.34E+00	1.24E+03	3.09E+00		
11-Nov-98						
25-Nov-98	3.21E+07	7.51E+00				
09-Dec-98						
n VALUES	9	9	8	8	3	3
MIN	2.72E+03	3.43E+00	6.21E+01	1.79E+00	2.00E+02	2.30E+00
MAX	3.21E+07	7.51E+00	3.52E+03	3.55E+00	8.00E+03	3.90E+00
STDDEV	1.07E+07	1.22E+00	1.24E+03	7.40E-01	4.37E+03	8.15E-01
95% CI	6.97E+06	7.96E-01	8.61E+02	5.13E-01	4.94E+03	9.22E-01
MEDIAN	3.00E+04	4.48E+00	5.99E+02	2.57E+00	7.00E+02	2.85E+00
MEAN		4.73E+00		2.57E+00		3.02E+00
GEOMEAN	5.34E+04		3.73E+02		1.04E+03	

SAMPLES NOT SENT

NO ANALYSES

NO DATA

HMT	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98	4.13E+04	4.62E+00	2.76E+02	2.44E+00	1.50E+03	3.18E+00
29-Apr-98	3.80E+04	4.58E+00	2.46E+02	2.39E+00		
13-May-98	4.20E+03	3.62E+00	9.66E+01	1.98E+00	1.20E+03	3.08E+00
27-May-98	6.00E+03	3.78E+00	3.45E+01	1.54E+00		
10-Jun-98	7.48E+03	3.87E+00			1.00E+03	3.00E+00
24-Jun-98	1.78E+03	3.25E+00	5.31E+02	2.73E+00		
08-Jul-98	2.40E+03	3.38E+00	1.10E+02	2.04E+00	5.00E+02	2.70E+00
22-Jul-98	5.00E+03	3.70E+00	1.24E+02	2.09E+00		
19-Aug-98	1.15E+04	4.06E+00	3.42E+02	2.53E+00		
02-Sep-98						
16-Sep-98	3.40E+04	4.53E+00	1.54E+02	2.19E+00	3.30E+03	3.52E+00
30-Sep-98	7.80E+04	4.89E+00	2.79E+03	3.45E+00	4.30E+03	3.63E+00
14-Oct-98						
28-Oct-98	4.04E+04	4.61E+00	1.93E+02	2.29E+00		
11-Nov-98						
25-Nov-98	6.88E+04	4.84E+00	1.38E+02	2.14E+00	3.00E+02	2.48E+00
09-Dec-98	2.04E+04	4.31E+00	3.80E+01	1.58E+00	4.00E+03	3.60E+00
n VALUES	14	14	13	13	8	8
MIN	1.78E+03	3.25E+00	3.45E+01	1.54E+00	3.00E+02	2.48E+00
MAX	7.80E+04	4.89E+00	2.79E+03	3.45E+00	4.30E+03	3.63E+00
STDDEV	2.52E+04	5.48E-01	7.35E+02	4.92E-01	1.60E+03	4.24E-01
95% CI	1.32E+04	2.87E-01	3.99E+02	2.67E-01	1.11E+03	2.94E-01
MEDIAN	1.60E+04	4.19E+00	1.54E+02	2.19E+00	1.35E+03	3.13E+00
MEAN		4.15E+00		2.26E+00		3.15E+00
GEOMEAN	1.40E+04		1.82E+02		1.41E+03	

SAMPLES NOT SENT
NO ANALYSES
NO DATA

HDL	FAECAL COLIFORMS		*Clostridium perfringens*		BACTERIOPHAGES	
DATE	FC	FC LOG	CP	CP LOG	SC	SC LOG
15-Apr-98	5.84E+03	3.77E+00	9.66E+01	1.98E+00	5.00E+02	2.70E+00
29-Apr-98	3.44E+03	3.54E+00	6.21E+01	1.79E+00		
13-May-98	4.72E+03	3.67E+00	2.14E+02	2.33E+00	2.80E+03	3.45E+00
27-May-98	1.88E+03	3.27E+00	3.45E+00	5.38E-01		
10-Jun-98	1.12E+02	2.05E+00	3.11E+01	1.49E+00		
24-Jun-98	1.16E+04	4.07E+00	1.38E+01	1.14E+00		
08-Jul-98	2.52E+03	3.40E+00	4.49E+01	1.65E+00	2.20E+03	3.34E+00
22-Jul-98	1.08E+02	2.03E+00	7.59E+01	1.88E+00		
19-Aug-98	5.92E+02	2.77E+00	4.49E+01	1.65E+00		
02-Sep-98	4.40E+01	1.64E+00	5.87E+01	1.77E+00	3.00E+02	2.48E+00
16-Sep-98	4.32E+03	3.64E+00	6.56E+01	1.82E+00	3.10E+03	3.49E+00
30-Sep-98	1.80E+02	2.26E+00	3.45E+01	1.54E+00		
14-Oct-98	1.00E+03	3.00E+00	5.73E+01	1.76E+00		
28-Oct-98	5.16E+03	3.71E+00	1.62E+02	2.21E+00		
11-Nov-98	1.04E+03	3.02E+00	9.32E+01	1.97E+00	2.00E+00	3.01E-01
25-Nov-98	5.40E+03	3.73E+00	2.31E+02	2.36E+00	9.10E+03	3.96E+00
09-Dec-98						
n VALUES	16	16	16	16	7	7
MIN	4.40E+01	1.64E+00	3.45E+00	5.38E-01	2.00E+00	3.01E-01
MAX	1.16E+04	4.07E+00	2.31E+02	2.36E+00	9.10E+03	3.96E+00
STDDEV	3.13E+03	7.43E-01	6.67E+01	4.49E-01	3.14E+03	1.22E+00
95% CI	1.53E+03	3.64E-01	3.27E+01	2.20E-01	2.33E+03	9.02E-01
MEDIAN	2.20E+03	3.34E+00	6.04E+01	1.78E+00	2.20E+03	3.34E+00
MEAN		3.10E+00		1.74E+00		2.82E+00
GEOMEAN	1.25E+03		5.53E+01		6.56E+02	

SAMPLES NOT SENT

NO ANALYSES

NO DATA

3.2 Concentrations of chemical and physical parameters at the sampling points in the Fontein Spruit: April 1998 – November 1998

FS 1	CHEMICAL VARIABLES								
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4-P mg/l
15-Apr-98	7.5		34.0	1.600	1.400	10.100	2.300	2.400	0.770
29-Apr-98	7.0		47.0	2.390	1.960	1.640	0.370	0.710	0.230
13-May-98	7.3		28.0	5.624	4.610	3.099	0.700	1.870	0.610
27-May-98	8.8	11.2	58.0	1.647	1.350	6.066	1.370	0.800	0.261
10-Jun-98	8.0	11.9	46.0	0.756	0.620	3.905	0.882	0.083	0.017
24-Jun-98	8.7	16.2	67.0	0.427	0.350	0.629	0.142	0.460	0.150
08-Jul-98	8.1	8.4	28.0	0.317	0.260	1.815	0.410	0.830	0.271
22-Jul-98									
19-Aug-98	7.9		66.0	1.037	0.850	0.443	0.100	0.830	0.271
02-Sep-98	7.9	1.1	54.0	0.671	0.550	2.635	0.595	0.882	0.288
16-Sep-98	7.9	6.6	38.0	5.432	4.477	0.974	0.220	2.010	0.656
30-Sep-98									
14-Oct-98	7.1	5.6	56.0	3.648	2.990	1.439	0.325	1.943	0.634
28-Oct-98	7.8	7.1	46.0	2.086	1.710	1.483	0.335	0.237	0.077
11-Nov-98									
25-Nov-98	7.5		41.0	1.574	1.290	0.930	0.210	0.680	0.222
09-Dec-98									
n VALUES	13	8	13	13	13	13	13	13	13
MIN	7.0	1.1	28.0	0.317	0.260	0.443	0.100	0.083	0.017
MAX	8.8	16.2	67.0	5.624	4.610	10.100	2.300	2.400	0.770
STDDEV	0.5	4.6	13.0	1.772	1.455	2.711	0.617	0.741	0.241
MEDIAN	7.9	7.8	46.0	1.600	1.350	1.640	0.370	0.830	0.271
MEAN	7.8	8.5	46.8	2.093	1.724	2.705	0.612	1.057	0.343

FS 1	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
15-Apr-98	940.0	611.0	8.6	19.1
29-Apr-98	892.0	579.8	3.1	16.5
13-May-98	859.0	558.4	4.9	
27-May-98	481.0	312.7	41.8	11.2
10-Jun-98	944.0	613.6	2.6	5.3
24-Jun-98	729.0	473.9	20.3	8.4
08-Jul-98	281.0	182.7	3.5	8.7
22-Jul-98				
19-Aug-98	741.0	481.7	>40	13.0
02-Sep-98	890.0	578.5	7.8	
16-Sep-98	883.0	574.0	13.4	17.4
30-Sep-98				
14-Oct-98	508.0	330.2	3.4	18.3
28-Oct-98	516.0	335.4	32.0	21.8
11-Nov-98				
25-Nov-98	257.0	167.1	85.8	24.0
09-Dec-98				
n VALUES	13	13	13	11
MIN	257.0	167.1	2.6	5.3
MAX	944.0	613.6	85.8	24.0
STDDEV	248.2	161.3	24.5	6.0
MEDIAN	741.0	481.7	8.2	16.5
MEAN	686.2	446.1	18.9	14.9

No Data

Meter not working

FS2	CHEMICAL VARIABLES								
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4 - P mg/l
15-Apr-98									
29-Apr-98	7.5		35.0	0.660	0.540	6.950	1.570	0.510	0.160
13-May-98	7.1		15.0	1.061	0.870	10.627	2.400	1.410	0.460
27-May-98	7.6	10.6	24.0	0.220	0.180	8.900	2.010	0.490	0.160
10-Jun-98	8.2	12.9	27.0	0.378	0.310	7.138	1.612	0.091	0.020
24-Jun-98	7.9	13.2	18.0	0.305	0.250	6.102	1.378	0.126	0.041
08-Jul-98	8.1	8.1	<4	0.159	0.130	6.952	1.570	0.790	0.258
22-Jul-98	8.2	6.2	19.0	0.268	0.220	5.978	1.350	0.440	0.144
19-Aug-98	7.4		59.0	0.586	0.480	1.993	0.450	0.390	0.127
02-Sep-98	7.9	10.3	20.0	0.268	0.220	5.291	1.195	0.174	0.057
16-Sep-98	7.9	12.9	36.0	2.342	1.920	5.092	1.150	1.500	0.489
30-Sep-98	7.8	4.3	23.0	0.220	0.180	2.922	0.660	0.270	0.088
14-Oct-98	7.6	7.5	54.0	2.855	2.340	2.387	0.539	1.843	0.601
28-Oct-98	7.8	6.2	51.0	0.390	0.320	3.591	0.811	0.110	0.036
11-Nov-98	7.9	7.4	14.0	0.244	0.200	2.621	0.592	0.878	0.286
25-Nov-98	7.5		48.0	0.561	0.460	3.365	0.760	0.370	0.121
09-Dec-98	7.7		16.0	0.329	0.270	2.922	0.660	0.200	0.065
n VALUES	16	11	16	16	16	16	16	16	16
MIN	7.1	4.3	14.0	0.159	0.130	1.993	0.450	0.091	0.020
MAX	8.2	13.2	59.0	2.855	2.340	10.627	2.400	1.843	0.601
STDDEV	0.3	3.1	15.5	0.788	0.646	2.525	0.570	0.544	0.178
MEDIAN	7.8	8.1	24.0	0.354	0.290	5.192	1.173	0.415	0.136
MEAN	7.8	9.1	30.6	0.678	0.556	5.177	1.169	0.600	0.195

FS2	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
15-Apr-98				
29-Apr-98	951.0	618.2	2.8	12.3
13-May-98	948.0	616.2	4.9	7.6
27-May-98	642.0	417.3	6.9	7.4
10-Jun-98	780.0	507.0	9.6	5.2
24-Jun-98	877.0	570.1	8.3	6.5
08-Jul-98	939.0	610.4	2.4	6.5
22-Jul-98	921.0	598.7	2.7	7.5
19-Aug-98	743.0	483.0	>40	11.3
02-Sep-98	769.0	499.9	2.2	
16-Sep-98	871.0	566.2	4.0	17.1
30-Sep-98	765.0	497.3	6.8	16.4
14-Oct-98	528.0	343.2	2.9	20.9
28-Oct-98	570.0	370.5	17.6	21.1
11-Nov-98	697.0	453.1	2.4	
25-Nov-98	328.0	213.2	32.8	21.0
09-Dec-98	508.0	330.2	2.9	
n VALUES	16	16	16	13
MIN	328.0	213.2	2.2	5.2
MAX	951.0	618.2	32.8	21.1
STDDEV	179.4	116.6	8.4	6.2
MEDIAN	767.0	498.6	4.0	11.3
MEAN	739.8	480.9	7.3	12.4

No Data

Meter not working

FS3	CHEMICAL VARIABLES							
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4 - P mg/l
15-Apr-98	7.7		29.0	1.700	1.400	21.100	4.800	2.300	0.750
29-Apr-98	7.6		24.0	0.630	0.520	23.160	5.230	0.880	0.290
13-May-98	7.9		16.0	0.293	0.240	47.955	10.830	1.150	0.384
27-May-98	8.2	14.5	13.0	0.354	0.290	44.103	9.960	0.620	0.202
10-Jun-98	8.3	18.3	8.0	0.268	0.220	41.924	9.468	0.177	0.058
24-Jun-98	8.1	17.2	6.0	0.268	0.220	43.408	9.803	0.283	0.092
08-Jul-98	7.8	8.2	<4	0.317	0.260	51.630	11.660	0.680	0.222
22-Jul-98	8.0	14.2	25.0	0.549	0.450	37.505	8.470	0.570	0.186
19-Aug-98	7.5		24.0	0.439	0.360	15.144	3.420	1.000	0.326
02-Sep-98	8.8	9.7	21.0	0.805	0.660	32.085	7.246	0.316	0.103
16-Sep-98	9.2	15.6	39.0	0.512	0.420	19.926	4.500	0.690	0.225
30-Sep-98	8.2	7.6	28.0	0.305	0.250	22.898	5.170	0.470	0.153
14-Oct-98	7.4	7.9	49.0	2.257	1.850	5.561	1.256	1.810	0.591
28-Oct-98	7.9	15.7	40.0	2.721	2.230	10.193	2.302	1.450	0.473
11-Nov-98	8.2	7.1	31.0	0.220	0.180	22.251	5.025	0.626	0.204
25-Nov-98	7.6		61.0	8.577	7.030	5.136	1.160	2.380	0.777
09-Dec-98	8.2		19.0	0.512	0.420	15.542	3.510	0.290	0.095
n VALUES	17	11	17	17	17	17	17	17	17
MIN	7.4	7.1	6.0	0.220	0.180	5.136	1.160	0.177	0.058
MAX	9.2	18.3	61.0	8.577	7.030	51.630	11.660	2.380	0.777
STDDEV	0.5	4.3	14.6	2.036	1.669	14.995	3.385	0.685	0.224
MEDIAN	8.0	14.2	24.5	0.512	0.420	22.898	5.170	0.680	0.222
MEAN	8.0	12.4	27.1	1.219	1.000	27.031	6.106	0.923	0.302

FS3	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
15-Apr-98	972.0	631.8	3.1	17.0
29-Apr-98	819.0	532.4	3.5	12.1
13-May-98	807.0	524.6	3.0	8.5
27-May-98	907.0	589.6	4.6	7.9
10-Jun-98	1031.0	670.2	3.9	5.9
24-Jun-98	1110.0	721.5	3.1	6.2
08-Jul-98	916.0	595.4	3.0	5.6
22-Jul-98	898.0	583.7	2.8	6.8
19-Aug-98	887.0	576.6	5.6	10.7
02-Sep-98	983.0	639.0	3.5	
16-Sep-98	998.0	648.7	14.0	17.6
30-Sep-98	1038.0	674.7	7.8	17.1
14-Oct-98	600.0	390.0	3.4	16.3
28-Oct-98	775.0	503.8	2.1	21.5
11-Nov-98	939.0	610.4	4.5	
25-Nov-98	564.0	366.6	13.1	23.0
09-Dec-98	943.0	613.0	3.6	19.0
n VALUES	17	17	17	15
MIN	564.0	366.6	2.1	5.6
MAX	1110.0	721.5	14.0	23.0
STDDEV	149.7	97.3	3.6	6.1
MEDIAN	916.0	595.4	3.5	12.1
MEAN	893.4	580.7	5.0	13.0

No Data

Meter not working

FS4	CHEMICAL VARIABLES								
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4 - P mg/l
15-Apr-98	8.0		41.0	0.850	0.700	39.500	8.900	2.300	0.760
29-Apr-98	7.7		18.0	0.550	0.450	30.730	6.940	0.610	0.200
13-May-98	7.5		10.0	0.293	0.240	57.564	13.000	1.130	0.369
27-May-98	7.7	12.7	11.0	0.281	0.230	47.202	10.660	0.530	0.173
10-Jun-98	8.1	13.8	11.0	0.281	0.230	43.580	9.842	0.312	0.102
24-Jun-98	7.9	17.6	<5	0.317	0.260	41.938	9.471	0.338	0.110
08-Jul-98	7.9	9.9	<4	0.268	0.220	48.531	10.960	0.990	0.323
22-Jul-98	7.8	8.0	<5	0.634	0.520	30.686	6.930	0.490	0.159
19-Aug-98	7.8		23.0	1.220	1.000	1.151	0.260	0.520	0.170
02-Sep-98	8.0	4.8	26.0	1.305	1.070	71.393	16.123	0.267	0.087
16-Sep-98	8.2	13.5	36.0	0.476	0.390	38.966	8.800	0.780	0.254
30-Sep-98	7.7	1.0	312.0	35.990	29.500	0.221	0.050	8.740	2.852
14-Oct-98	7.5	7.2	98.0	8.011	6.566	4.060	0.917	3.068	1.009
28-Oct-98	8.0	17.5	40.0	2.721	2.230	10.193	2.302	1.450	0.473
11-Nov-98	8.2	5.8	22.0	0.281	0.230	60.774	13.725	0.622	0.203
25-Nov-98	7.9		39.0	1.440	1.180	19.350	4.870	8.430	1.119
09-Dec-98	8.4		14.0	0.488	0.400	63.320	14.300	0.370	0.121
n VALUES	17	11	17	17	17	17	17	17	17
MIN	7.5	1.0	10.0	0.268	0.220	0.221	0.050	0.267	0.087
MAX	8.4	17.6	312.0	35.990	29.500	71.393	16.123	8.740	2.852
STDDEV	0.2	5.3	78.7	8.638	7.081	22.343	5.024	2.655	0.684
MEDIAN	7.9	9.9	24.5	0.550	0.450	39.500	8.900	0.622	0.203
MEAN	7.9	10.2	50.1	3.259	2.672	35.833	8.121	1.820	0.499

FS4	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
15-Apr-98	1002.0	651.3	4.7	17.0
29-Apr-98	988.0	642.2	3.9	12.1
13-May-98	971.0	631.2	1.6	7.2
27-May-98	865.0	562.3	2.8	7.1
10-Jun-98	970.0	630.5	6.6	5.3
24-Jun-98	919.0	597.4	3.7	5.5
08-Jul-98	963.0	626.0	2.8	5.0
22-Jul-98	946.0	614.9	3.1	6.4
19-Aug-98	823.0	535.0	6.2	10.5
02-Sep-98	1018.0	661.7	2.1	
16-Sep-98	1037.0	674.1	2.9	17.8
30-Sep-98	1182.0	768.3	14.4	18.4
14-Oct-98	676.0	439.4	5.0	16.4
28-Oct-98	818.0	531.7	2.6	21.3
11-Nov-98	1074.0	698.1	2.7	
25-Nov-98	605.0	393.3	12.3	21.0
09-Dec-98	1121.0	728.7	2.1	19.0
n VALUES	17	17	17	15
MIN	605.0	393.3	1.6	5.0
MAX	1182.0	768.3	14.4	21.3
STDDEV	144.9	94.2	3.6	6.2
MEDIAN	970.0	630.5	3.1	12.1
MEAN	939.9	610.9	4.7	12.7

No Data

Meter not working

FS5	CHEMICAL VARIABLES							
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4 - P mg/l
26-Mar-98	7.2	8.4	37.0	4.480	3.672	3.300	0.750	73.180	24.393
29-Apr-98	6.3		22.0	0.370	0.300	48.930	11.040	1.050	0.340
13-May-98	7.0		18.0	0.378	0.310	70.095	15.830	1.830	0.597
27-May-98	8.0	10.6	14.0	0.256	0.210	65.977	14.900	0.470	0.153
10-Jun-98	8.0	11.9	23.0	0.610	0.500	65.202	14.725	0.301	0.098
24-Jun-98	8.0	4.2	7.0	0.683	0.560	69.923	15.791	0.240	0.078
08-Jul-98	8.1	8.3	5.0	0.281	0.230	30.288	6.840	0.310	0.101
22-Jul-98	8.0	7.1	31.0	0.781	0.640	56.767	12.820	0.200	0.065
19-Aug-98	7.7		26.0	0.390	0.320	42.199	9.530	0.570	0.186
02-Sep-98	7.7	0.5	39.0	0.769	0.630	71.694	16.191	0.516	0.168
16-Sep-98	8.1	8.3	42.0	1.623	1.330	32.856	7.420	0.910	0.297
30-Sep-98	7.7	1.2	48.0	12.481	10.230	9.742	2.200	6.500	2.121
14-Oct-98	7.5	7.5	46.0	2.672	2.190	11.238	2.538	1.839	0.600
28-Oct-98	7.9	4.5	35.0	1.074	0.880	24.505	5.188	0.509	0.166
11-Nov-98	7.9	4.7	17.0	1.074	0.310	60.774	12.301	0.549	0.179
25-Nov-98	7.7		36.0	0.329	0.270	29.800	6.730	1.620	0.529
09-Dec-98	8.2		19.0	0.427	0.350	71.734	16.200	0.240	0.078
n VALUES	17	12	17	17	17	17	17	17	17
MIN	6.3	0.5	5.0	0.256	0.210	3.300	0.750	0.200	0.065
MAX	8.2	11.9	48.0	12.481	10.230	71.734	16.200	73.180	24.393
STDDEV	0.5	3.5	13.2	2.984	2.457	23.814	5.348	17.545	5.849
MEDIAN	7.9	7.3	26.0	0.683	0.500	48.930	11.040	0.549	0.179
MEAN	7.7	6.4	27.4	1.687	1.349	45.001	10.058	5.343	1.774

FS5	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
26-Mar-98	132.0	85.8	11.0	15.5
29-Apr-98	905.0	588.3	2.1	13.4
13-May-98	878.0	570.7	2.9	7.1
27-May-98	970.0	630.5	2.6	8.2
10-Jun-98	1017.0	661.1	3.5	5.2
24-Jun-98	1247.0	810.6	4.4	5.5
08-Jul-98	714.0	464.1	4.0	5.4
22-Jul-98	801.0	520.7	3.8	6.9
19-Aug-98	977.0	635.1	4.4	11.7
02-Sep-98	1034.0	672.1	2.3	
16-Sep-98	1010.0	656.5	5.1	13.8
30-Sep-98	1097.0	713.1	3.4	14.1
14-Oct-98	665.0	432.3	4.9	14.0
28-Oct-98	841.0	546.7	5.9	18.2
11-Nov-98	1118.0	726.7	3.6	
25-Nov-98	654.0	425.1	10.5	
09-Dec-98	1148.0	746.2	2.5	18.0
n VALUES	17	17	17	14
MIN	132.0	85.8	2.1	5.2
MAX	1247.0	810.6	11.0	18.2
STDDEV	259.2	168.5	2.6	4.5
MEDIAN	970.0	630.5	3.8	12.6
MEAN	894.6	581.5	4.5	11.2

No Data

Meter not working

ERL	CHEMICAL VARIABLES							
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4 - P mg/l
15-Apr-98	7.4		15.0	0.190	0.160	1.730	0.390	1.300	0.420
29-Apr-98	7.1		16.0	0.207	0.170	1.550	0.350	2.790	0.910
13-May-98	8.3	11.9	14.0	0.122	0.100	0.664	0.150	1.410	0.460
27-May-98	8.5	11.9	12.0	0.134	0.110	0.270	0.061	0.606	0.198
10-Jun-98	8.3	12.6	<5	0.183	0.150	0.208	0.047	0.548	0.179
24-Jun-98	8.5	7.7	10.0	0.134	0.110	1.284	0.290	1.790	0.584
08-Jul-98	8.7	5.3	18.0	0.317	0.260	2.037	0.460	0.440	0.144
22-Jul-98	7.5		7.0	0.134	0.110	0.133	0.030	0.318	0.104
19-Aug-98	7.7	3.9	20.0	0.207	0.170	0.283	0.064	1.136	0.371
02-Sep-98	7.9	10.4	9.0	0.134	0.110	0.177	0.040	0.986	0.322
16-Sep-98	7.7	3.8	11.0	0.110	0.090	0.221	0.050	0.230	0.075
30-Sep-98	7.9	7.7	10.0	0.207	0.170	0.151	0.034	0.759	0.248
14-Oct-98	7.9	9.6	13.0	0.134	0.110	0.651	0.147	0.386	0.126
28-Oct-98	8.4	5.0	11.0	0.134	0.110	0.983	0.222	1.572	0.513
11-Nov-98	8.1								
25-Nov-98	7.6		8.0	0.293	0.240	1.196	0.270	0.250	0.082
09-Dec-98									
n VALUES	16	11	15	15	15	15	15	15	15
MIN	7.1	3.8	7.0	0.110	0.090	0.133	0.030	0.230	0.075
MAX	8.7	12.6	20.0	0.317	0.260	2.037	0.460	2.790	0.910
STDDEV	0.5	3.3	3.8	0.062	0.051	0.649	0.146	0.714	0.233
MEDIAN	7.9	7.7	11.5	0.134	0.110	0.651	0.147	0.759	0.248
MEAN	8.0	8.2	12.4	0.176	0.145	0.769	0.174	0.968	0.316

ERL	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
15-Apr-98	981.0	637.7	2.5	18.3
29-Apr-98	979.0	636.4	2.6	16.9
13-May-98	874.0	568.1	5.1	11.9
27-May-98	277.0	180.1	2.2	13.6
10-Jun-98	372.0	241.8	3.8	12.2
24-Jun-98	249.0	161.9	3.7	11.3
08-Jul-98	743.0	483.0	6.7	11.4
22-Jul-98	823.0	535.0	3.2	14.3
19-Aug-98	381.0	247.7	1.7	
02-Sep-98	387.0	251.6	2.4	16.5
16-Sep-98	360.0	234.0	2.9	19.5
30-Sep-98	361.0	234.7	1.8	20.9
14-Oct-98	322.0	209.3	1.1	22.8
28-Oct-98	288.0	187.2	2.1	
11-Nov-98	148.0	96.2	3.4	
25-Nov-98	219.0	142.4	1.1	21.1
09-Dec-98				
n VALUES	16	16	16	13
MIN	148.0	96.2	1.1	11.3
MAX	981.0	637.7	6.7	22.8
STDDEV	286.9	186.5	1.5	4.1
MEDIAN	366.5	238.2	2.5	16.5
MEAN	485.3	315.4	2.9	16.2

No Data

Meter not working

IND	CHEMICAL VARIABLES								
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4 - P mg/l
15-Apr-98	7.6		8.0	0.098	0.080	35.500	8.000	0.370	0.120
29-Apr-98	7.5		5.0	0.110	0.090	33.520	7.570	0.520	0.170
13-May-98	7.7		4.0	0.073	0.060	33.298	7.520	0.520	0.170
27-May-98	7.5	8.7	11.0	0.134	0.110	31.837	7.190	0.670	0.219
10-Jun-98	8.0	12.5	25.0	0.122	0.100	30.288	6.840	0.100	0.100
24-Jun-98	7.7	12.6	<5	0.622	0.510	28.853	6.516	1.108	0.362
08-Jul-98	7.9	9.6	5.0	0.122	0.100	28.561	6.450	<0.3	<0.1
22-Jul-98	7.5	11.7	47.0	0.403	0.330	31.439	7.100	0.450	0.147
19-Aug-98	7.7		<5	0.110	0.090	29.579	6.680	0.530	0.173
02-Sep-98	8.6	1.6	22.0	0.207	0.170	29.707	6.709	0.375	0.122
16-Sep-98	8.3	11.3	12.0	0.171	0.140	29.003	6.550	1.000	0.326
30-Sep-98	7.8	4.1	9.0	0.159	0.130	27.011	6.100	0.300	0.098
14-Oct-98	7.6	5.5	10.0	0.244	0.200	28.410	6.416	0.548	0.179
28-Oct-98	7.8	6.5	27.0	2.904	2.380	20.457	4.620	1.545	0.504
11-Nov-98	8.0	3.7	25.0	0.146	0.120	28.751	6.493	0.179	0.058
25-Nov-98	7.9		9.0	0.134	0.110	30.951	6.990	0.270	0.088
09-Dec-98	8.1		7.0	0.439	0.360	30.110	6.800	<0.2	<0.1
n VALUES	17	11	17	17	17	17	17	17	17
MIN	7.5	1.6	4.0	0.073	0.060	20.457	4.620	0.100	0.058
MAX	8.6	12.6	47.0	2.904	2.380	35.500	8.000	1.545	0.504
STDDEV	0.3	3.9	11.9	0.671	0.550	3.243	0.730	0.385	0.121
MEDIAN	7.8	8.7	10.0	0.146	0.120	29.707	6.709	0.520	0.170
MEAN	7.8	8.0	15.1	0.365	0.299	29.840	6.738	0.566	0.189

IND	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
15-Apr-98	965.0	627.3	1.3	
29-Apr-98	957.0	622.1	1.6	17.9
13-May-98	951.0	618.2	1.9	16.4
27-May-98	273.0	177.5	77.8	16.3
10-Jun-98	1002.0	651.3	1.6	14.6
24-Jun-98	964.0	626.6	1.2	15.3
08-Jul-98	1033.0	671.5	1.7	14.4
22-Jul-98	875.0	568.8	2.4	15.6
19-Aug-98	671.0	436.2	1.8	16.1
02-Sep-98	899.0	584.4	3.1	
16-Sep-98	885.0	575.3	2.5	18.4
30-Sep-98	962.0	625.3	3.3	18.7
14-Oct-98	970.0	630.5	2.0	19.7
28-Oct-98	963.0	626.0	1.0	20.7
11-Nov-98	971.0	631.2	1.2	
25-Nov-98	883.0	574.0	2.2	21.0
09-Dec-98	943.0	613.0	1.7	20.0
n VALUES	17	17	17	14
MIN	273.0	177.5	1.0	14.4
MAX	1033.0	671.5	77.8	21.0
STDDEV	183.4	119.2	19.0	2.2
MEDIAN	957.0	622.1	1.8	17.2
MEAN	892.2	579.9	6.4	17.5

No Data

Meter not working

BCH	CHEMICAL VARIABLES								
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4 - P mg/l
15-Apr-98									
29-Apr-98									
13-May-98									
27-May-98									
10-Jun-98									
24-Jun-98									
08-Jul-98	8.5	5.3	45.0	14.872	12.190	2.227	0.503	6.320	2.062
22-Jul-98	8.5	12.8	49.0	7.174	5.880	2.958	0.668	1.933	0.631
19-Aug-98	8.8		14.0	3.318	2.720	1.151	0.260	1.530	0.499
02-Sep-98	7.6	8.9	23.0	1.586	1.300	2.826	0.638	1.809	0.590
16-Sep-98	7.7	12.6	44.0	2.257	1.850	1.506	0.340	1.930	0.630
30-Sep-98	7.7	0.1	27.0	0.488	0.400	1.993	0.450	2.000	0.653
14-Oct-98	7.9	4.1	8.0	0.584	0.440	0.903	0.204	0.437	0.143
28-Oct-98	7.9	9.1	45.0	4.965	4.070	0.266	0.006	3.414	1.114
11-Nov-98									
25-Nov-98	8.1		803.0	72.346	59.300	2.480	0.560	81.300	10.212
09-Dec-98									
n VALUES	9	7	9	9	9	9	9	9	9
MIN	7.6	0.1	8.0	0.488	0.400	0.266	0.006	0.437	0.143
MAX	8.8	12.8	803.0	72.346	59.300	2.958	0.668	81.300	10.212
STDDEV	0.4	4.7	257.5	23.087	18.927	0.918	0.219	26.345	3.187
MEDIAN	7.9	8.9	44.0	3.318	2.720	1.993	0.450	1.933	0.631
MEAN	8.1	7.6	117.6	11.954	9.794	1.812	0.403	11.186	1.837

BCH	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
15-Apr-98				
29-Apr-98				
13-May-98				
27-May-98				
10-Jun-98				
24-Jun-98				
08-Jul-98	611.0	397.2	2.2	11.3
22-Jul-98	645.0	419.3	4.9	10.0
19-Aug-98	1076.0	699.4	2.1	13.4
02-Sep-98	357.0	232.1	3.1	
16-Sep-98	421.0	273.7	16.0	18.1
30-Sep-98	399.0	259.4	6.5	18.2
14-Oct-98	388.0	252.2	3.8	15.4
28-Oct-98	389.0	252.9	2.0	22.0
11-Nov-98				
25-Nov-98	1108.0	720.2	242.0	24.0
09-Dec-98				
n VALUES	9	9	9	8
MIN	357.0	232.1	2.0	10.0
MAX	1108.0	720.2	242.0	24.0
STDDEV	297.4	193.3	79.1	5.0
MEDIAN	421.0	273.7	3.8	16.8
MEAN	599.3	389.6	31.4	16.6

No Data

Meter not working

HMT	CHEMICAL VARIABLES								
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4 - P mg/l
15-Apr-98	7.7		21.0	0.450	0.370	0.780	0.180	1.100	0.360
29-Apr-98	7.0		20.0	0.490	0.403	1.110	0.250	0.660	0.220
13-May-98	6.8		21.0	0.256	0.210	3.144	0.710	0.670	0.219
27-May-98	7.5	7.1	15.0	0.256	0.210	2.303	0.520	0.580	0.189
10-Jun-98	7.9	11.0	17.0	0.305	0.250	3.139	0.709	0.113	0.037
24-Jun-98	7.7	11.0	10.0	0.329	0.270	2.953	0.667	0.484	0.158
08-Jul-98	8.1	8.6	12.0	0.232	0.190	5.491	1.240	<0.3	<0.1
22-Jul-98	8.1	0.8	75.0	1.110	0.910	6.553	1.480	0.510	0.166
19-Aug-98	8.4		32.0	1.305	1.070	1.107	0.250	0.780	0.254
02-Sep-98									
16-Sep-98	8.0	13.5	46.0	1.647	1.350	1.594	0.360	1.800	0.587
30-Sep-98	7.8	4.2	44.0	3.087	2.530	1.373	0.310	0.880	0.287
14-Oct-98									
28-Oct-98	8.2	6.6	54.0	1.074	0.833	1.462	0.330	0.400	0.131
11-Nov-98									
25-Nov-98	8.6		26.0	0.305	0.250	4.605	1.040	1.160	0.378
09-Dec-98	8.4		22.0	0.403	0.330	2.878	0.650	0.770	0.251
n VALUES	14	8	14	14	14	14	14	14	14
MIN	6.8	0.8	10.0	0.232	0.190	0.780	0.180	0.113	0.037
MAX	8.6	13.5	75.0	3.087	2.530	6.553	1.480	1.800	0.587
STDDEV	0.5	4.1	18.6	0.803	0.657	1.757	0.397	0.419	0.137
MEDIAN	7.9	7.9	21.5	0.427	0.350	2.590	0.585	0.670	0.220
MEAN	7.9	7.9	29.6	0.804	0.655	2.749	0.621	0.762	0.249

HMT	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
15-Apr-98	824.0	535.6	5.6	17.2
29-Apr-98	852.0	553.8	4.1	11.2
13-May-98	849.0	551.9	3.7	7.2
27-May-98	479.0	311.4	2.2	7.3
10-Jun-98	691.0	449.2	2.4	4.6
24-Jun-98	570.0	370.5	1.8	6.1
08-Jul-98	590.0	383.5	2.0	5.0
22-Jul-98	497.0	323.1	3.8	6.3
19-Aug-98	824.0	535.6	1.8	10.0
02-Sep-98				
16-Sep-98	551.0	358.2	28.4	16.2
30-Sep-98	776.0	504.4	66.8	13.6
14-Oct-98				
28-Oct-98	642.0	417.3	over	19.6
11-Nov-98				
25-Nov-98	416.0	270.4	83.5	
09-Dec-98	863.0	561.0	3.9	21.0
n VALUES	14	14	14	13
MIN	416.0	270.4	1.8	4.6
MAX	863.0	561.0	83.5	21.0
STDDEV	154.1	100.1	28.3	5.2
MEDIAN	666.5	433.2	3.8	10.0
MEAN	673.1	437.5	16.2	11.2

No Data

Meter not working

HDL	CHEMICAL VARIABLES								
DATE	pH	DO mg/l	COD mg/l	NH4 mg/l	NH4 - N mg/l	NO3 mg/l	NO3 - N mg/l	PO4 mg/l	PO4 - P mg/l
15-Apr-98	7.8		64.0	0.180	0.150	25.700	5.800	1.400	0.450
29-Apr-98	8.0		63.0	0.200	0.160	8.990	2.030	0.880	0.290
13-May-98	7.5		53.0	0.195	0.160	16.516	3.730	0.910	0.270
27-May-98	8.3	11.2	27.0	0.146	0.120	9.122	2.060	0.420	0.137
10-Jun-98	10.6	8.5	29.0	0.195	0.160	2.360	0.533	0.309	0.101
24-Jun-98	8.7	<0.1	203.0	1.330	1.090	0.602	0.014	2.641	0.862
08-Jul-98	8.1	8.9	<4	0.488	0.400	25.591	5.780	<0.3	<0.1
22-Jul-98	7.9	8.8	20.0	0.256	0.210	6.465	1.460	1.290	0.421
19-Aug-98	7.6		36.0	0.134	0.110	0.664	0.150	0.480	0.153
02-Sep-98	8.1	9.8	81.0	0.842	0.690	7.421	1.676	1.496	0.488
16-Sep-98	8.0	10.7	35.0	0.500	0.410	8.945	2.020	1.620	0.529
30-Sep-98	9.4	6.0	88.0	0.329	0.270	3.542	0.800	4.250	1.387
14-Oct-98	8.3	6.5	53.0	0.952	0.780	5.973	1.349	2.248	0.733
28-Oct-98	7.7	9.3	50.0	1.305	1.070	20.178	4.557	0.999	0.326
11-Nov-98	8.9	3.2	80.0	0.683	0.560	9.684	2.187	1.746	0.570
25-Nov-98	8.0		50.0	1.074	0.330	4.605	2.020	0.450	0.147
09-Dec-98									
n VALUES	16	11	16	16	16	16	16	16	16
MIN	7.5	3.2	20.0	0.134	0.110	0.602	0.014	0.309	0.101
MAX	10.6	11.2	203.0	1.330	1.090	25.700	5.800	4.250	1.387
STDDEV	0.8	2.4	44.1	0.425	0.330	8.074	1.807	1.040	0.340
MEDIAN	8.1	8.9	53.0	0.409	0.300	8.183	2.020	1.290	0.421
MEAN	8.3	8.3	62.1	0.551	0.417	9.772	2.260	1.409	0.458

HDL	PHYSICAL VARIABLES			
DATE	Conductivity uS/cm	Total dissolved solids mg/l	Turbidity NTU	Temperature C
15-Apr-98	821.0	533.7	3.5	16.3
29-Apr-98	890.0	578.5	3.7	11.1
13-May-98	897.0	583.1	2.1	7.8
27-May-98	519.0	337.4	1.5	8.6
10-Jun-98	785.0	510.3	1.2	8.5
24-Jun-98	511.0	332.2	>40	13.2
08-Jul-98	766.0	497.9	4.7	5.0
22-Jul-98	750.0	487.5	4.8	8.7
19-Aug-98	535.0	347.8	1.8	13.1
02-Sep-98	1045.0	679.3	2.7	
16-Sep-98	784.0	509.6	1.4	15.0
30-Sep-98	1599.0	1039.4	2.1	23.8
14-Oct-98	485.0	315.3	3.0	15.0
28-Oct-98	839.0	545.4	5.1	19.7
11-Nov-98	1234.0	802.1	10.8	
25-Nov-98	477.0	310.1	10.6	21.0
09-Dec-98				
n VALUES	16	16	16	14
MIN	477.0	310.1	1.2	5.0
MAX	1599.0	1039.4	10.8	23.8
STDDEV	299.5	194.7	3.0	5.5
MEDIAN	784.5	509.9	3.0	13.2
MEAN	808.6	525.6	3.9	13.3

No Data

Meter not working

APPENDIX 4

4.1 Data capturing form

WATER QUALITY RESEARCH IN THE DEVELOPING COMMUNITY OF MANGAUNG

This is a research project, therefore information given will be handled with care
The identity of the respondant will not be made public
The field surveyor will explain the terminlogy and interpret the questions asked

DATA CAPTURING FORM

AREA NUMBER:

FIELD WORKER: **DATE:** DWELLING NUMBER:

1 PERSONAL DETAIL

1.1 Number of inhabitants

A= 1-2	B= 2-4	C= 4-6	D= 6-8	E= 8+	

1.2 Type of dwelling

A= Shack	B= Municipal	C= Traditional	D= Concrete	E= Shelter	

1.3 Ownership

A= squatter	B= Self-build	C= Title deed	D= Familiy	E= Rent	

1.4 Years in the same dwelling

A=1	B=2	C=3	D=4	E=5+	

1.5 Income of person responsible for paying municipal services

A=0-R500	B=501-R1000	C=1000-1500	D=1501-2000	E=2000+	

2 SOCIO-ECONOMIC SERVICE ENVIRONMENT

2.1 Services available

A= Water	B=Electricity	C=Sewage	D=Removal	E=Storm water	

2.2 Payment for services

Type		Amount			
Water &		A= 0-R50	B= 56-R100	C= 101- R200	D= R201+
Electricity&					
Sewage & removal					

2.3 Willingness to pay for services. Do you think you should pay for services?

A= Yes	B= No				

2.4 Do you pay your service every month?

A= Yes	B= No				

2.5 The reason for not paying your service, is because the service is:

A=Inadequate	B=Abscent	C=Vandilised	D=Expensive	E=free o char.	F=Income low

2.6 How would you rate the services in general? (To be completed by the field worker)

A=Inadequate	B=Inconvenient	C=Vandalised	D=Illegal connection	E=Badly maintained	F=adequate

3 WATER SUPPLY

3.1 Current level of water supply for the dwelling

A=<RDPlevel* *25 liter per capita per day	B=>RDPlevel	C=house tap	D=Yard tap	E=Public stands	F=Collection systems

3.2 If water is stored from C,D,E (3.1) indicate the method of storage

A=Bucket	B=Drum	C=Zink bath	D=Container		

3.3 Is water available when needed?

A=Yes	B= Mostly yes	C=Mostly no			

3.4 The storage method for back-up environmental water supply

A= Water tank	B=Ground water	C=River	D=Rain water collection		

3.5 Is this method liable to pollute water (to be completed by the field worker)

A=Yes	B=No				

DWELLING NUMBER:

4 EXCRETA DISPOSAL SYSTEM

4.1 Domestic sanitation system

A= full water borne	B=Septic tank	C=Bucket system	D=VIP Vent. improv. Latrine	E=Pit latrine	F=No facility

4.2 Distribution of facilities

A=Own indoor	B=Own outdoor	C=Communial	D=Sharing with another dwelling	

4.3 If applicable, is the facility serviced effectively?

A-Yes	B=No				

4.4 If yes, how often?

A= 1/ week	B=2/week	C=1/month	D=2/month	E=Irregular	F=On demand

4.5 If not serviced, what facility is used

A=Neighbour's	B=Environment	C=Other public places			

4.6 Is there any animal , human or vector contact with excreta?

A=Yes	B=No				

4.7 Does excreta cause a nuisance or health risk?(To be completed by field worker)

A=Yes	B=No				

4.8 If Yes, indicate the reason according to you as: defects of / ineffectiveness of

A=Construction	B=Function	C=Unhygienic	D=Disposal		

4.9 Is the infant (younger than 5 years) toilet trained?

A=Yes	B=No				

4.10 Facility used by infant

A=Toilet	B=Environment	C=Disposable nappies in toilet	D= Nappies in dustbin

4.11 Estimated number of users per toilet facility

A=1-2	B=3-4	C=5-6	D=6+		

5 SOLID WASTE DISPOSAL SYSTEM

5.1 How is domestic refuse stored?

A= Communial skip	B= Plastic bags	C=Litter bins	D=Dumped		

5.2 How is refuse removed?

A= Communial Skips	B=Curbside collection	C=Communial litter collection	D=Serviced public spaces	E=Extras dumped into the river

5.3 How is refuse disposed?

A=Municipality	B=Burnt	C=Dump into river	D=Dump into channels	E=Dump on heap	

6 WASTE WATER DISPOSAL SYSTEM

6.1 How is waste water (Grey / sullage e.g. cooking, baths,sinks, washing, backyard industry diposed?

A=Drain	B=Toilet	C=Surface	D=River	E=Channel	

6.2 Type of land-use activity / backyard industry

A=Agricultural	B=Animal slaughtering	C=Motor mechanics	D=Food vendors	E=Life stock	

7 STORM WATER

7.1 Infrastructure available for storm water

A=Open lined channel	B=Open unlined channel	C=Natural flow	D=Stormwater pipes	E=Closed channels	

7.2 Condition of stormwater facility

A=Damaged pipes	B= Over flow manholes	C= No lid on manhole	D=Dangerous	E=In a good condition	

8 ENERGY SOURCE

8.1 Electricity supply

A=Full grid	B=Low current	C=No electricity supply			

8.2 How is the remains of alternative energy sources (e.g.fossil fuel sources, coals etc.) disposed?

A=Drain	B=Toilet	C= Dumped	D= River	E=Channels	