An enhanced microbial water quality monitoring design using a novel area prioritization approach to site selection

by

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SUMMARY

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The Department of Water Affairs and Forestry (DWAF) is the custodian of South Africa's water resources and its primary role is to maintain the fitness for use of water on a sustained basis. DWAF recognized that management and assessment of fitness for use can only be based on reliable monitoring data. For this purpose DWAF has already for a number of years operated a national programme which collects data on the chemical and physical quality of South Africa's water resources.

The microbial quality of surface water is of growing concern in a number of areas in South Africa. Water of poor microbial quality has serious implications for domestic, recreational and agricultural use due to the risk of water-borne diseases. DWAF acknowledged the need for information on the microbial quality of South Africa's water resources to assess and manage the

potential health risk to water users. As an initial step the development of a national microbial monitoring programme to assess the faecal pollution of surface waters was initiated. This study describes the development of the conceptual design of such a programme and demonstrates how a novel area prioritization procedure enhanced the design.

The focus of the programme was to be areas where human health might be severely impacted by the microbial quality of surface water. To identify such areas, a procedure for the identification and prioritization of specific areas of concern was developed and used as part of the design approach. Two factors were identified for the quantification of the potential health risk. They were the threat of microbial pollution of water (the result of land use) and the exposure of consumers to the water (sensitivity of water uses). A number of land and water uses information sources therefore served as the basis for determining priority among the different areas.

The described approach to identify and prioritize specific areas of concern has a number of benefits. Primarily, the approach assists in focusing the monitoring efforts on problem areas without a need for extensive historical microbial water quality data. The approach could be used to optimize the spatial distribution of sampling stations and assist in determining their national distribution. The approach also allows for phased implementation of the programme which facilitates the development of skills and capacity, as well as required infrastructure needed for the large scale operation of the programme. The approach to focus on impacted areas is generic enough not to be restricted to the design of microbial water quality monitoring systems. Other monitoring objectives could also be dealt with in the same manner.

During evaluation of the design on a pilot scale the conceptual design was found to meet the set information objectives. The conceptual design for the programme also deals effectively with constraints and changes in the external environment in which it has to operate. Implementation of the national programme has started and plans to expand the programme are progressing well. The concept of high risk areas and the procedure to identify and prioritize such areas as developed during this study is a critical component of the overall design. The programme appears to address a significant information need on an important aspect of water resources management and to do so in an efficient and effective manner.

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DECLARATION

I declare that the thesis, which I hereby submit for the degree Philosophiae Doctor at the University of Pretoria has not previously been submitted by me for a degree at another university.

SNVenter.

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30/10/2001

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LIST OF ABBREVIATIONS

ADB	Assessment Data Base
BOD	biological oxygen demand
cfu	colony forming unit
CMA	catchment management agency
DWAF	Department of Water Affairs and Forestry
EMAP	Environmental Monitoring and Assessment Programme
GEMS	Global Environmental Monitoring Systems
HIS-QDB	Hydrological Information System - Quality Databank
ITMF	Intergovernmental Task Force on Monitoring Water Quality
IWQS	Institute for Water Quality Studies
LUV	land use value
MAIS	Monitoring and Information Strategy
MCDM	multi-criteria decision models
MPN	most probable number
NASQAN	National Stream Quality Accounting Network
NAWQA	National Water Quality Assessment Programme
NMP	National Monitoring Programme
NWQMC	National Water Quality Monitoring Council
PHRI	potential health risk index
PV	priority value
RDP	Reconstruction and Development Programme
SOP	standard operating procedure
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WHO	World Health Organization
WMS	Water Management Systems
WUV	water use value

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The Water Act of 1956, Act 54 of 1956 (Union of South Africa, 1956) named the Department of Water Affairs and Forestry (DWAF) as the custodian of South Africa's water resources and specified its primary role to be that of maintaining the fitness for use of water on a sustained basis. The fitness of use concept implies the evaluation of the water quality in terms of specific user requirements. This can however, only be done effectively when based on reliable data sets. The need for water quality monitoring systems to assess the quality of rivers, reservoirs, wetlands, estuaries and ground water has therefore been expressed on a number of occasions (Department of Water Affairs and Forestry, 1986; Department of Water Affairs and Forestry, 1991).

In terms of surface water quality a number of persistent problems have been identified. These include salination, suspended matter (sediments), eutrophication, micropollutants (mainly pesticides) as well as microbial pollutants. By 1990 DWAF already had a national programme operational for a number of years which collected data on the chemical and physical quality of South Africa's water resources. It was, however, recognized that management and assessment of fitness for use could not be based on chemical and physical information alone (Department of Water Affairs and Forestry, 1991).

The microbial quality of surface water is of great concern in a number of areas in South Africa. Many communities lack appropriate sanitation infrastructure. The problem is not confined to rural areas, where it is roughly estimated that as many as 85% of the population does not have adequate sanitation services. Due to the inflow of people from rural areas and neighbouring countries large informal settlements have developed in and around the urban centres. It is estimated that as many as 31% of the urban population or 7.6 million people could be without appropriate sanitation services (National Sanitation Task Team, 1995). This has serious implications for the utilization of surface water for domestic, recreational and agricultural purposes as it poses a risk of contracting water-borne diseases (Verma and Srivastava, 1990).

This situation has led to the identification of the need to monitor the microbial water quality on a regular basis in a more structured way in order to assess and manage the potential health risk to water users.

1.2 NATIONAL MICROBIAL SURFACE WATER QUALITY MONITORING SYSTEM

In 1994 DWAF initiated the development of a national microbial monitoring programme to assess the faecal pollution of surface waters. The suggested aim of the microbial water quality monitoring programme was to assess the status and trends of faecal pollution as information on the extend of faecal pollution was needed for strategic planning and allocation of resources by the Department. The Department approached the CSIR (a contract research organization) to oversee the design of the national microbial monitoring programme to utilize the expertise within the organization to develop the conceptual design. During the course of the next two years (1994 - 1996) an agreement was reached on the design framework to be followed and the specific monitoring objectives to be achieved by the proposed programme. The agreement between DWAF and the CSIR served as the basis for the preparation of a conceptual design for the programme.

1.3 CONCEPTUAL DESIGN

The aim of the present study was to develop a novel sampling site selection procedure and to demonstrate how this procedure enhanced the design of a national microbial surface water quality monitoring programme. The research resulted in the completion of a conceptual design which served as the basis for the full scale implementation the microbial monitoring programme in South Africa. The principal requirement of the programme was that it should provide information necessary for the management of the potential health risk posed by surface water resources of poor microbial quality. The design also had to take local conditions and constraints, that might impact on the successful implementation of the programme, into account.

Chapter 2 sketches the broader context in which the reported research was performed. Problems associated with surface water quality, and with the microbial quality in particular are described.

Examples of how various countries have approached the monitoring and assessment water quality are also given. The chapter concludes with a short review of the recent developments in and approaches used for the design of water quality information systems and highlights among others the need for objective sampling sites selection procedures.

The following four chapters deal with the development of the actual conceptual design. In Chapter 3 the approach used for the design and implementation of the microbial programme is dealt with by presenting the design and implementation framework. Thereafter, specific attention is given to all activities which led to the development of the final conceptual design and the tasks that were performed are discussed in detail. In Chapter 4 a description of the proposed conceptual design is given and the development of the novel sampling site selection procedure is discussed in detail. This is followed by the last two actions of the conceptual design phase. In Chapter 5 the proposed procedure for the selection of sampling site is applied and evaluated in the context of the microbial monitoring programme. Chapter 6 discusses the results of a pilot study to test various parts of the conceptual design in practice.

Chapter 7 discusses the efficacy of the design to deal with implementation constraints as well as emerging issues. The chapter concludes with an assessment to determine the possible impact of the promulgation of the Water Services Act, Act 108 of 1997 (Republic of South Africa, 1997) and National Water Act, Act 36 of 1998 (Republic of South Africa, 1998) on the design. Finally the major conclusions of the reported study are presented in Chapter 8.

CHAPTER 2: LITERATURE OVERVIEW

2.1 WATER QUALITY

2.1.1 Background

The latter part of the 20th century has been characterized by a growing international awareness of the importance of adequate water of appropriate quality for sustainable development. The Mar del Plata Water conference in 1977 served as a major catalyst to create a greater international awareness of the growing crisis in the quality and management of water resources (Falkenmark, 1998). As part of this global awareness the United Nations (UN) declared the 1980s as the International Drinking Water Supply and Sanitation Decade. The UN International Conference on Water and the Environment in Dublin as well as the UN Conference on Environment and Development (Earth Summit) in Rio de Janeiro in 1992, again placed a strong emphasis on the sustainable management of water resources as articulated in Agenda 21 (Björklund and Kuylenstierna, 1998). Although these efforts have resulted in improved access to water for millions of people (World Health Organization, 1996) many problems still remain. In 1995, 20 % of the world population still lacked access to safe drinking water, nearly 50% lacked access to adequate sanitation and the World Health Organization estimates that 5 million people die each year from diseases caused by unsafe drinking water (Björklund and Kuylenstierna, 1998). The 20th century has therefore failed in providing access to water for all, one of the fundamental human rights implicitly and explicitly supported by international law and declarations (Gleick, 1998).

To address the urgent water issues of the 21st century, the second World Water Forum was held in The Hague in March 2000 to discuss an international *Framework for Action*. The issues addressed included among others, greater participation of water users, the extention of sanitation coverage and restoration of surface and ground water quality (HRH The Prince of Orange and Rijsberman, 2000). Although action to address these issues need to be taken at a national and local level, international co-operation is often essential for the successful implementation of these strategies through the establishment of partnerships to enhance the exchange of information, expertise and resources.

Reliable data is, however, essential for the development of appropriate policies and action plans. One of the major conclusions of the UN Commission for Sustainable Development's Comprehensive Freshwater Assessment was that access to reliable data was inadequate and thus inhibits the development of appropriate water resource management policies. The report described the situation in the developing world and particularly in Africa as serious. It was also noted that even developed countries have reduced their integrated monitoring efforts mostly due to budgetary constraints. It was suggested that governments will need to assign higher priority to this issue in order to create greater capacity for integrated water management (Björklund and Kuylenstierna, 1998).

2.1 2 Surface water

Access to safe water remains a serious problem in the world, especially in developing countries, and leads to serious impacts on the population's health and economic productivity. For many countries surface waters are the major water resource. In South Africa surface water supplies about 85% of the total water consumption (Department of Water Affairs and Forestry, 1991). Surface water resources are very vulnerable to external impacts and a number of water quality problems are experienced globally. Poor water quality is often due to rapid industrialization, urbanization and population growth, but could also be compounded by growing water scarcity in certain regions. Water quality problems include among others acidification, eutrophication, toxicity due to micropollutants and deterioration of the ecosystem (Ongley, 1998). Apart from the abovementioned issues, many developing countries also have to cope with serious microbiological pollution. Due to the lack of proper sanitation systems the most widespread contamination source of surface water in developing areas, continues to be human wastes (Ford and Colwell, 1995, Chapman, 1996). Poor microbial water quality has serious consequences for communities who have to rely on surface water for drinking, irrigation and recreation.

2.1.3 Microbial water quality

2.1.3.1 Water associated diseases

According to Bradley (1977) infective diseases associated with water can be classified into five categories viz. water-borne, water-washed and water-based infections as well as infections with water-related insect vectors and diseases of defective sanitation.

Water-borne diseases are those diseases where the pathogenic organisms are carried passively in the water supplies. The organisms are usually highly infective and therefore only a few organisms are needed to initiated the infection. Avoiding contamination of the water as well as treating the water to improve the quality can minimize the risk to humans. The most important diseases in this category are typhoid, cholera, infective hepatitis and giardiasis.

Water-washed diseases are described as the diseases mainly spread by means of personal contact, water or food in situations where there is a lack of water for washing or personal hygiene. Due to the rapid changes of the demographics in South Africa resulting in the development of informal settlements with poor provision for water and sanitation, a higher incidence of water-washed diseases can be expected. Diseases such as skin and eye infections as well as diarrhoeal diseases are included among the water-washed diseases. Only improving the quality of the water will not minimize water-washed diseases. Improving the availability, access to and quantity of water for domestic use usually provide far better results.

The water-based diseases include all the worm infections which are not spread passively from person to person in the water e.g. bilharzia. Several of the waster-based diseases depend on aquatic snails for transmission. The diseases such as malaria and sleeping sickness are spread by insects that breed in water, or that are closely associated with water and are grouped as having water-related insect vectors. Managing the microbial water quality does not have any effect on the spread of water-based diseases and they were therefore not considered when the impact of land use on water quality and human health were determined.

It is impossible to separate the water-borne and some of the water-washed diseases from those affected by poor sanitation as the spread of many of the diseases affected by poor sanitation depends initially on faecal contamination of the water. There are however, a few infections where providing appropriate sanitation is more important to limit the disease than improving the quality of the water supplied for domestic use, e.g ascariasis (Bradley, 1977).

In terms of surface water quality, water-borne diseases are of the greatest concern (Grabow, 1996). Apart from the bacteria and viruses normally linked to water-borne transmission such as *Vibrio cholerae* (Craun *et al.*, 1991), *Salmonella* (Kramer *et al.*, 1996) , Rotavirus and the entroviruses (Williams and Akin, 1986), there have been an increased number of reports of waterborne transmission of emerging pathogens (Centers for Disease Control and Prevention, 1994). Included among the emerging pathogens are bacteria such as *E. coli* 0157:H7 (Feng, 1995) and *Helicobacter pylori*. Protozoan parasites such as Cryptosporidium and the microsporidia have also been implicated (Franzen and Müller, 1999).

2.1.3.2 Microbial pollution sources

Point, as well as non-point pollution sources, contribute to the microbial contamination of surface waters. The contribution of each of these type of sources is dependant on the land uses practice within the specific catchment. The major point sources contributing to microbial pollution are municipal and industrial effluents containing inadequately treated sewage. A wide range of sources could contribute to non-point source pollution. Included among them are storm water, sewer overflows, runoff from urban, sub-urban and agricultural land recreational activities (Faust *et al.*, 1977; Venter et al, 1997; United States Environmental Protection Agency, 2000a).

In South Africa the use of land in a catchment for housing and agriculture are known to have an impact on the microbial quality of the surface water in the catchment. The lack of adequate sanitation has severely impacted water quality and the supply of sanitation services to all communities remains one of the main concerns of the South African government (National Sanitation Task Team, 1995, Department of Water Affairs and Forestry, 1999). Informal settlements, often associated with no or limited sanitation services, typically develop in close proximity to rivers and direct faecal contamination of surface water takes place. Problems have also been associated with existing sanitation infrastructure. A study was performed in a peri-urban area in Gauteng, between 1991 and 1993 to determine the effect of various land uses on the microbial surface water quality (Venter *et al.*,1996). The main contribution to the poor microbial quality of the river, as measured in terms of the faecal coliform group, was associated with a single tributary draining a formal and adjacent informal settlement. The poor quality was largely due to the lack of appropriate sanitation services. A number of waste water treatment plants also made a substantial contribution to the microbial pollution as they had difficulty in meeting the "relaxed" effluent standard of a maximum of 1000 faecal coliforms / 100 ml. High microbial levels in the effluent from treatment works is often the result of overloading, staff and operational problems, poor maintenance or financial constraints (Venter *et al.*, 1997).

Faecal pollution of rivers, due to surface runoff, is also a major problem in many areas in South Africa. As already mentioned, the lack of sanitation is often the major contributor, but other factors could also be of importance. In many areas, inadequate or poorly operated sanitation systems regularly result in blocked sewer lines which contribute to non-point source faecal pollution. In some areas the bucket system (collection of faecal material in buckets for central disposal) is still in operation and pollution due to spillages and handling is a common occurrence.

Livestock farming can also lead to the contamination of runoff. In a study on the contribution of non-point sources towards the microbial quality of surface water in a rural area in the Rhode River catchment in the USA, an estimated 68% of the faecal coliforms discharged into the river was associated with pastures, which only occupied a small fraction (22%) of the total area investigated (Faust *et al.*, 1977). Other investigators have also found an appreciable risk of feacal pollution of surface water even in areas without large numbers of livestock (Brenner and Mondok,1995).

During the study performed in a peri-urban area in Gauteng, the effect of large industries and mining activities on the microbial quality of the surface water was lower than the effect of no or poor sanitation. Although the contribution of industrial sites to the level of faecal coliforms in the river was larger than that of the mining activities, the mean faecal coliform value for effluent from the industrial site was only five times higher than the mean value measured at the point where the effect of the mining activity could be measured. The mean faecal coliform values measured at the various wastewater treatment works and areas draining informal settlements were at least ten to a hundred times higher than the mean value of the industrial site's effluent (Venter *et al*, 1996).

2.1.3.3 Impact on water use

Estimates are that water-borne diseases are the cause of between 3 and 5 million deaths and 900 million episodes of illness each year (World Bank, 1992). The greatest impact of water of poor microbial quality is on children, the elderly and those with compromised immune systems as they are more likely to suffer from waterborne diseases. The largest recorded water-borne outbreak occurred in Milwaukee, USA in 1993 and was caused by *Cryptosporidium*. It was reported that about 403000 people were affected and the cost to the community was estimated to be well over \$55 million (MacKenzie *et al*, 1994). Human exposure to water-borne diseases could associated with a number of water use activities and contaminated surface water plays an important role.

In South Africa it is estimated that only 70% of the population had water supply services by the end of 1994 (WHO, 1996). The policy of the government (African National Congress, 1994) is to ensure that all South Africans should have access to basic water supply services and increased investment in this area has improved the situation. There are, however, still areas where people are using untreated surface water for domestic purposes due to the lack of reliable water supply infrastructure (DWAF, 1999). Some households may also use surface water as an alternative source, due to the fact that surface water may be more convenient to access.

Some communities are supplied with surface water after partial treatment. In many instances disinfection is absent, neither properly controlled nor followed by filtration necessary for the removal of pathogens such as protozoan parasites. The water may therefore still pose a health risk to members of the community, especially small children, the elderly or the sick.

Apart from the use of surface water for normal full and partial contact recreation, many people are also exposed to surface water through other activities such as laundering. Another possible exposure to contaminated surface water could be through the irrigation of crops that will be consumed raw. A number of cases exist where a water-borne disease such as cholera has been contracted when contaminate primarily d fresh vegetables were consumed (Mosley and Khan, 1979).

2.1.3.4 Conclusions

In the past, the focus of water quality monitoring programmes has been on chemical risks with little attention being paid to microbial pollutants (Le Foll *et al.*, 1977; Department of Water Affairs, 1986; Thorpe, 1987; Leahy *et al.*, 1993). There is, however, a realization that a greater focus on the assessment of the microbial quality of surface water is needed in order to ensure effective management and control of microbial water quality problems on a catchment basis (Sobsey *et al.*, 1993; Chapman, 1996; Grabow 1996).

2.1.4 Microbial variables for water quality monitoring

2.1.4.1 Indicator organisms

Routine monitoring of surface water for the possible presence of all water associated pathogens is impractical due to the complex and time consuming nature of the available detection methods and the wide range and diversity of organisms. The low number of pathogens relative to the microbiological population as well as inadequate and expensive methods also limit the detection of pathogens. For a general indication of microbial quality the water is tested for the presence of indicator organisms. For an organism to serve as a reliable indicator of pathogenic organisms it should have the following characteristics (Olivieri, 1982; World Health Organization, 1984):

- it should always be present when the pathogen is present in the water and should be absent from unpolluted water;
- it should be present in numbers that show correlation with the degree of pollution;
- it should be present in numbers greater than that of the pathogens it indicates;
- its should respond to natural environmental conditions in a similar manner to the pathogens;
- it should be readily detected by simple and accurate methods;
- it should not be pathogenic to humans or animals.

None of the available indicator organisms comply with the above criteria under all conditions and most indicators used represent some compromise of these properties. The most commonly used indicator organisms for monitoring of surface water quality are discussed below.

Total coliforms

The total coliform group is characterised by an ability to ferment lactose at 37 °C and includes *Escherichia, Citrobacter, Enterobacter* and *Klebsiella* species. The total coliform group gives an indication of the general sanitary quality of the water since some of the bacteria are of faecal origin. Many of the bacteria may, however, occur naturally in aquatic environments and some are even able to grow in water with a low temperature and low organic content (Toranoz, 1991).

Faecal coliform group / E. coli

The faecal coliform or thermotolerant coliform group and more specific *E. coli*, is the most common bacterial indicators of faecal pollution. No clear distinction can, however, be made between pollution originated from humans or animals. This does not render this group unsuitable as some pathogens cause diseases of both humans and animals. The faecal coliform group is characterised by their ability to ferment lactose at 44.5 °C and represents the genus *Escherichia* and to a lesser extend some *Enterobacter, Citrobacter* and *Klebsiella* strains. *E. coli* is the best indicator of faecal origin since it is present in the faeces of man, animals, and birds in large numbers and is rarely found in natural habitats not polluted by faecal material. The behaviour of faecal coliforms / *E. coli* in the aquatic environment is similar to that of other enteric bacterial pathogens. Due to differences in survival patterns, faecal coliform bacteria are however not always suitable as indicators for the presence of viruses and protozoan parasites (Olivieri, 1982, World Health Organization, 1984).

Faecal streptococci

The occurrence of faecal streptococci in water serves as a general indication that faecal contamination of the water took place. However, not all of the bacteria in this group are of faecal origin, those that are predominantly of faecal origin were reclassified as the enterococci. The faecal streptococci occur in human and animal faeces, but are considerably less numerous than the total or faecal coliform group. Faecal streptococci are however more resistant to environmental stress than coliform bacteria. The faecal streptococci are often used to supply supplementary data when used in conjunction with information on the faecal coliform group (Olivieri, 1982, World Health Organization, 1984).

Faecal coliform - Faecal streptococci ratio

Some researchers suggested the use of the ratio of faecal coliforms to faecal streptococci for locating the source of faecal pollution, since it was found that faecal streptococci were present in greater numbers in the faeces of animals than in the faeces of humans. A faecal coliforms to faecal streptococci ratio of greater than 3:1 is usually associated with human pollution, whereas a ratio of smaller than 0.7:1 is indicative of contamination by animals. The range of ratios between these two values is very difficult to interpret. This ratio should only be used when the source of recent pollution is investigated, due to the fact that faecal coliforms and faecal streptococci have different die off rates. It is not recommended to use this ratio for the management of surface water quality (Olivieri, 1982, World Health Organization, 1984).

Clostridia

Clostridia are anaerobic spore forming bacteria which occur in the faeces of humans and animals. This group includes *C. perfringens* which is mainly of faecal origin, but other clostridia which could be of non-faecal origin are also included. Due to the high resistance of spores to environmental stress, clostridia have been used as an indicator for the detection of remote sources of pollution. They however, tend to accumulate in the environment eg. in sediments and quantitative data can be difficult to interpret (Sorensen *et al.*, 1989; Toranzos, 1991).

Heterotrophic plate counts

Heterotrophic plate counts are performed to monitor the general microbiological quality of the water but are of little value for the study of faecal pollution, as many of the bacteria may be natural inhabitants of surface water. They may however, give some indication of the ability of the water to support microbial growth (World Health Organization, 1984).

Coliphages

The faecal coliform group is not always a reliable indicator for viruses in water because the conditions under which they occur and their survival in water may differ from that of bacteria. In addition, their minimum infectious dose is much lower compared to that of bacterial pathogens. Coliphages are bacterial viruses which use *Escherichia coli* as host organism. They were proposed as an indicator for viruses, especially the enteric viruses, since they have similar survival patterns in water. Coliphages are present in high numbers in the faeces of humans and animals and may serve as an indicator for faecal pollution. One of the difficulties of using coliphages however, is that a clear correlation between the number of coliphages and enteric viruses has not been established and enteric viruses are sometimes isolated from water without detecting any coliphages (Goyal, 1983). Nevertheless, simple and rapid methods exist for the detection of coliphages and therefore they are still widely used in water quality monitoring studies (Goyal,1983; Grabow, 1986; Borrego, 1987; Hernandez-Delgado *et al.*, 1991; IAWPRC Study Group on Health Related Water Microbiology, 1991).

Other indicators

Bifidobacterium, Pseudomonas aeruginosa, Klebsiella and some *Vibrio* species were proposed as alternative bacterial indicators and various bacterial phages other than coliphages were proposed as viral indicators. At present their application is very limited and they are seldom used for the monitoring of surface water quality (Olivieri, 1982; Grabow, 1986; IAWPRC Study Group on Health Related Water Microbiology, 1991).

2.1.4.2 Pathogens

The presence of a number of important pathogen groups cannot be demonstrated by the use of current indicator organisms and they are therefore included in some water quality monitoring programmes.

Enteric viruses

Low levels of enteric viruses need to be detected in water because their infectious dose is low. As poor correlation between numbers of coliphages and enteric viruses was found and since the inability of the coliphages to indicate the presence of enteric viruses under all circumstances was documented, direct detection of viruses is performed in some of the monitoring studies (Goyal, 1983). The methods for the detection of viruses are however, labourious, time consuming and expensive and require an appropriately equipped laboratory.

Protozoan parasites

The presence of protozoan parasite cysts (*Giardia*) and oocysts (*Cryptosporidium*) in water poorly correlates with any of the bacterial and / or viral indicators used for the monitoring of water quality and therefore only direct monitoring of the cysts or oocysts could give an indication of their presence. They are very important water-borne, human pathogens and the presence of *Giardia* cysts in water has been implicated in a number of water-borne disease outbreaks (Erlandsen and Bemrick, 1988). Both cysts and oocysts have a very low infective dose and are very resistant to environmental stress and chlorine disinfection. Studies have indicated that animals can serve as a reservoir for these organisms (Regli *et al.*, 1988; Fayer *et al.*, 2000; Slifko *et al.*, 2000). The monitoring of protozoan parasite cysts and oocysts is however, complicated and methods for the concentration and detection of the parasites are still to be fully standardized.

2.2 WATER QUALITY ASSESSMENT PROGRAMMES

2.2.1 Background

The design of water quality monitoring systems is not well documented in the scientific literature. When documented, the information is often contained in specific project reports, that are not widely distributed outside the organizations involved. Information on the approach followed, the monitoring network and data assessment procedures often have to be inferred from instruction manuals or reports containing the final assessment of the data. In some cases, where the design was well documented, it remains difficult to verify whether the programme was implemented and / or still being used without major alterations. Providing a comprehensive overview of national monitoring programmes dealing with surface water quality is impossible. Section 2.2 will therefore rather focus on a few relevant national and international monitoring programmes. An effort will also be made to highlight specific problems or novel approaches that were used.

2.2.2 International programmes

The Global Environmental Monitoring Systems project on freshwater quality (GEMS/ Water) is a joint UN Environment Programme (UNEP) and World Health Organization (WHO) programme. Initiated in 1974 it was the first programme of its kind to address global issues of water quality through a network of monitoring stations in rivers, lakes, reservoirs and aquifers on all continents. The program has contributed to the establishment and expansion of national water quality monitoring systems in 66 countries. Technical cooperation with developing countries to build capacity and to increase the reliability, relevance and cost-effectiveness of the data is one of the main focuses of the programme (United Nations Environment Programme, GEMS/WATER, 2001). Although the collection of chemical data is most common, the total and/ or faecal coliform groups are measured at some of the sampling stations (Chapman, 1996).

One of the outputs of the GEMS/WATER project was an Atlas of Global Water Quality which presented information and findings for 82 of the major watersheds for the period 1976 - 1990. One of the conclusions was that most of the GEMS stations experienced microbial contamination. At these stations faecal coliform counts ranged between 1000 and 10 000/100 ml and occasional peaked at values exceeding 100 000/100 ml. Variance in values between various countries were observed and this could possibly be ascribed to methodological and reporting differences (United Nations Environment Programme, GEMS/WATER, 2001).

2.2.3 United States of America

2.2.3.1 Overview

The United States of America (USA) water quality monitoring programmes operated at a national or state level are examples of the best documented programmes in the world. The water quality monitoring programmes are operated for a number of purposes and the information generated is ultimately used to address issues such as human health protection, preservation and restoration of the ecology and sustainable economic development. A number of federal, state, regional and local agencies are involved in the monitoring of water resources (United States Geological Survey, 1995a).

At a national and interstate level the most important agencies involved in freshwater water quality monitoring are the United States Environmental Protection Agency (USEPA) and the United States Geological Survey (USGS). Some of the other federal agencies involved deal with specific issues such as biomonitoring, wetlands or the quality of oceanic resources (United States Environmental Protection Agency, 2000a).

Section 305(b) of the American Clean Water Act requires states and other jurisdictions to submit biennial water quality reports to the USEPA. The USEPA has the duty to summarize the water quality data and compile a national inventory to be table before the US Congress. A variety of resources such as fresh surface waters, ground water and coastal water are dealt with in the report. Section 305(b) reporting is the main process by which the maintenance and improvement of water resource quality in the USA is assessed. Information collected under Section 305(b) is also used to identify current problems and to prepare a list of impaired water under Section 303 (d) of the Clean Water Act (United States Environmental Protection Agency, 2000b). Information collected under Section 305(b) could also serve as a basis for the development of source water assessment and protection programmes provided for under the 1996 amendment of the Safe Drinking Water Act (United States Environmental Protection Agency, 2000a).

Apart from the National Water Quality Inventory the USEPA oversees among others, the Section 319 National monitoring program (NMP) which deals with issues concerning non-point source pollution and control thereof (Lombardo *et al.*, 2000). The USEPA also conducts its own national monitoring programme to provide status and trend information for a statistically selected group of waters representing a variety of ecosystems as part of the Environmental Monitoring and Assessment Programme (EMAP) (United States Environmental Protection Agency, 2000a)

The USGS conducts extensive chemical monitoring through its National Stream Quality Accounting Network (NASQAN) at fixed stations covering the major rivers in the United States. The National Water Quality Assessment Programme (NAWQA) also operated by the USGS uses a different approach in terms of temporal and spatial coverage to study the status and trends in the quality of water, sediments and biota (United States Geological Survey, 2001).

2.2.3.2 National Water Quality Inventory (305(b) monitoring)

Background

The National Water Quality Inventory (305(b) monitoring) is probably the most extensive water quality assessment worldwide. In order to perform the assessment required by the United States Clean Water Act of 1972 states have to perform a number of tasks. One of the initial tasks is to assign designated water uses to the water sources under their jurisdiction. The most commonly used categories are swimming, the protection of the aquatic ecosystem and in some cases the supply of drinking water after conventional treatment. This should be followed by the development of suitable water quality standards to measure the level of impairment or support. After setting standards states have to assess the degree to which these standards are met and report that to the USEPA on a biannual basis. Finally states should develop a antidegradation policy intended to prevent water from deteriorating from their current condition. The latest report to congress was on the data reported in 1998 (United States Environmental Protection Agency, 2000a).

Data sources

Although reporting and assessment procedures are well regulated, the initial data sources are quite varied. The programme allows for the use of monitoring and evaluated data during assessments. The monitoring data represents site-specific ambient data collected during the last

5 years. In general such data come from diverse monitoring programmes run by state or local agencies. States could also use data generated by the programmes operated by federal agencies such as EMAP, NAWQA and NASQAN. Evaluated data include information on land use activities, the location of pollution sources, questionnaires and estimates from predictive modeling. Monitoring data older than five years could also be included (United States Environmental Protection Agency, 1997a; United States Environmental Protection Agency, 1997b).

Coverage

One of the main challenges of the programme is to improve comprehensive coverage. During the last assessment in 1998 only 23% of the streams and rivers and 42% of the lakes, ponds and reservoirs have been assessed (United States Environmental Protection Agency, 2000a). Achieving the goal of representative comprehensive spatial coverage will require a combination of monitoring approaches as well as the collection of data from a variety of sources including volunteer monitoring (United States Environmental Protection Agency, 1997b).

One of the major problem with the use of data collected from various agencies is that the selection of sampling sites are determined with a specific purpose in mind and the sites may not be representative of the overall conditions of the water source. One of the proposed approaches to improve the representativeness of sites is the probability-based selection of sites from different classes of waterbodies. This approach requires considerable effort in grouping the water sources according to different classes but the end result could be cost-effective. Sites are finally selected from each of the classes at random. Another approach followed by nearly half of the states is a rotating basin approach. Under this approach a different subset of catchments are intensively monitored each year (United States Environmental Protection Agency, 1997b).

Data storage

Many of the state environmental agencies, the USEPA and other federal agencies use the STORET data base to store and manage water quality and biological monitoring data (Saito *et al.*, 1994). This data base has been improved to allow access via the internet. The Assessment data base (ADB) records surface water assessments and assists in the preparation of the 305 (b) reports. Plans are in place to link the ADB with STORET (United States Environmental Protection Agency, 2000a).

Overall assessment

Assessment is always performed according to the designated water uses linked to a specific water sources. Using the set standards the degree of support for the designated water uses are determined based on monitoring or evaluated data. If the source has been found to be impaired, the causes and possible sources of impairment also have to be specified according to the categories provided by the USEPA.

Microbial assessment

In terms of the microbial quality of the water the assessment could be based on a variety of monitoring data. The USEPA makes provision for data such as water column survey where *E.coli* or the faecal coliform group are the predominant variables determined, shellfish surveys, sediment analyses or community water supply scheme where both the ambient and final treated water are monitored.

The assessment for the microbial quality of water should be based on the criteria for the various uses as determined by the various states. Although each state could adopt their own criteria, the USEPA has encouraged the states to adopt standards consistent with their recommendations. The water use mostly affected by poor microbial quality is recreational use and depending on the indicator organism used either the 1976 or 1986 recommendations will apply (United States Environmental Protection Agency, 1976; United States Environmental Protection Agency, 1986).

Reporting

Apart from the assessments performed under Section 305 (b) of the act, states also have to provide a list of all their impaired waters as required by Section 303 (d). At present the USEPA is developing a consolidated 305 (b) / 303 (d) assessment approach that would consolidate and improve the reporting requirements. The proposed Consolidated Assessment and Listing Methodology (CALM) should also result in improved decision making on impaired waters and better communication of water quality assessments to the public (United States Environmental Protection Agency, 2001).

2.2.3.3 National Water-Quality Assessment Program

NAWQA is designed to assess water quality conditions in representative river basins and aquifers in the USA. The programme tries to describe and explain the relationships between certain water quality conditions and specific natural factors or human activities. Using this information, the factors that most affect the quality of water resources in different parts of the USA are to be determined (United States Geological Survey, 2001).

The temporal and spatial coverage of the NAWQA programme is quite unique. The programme focuses on 59 of the most important river basins and aquifers which cover the sources of drinking water used by 70% of the American population. A similar design and the use of standardized methods allow for comparison among the study units. To improve the cost effectiveness and management of the programme, monitoring is conducted on a rotational rather than continuous basis. Only one third of the study units are subjected to a 3 - 5 year period of intensive monitoring at any given time. The alternate units are subjected to a period of less intensive monitoring which lasts between 5 - 6 years (Stamer *et al.*, 1987).

The faecal coliform group was among the variables proposed for inclusions during the design of the project (McKenzie and Rinella, 1987) but the programme has developed a focus on chemical quality. Apart from the reports dealing with specific study units the data are also reported as national synthesis assessments which only focus on specific water quality issues. Due to environmental and public health concerns, nutrients, volatile organic compounds, trace elements and pesticides were selected for the initial national reporting (United States Geological Survey, 2001).

2.2.3.4 National Water Quality Monitoring Council

In 1992 the Intergovernmental Task Force on Monitoring Water Quality (ITFM) was formed to review and evaluate water quality monitoring efforts across the USA and to make proposals for the possible improvement and coordination of these efforts. In its final report the ITFM came up with a strategy and recommendations on how to integrate monitoring activities in order to meet the full range of needs more effectively and economically (United States Geological Survey, 1995b). These recommendation led to the formation of the National Water Quality Monitoring Council (NWQMC) in 1997 (National Water Quality Monitoring Council, 1998).

The NWQMC consists of representatives of federal, state, tribal and local governments as well as watershed groups and the private sector which will include volunteer monitoring groups. The council will make use of focus and working groups to address issues such as water information strategies,data management and comparison, institutional collaboration as well as public awareness. The council will provide technical support and made recommendations to improve water quality monitoring in the USA. Implementation of these recommendation will however, be on a voluntary basis (National Water Quality Monitoring Council, 1998).

2.2.4 Europe

2.2.4.1 European Community

Until December 2000 monitoring of surface water quality in European community countries has been influenced by three directives i.e. 75/440/EEC, 76/160/EEC and 79/869/EEC and the information collection decision 79/869/EEC. Most of these directives and decision are now replaced by the Water Framework Directive 2000/60/EC but this new directive has not yet been implemented (European Communities, 1999).

Directive 76/160/EEC dealt with recreational waters whereas the purpose of 75/440/EEC was to ensure that surface water abstracted for use of drinking water should be of a certain standard and that it is given adequate treatment before being used for public supply. The 79/869/EEC directive supplemented the 75/440/EEC directive by recommending methods of measuring different surface water parameters and setting the frequencies for such measurements. Surface waters were classified into four water quality groups according to the values of 46 variables including temperature, lead, BOD and the faecal coliform group (Haigh, 1990).

The decision 79/869/EEC and its amendments established a system for the exchange of information on the quality of rivers and watercourses in the European Community. According to this decision, member states had to provide the Commission with water quality data on an annual basis. The stations for which data had to be supplied were representative of the major rivers in member countries (Haigh, 1990).

The overall goal of the new Water Framework as expressed in article 4 is to achieve good water status and countries have to put the necessary systems in place to protect, enhance and restore all water bodies of surface and ground water. The previous emphasis on water quality monitoring and enforcement of standards will be replaced by a system of quality management and health protection. The framework also emphasizes that land and water management cannot be treated in isolation and that the most appropriate spatial scale for management will be the catchment (Ferrier *et al.*, 2001). As part of the framework, the development of management plans for all river basins are required. The development of these plans should encourage the participation of all interested parties and it is hoped that this will get citizens more closely involved (McCann, 2001).

2.2.4.2 United Kingdom

The water quality in about 40 000 km of rivers and canals in England, Wales and Scotland are measured routinely. This programme was started in 1974 and was previously known as the Harmonised Monitoring scheme (Price, 1975; Thorpe, 1987) The programme is presently under the control of the Environment Agency (Ferrier et al., 2001). The data collected are used to classify the water quality according to the General Quality Assessment scheme which consists of a chemical and biological grading system. The chemical grading is based on BOD, dissolved oxygen and ammonia levels and the biological grading on the number and diversity of macro-invertebrates. Both grading systems were used for the 1996 River Quality Survey. Microbial quality is not used in the grading scheme and since it is only foreseen that aesthetics and nutrients would be included in future microbial quality will not be addressed at a national level (Department of Environment, Transport and the Regions, 2000).

2.2.5 Asia and the Pacific countries

Apart from New Zealand and Australia, with a strong emphasis on managing natural resources for sustainable development, little information is available on water quality monitoring in this region. Many of the countries in this region could be considered as developing nations and will be dealt with in the next section.

2.2.5.1 New Zealand

Most of the information collected on the water quality of surface waters in New Zealand is collected by unitary authorities and regional councils involved with water supply and disposal. The data are primarily collected for local use and a variety of parameters and monitoring regimes are used. This makes it difficult to provide a national picture of surface water quality. Better standardization and integration of these systems are foreseen and will enhance national state of the environment reports (Ministry for the Environment, 1997).

Not all the monitoring is conducted at a local level. The National Water Quality Network for New Zealand began operation in 1989 and is at present under the control of the National Institute of Water and Atmospheric Research. The design was well documented and was based on the information requirements of government to determine trends and status. Sampling sites are divided between baseline and impacted sites. Baseline sites are considered to be those where little impact of pollution sources has been noticed. The impacted sites on the other hand are downstream of the impact of agriculture, industries and the urban environment. It was foreseen that the continuance of the monitoring network should be reconsidered on a periodic basis but it was stressed that in order to detect meaningful trends the programme should be run for at least 5 years without any changes (Ward et al., 1990). At present a number of rivers streams and lakes are surveyed on a monthly basis.

No bacterial measurements were included in the national programme due to uncertainty of which indicator to use as well as logistical problems when dealing with such samples. The freshwater microbiological research programme has however been established in 1997 to address this issue. The presence and level of various pathogens as well as a number of indicator organisms will be measured in surface waters. This data should provide a scientific basis for the selection of the most appropriate parameters to be used for monitoring and guideline development (Ministry for the Environment, 1998).

2.2.5.2 Australia

Water availability and quality are at the centre of economic development and environmental management for Australia. Information on water quality therefore forms a major part of the assessment of Australia's water resources which forms part of the National Land and Water Resources Audit conducted by the National Heritage Trust. The data collection is not centrally controlled but relies on the supply of information by a number of commonwealth, regional or local agencies as well as research groups including those at universities. The existence of different sources of information places a constraint on the interpretation of the data to detect national trends. At present the audit only focuses on the key variables of turbidity, nutrients and salinity. Data on the microbial water quality are not collected on a national basis although microbial water quality is a cause of concern in certain areas (National Land and Water Resources Audit, 2001).

2.2.6 Developing countries

Water quality programmes in developing countries often suffer from traditional monitoring approaches. Water quality monitoring programmes are often fragmented between various government departments, collect the wrong type of information and the data collected are not assessed or evaluated. In most cases the data cannot be used for regulation and enforcement, to scope alternative management options or test policy options (Ongley, 1998). It was also found that many of the developing countries used inaccurate procedures in the search for simpler and cheaper methods (World Health Organization, 1985). The suggestion has been made that many of the national programmes should be redesigned in order to achieve cost-efficiency. According to Ongley (1998) water quality monitoring programmes should provide information for water resource planning and management and attention should also be given to social, institutional and legal components (Ongely, 1998).

2.2.7 South Africa

Previously most of the long term monitoring of South Africa's surface waters was conducted by DWAF. A number of chemical variables were determined but the microbial quality was not addressed. The samples have mainly been collected at irregular intervals at sites selected for flow recording. Although the database created contained valuable information the collected data were inadequate to effectively measure spatial and temporal water quality changes (Harris *et al.*,1992).

In 1992 the design for a national river water quality assessment programme was completed. The objective of the programme was to produce water quality data that could be used to determine fitness for use and changes in quality over time and space. The proposed variables were all indicators of broad classes of water quality problems and included turbidity, pH, dissolved oxygen, total suspended solids, chlorophyll *a* and *E. coli*. An index was suggested as an ideal way of presenting information on the suitability of the water for specific uses. The construction of an index which combine the abovementioned six variables was therefore proposed. The major uses to be addressed were domestic (after treatment), industrial, agricultural water supply and recreation. The proposed programme was not intended to meet all the management information requirements and separate monitoring systems were proposed to address regional issues and compliance monitoring (Harris *et al.*,1992). Due to a number of constraints the national river water quality assessment programme was never implemented.

The new National Water Act of 1998 requires the collection of data for the assessment of all aspects of South Africa's water resources. DWAF has initiated the development of the Monitoring and Information Strategy (MAIS) which will be responsible for the efficient exchange of knowledge to enhance water resource management. A major aspect of MAIS will be the management of water quality monitoring programmes addressing the efficient collection, storage and dissemination of data and the reporting of information. Attention will also be given to the development and coordination of monitoring effort at a national, provincial and local level. The MAIS will hopefully be implemented by 2004 (Harris and Howman, 2000).

2.3 MONITORING PROGRAMME DESIGN

2.3.1 Introduction

During the 1970s the importance of the supply of adequate water of appropriate quality for sustainable development was realized (Falkenmark, 1998). With the development of water quality management policies came the awareness that the existing water quality monitoring programmes were not providing reliable information necessary for effective water quality management (United States Environmental Protection Agency, 1977; Ward *et al.*, 1986; Ward *et al.*, 1990; Ward, 1996). Most programmes had no clear objectives or when provided, the objectives did not necessarily correspond with the requirements of the information users (Ward *et al.*, 1986). Many programmes also focused on the collection of water quality data without giving any attention to the stochastic nature of the data (Ward and Loftis, 1983) or converting the collected data into the required information.

2.3.2 Design framework

During the last two decades the development of new design approaches or frameworks for water quality monitoring systems were mainly driven by the need for reliable water quality information. Monitoring programmes are now being viewed as integrated systems consisting of a number of linked components. The design of any water quality monitoring programme should therefore be approached systematically and should be driven by the expectations of information users (Sanders *et al.*, 1983; Whitfield, 1988; Ward and Loftis, 1989; Ward *et al.*, 1990). A need for a statistical approach during the initial design and interpretation of the results has also been recognized (Ward and Loftis, 1983).

Previously the design of monitoring programmes have often just focused on the monitoring network and issues such as information requirements, data storage, data assessment and the dissemination of information received minimal attention. A more systematic design approach could also result in a more cost-effective programme (Ward and Loftis, 1986). A number of researchers have therefore produced comprehensive lists, approaches or frameworks which could serve as the basis for the design of a water quality monitoring programme.

Sanders *et al.* (1983) suggested a framework which is focused on the major tasks to be addressed during the design phase. The five steps entail:

a) Define information needs of management;
b) Define information that can be produced by monitoring;
c) Design monitoring network;
d) Document data collection procedures;
e) Document information generation and reporting procedures.

This framework has since been discussed and further elaborated upon on a number of occasions in the scientific literature (Ward *et al.*, 1986, Ward and Loftis, 1989; Ward *et al.*, 1990). Clear guidance is given on how each of these steps could be approached and possible methodologies to be used.

In the literature produced to primarily assist with the design of GEMS /WATER monitoring programmes Chapman (1996) and Bartram and Ballance (1996) suggested similar lists of the key elements of a monitoring or assessment programme. The focus of Bartram and Ballance was, however, more on the monitoring network whereas Chapman addressed broader issues related to assessment. According to Chapman the key elements are:

a) Objectives;
b) Preliminary surveys;
c) Monitoring design;
d) Field monitoring operations;
e) Hydrological monitoring;
f) Laboratory activities;
g) Data quality control;
h) Data storage treatment and reporting;
i) Data interpretation;
j) Water management recommendations.

Neither Chapman (1996) or Bartram and Ballance (1996) presented detailed guidance on how these tasks could be approached and what role statistics could play. On their part, they have stressed the use of preliminary short term surveys to determine technical issues related to the design as well as to test the financial feasibility of the complete programme. As in the case with Ward *et al.* (1990) the importance of specifying the purpose of the programme and setting the specific goals or objectives were stressed.

Most design approaches are optimized to produce a monitoring programme that deals effectively with one type of monitoring system eg. trend assessment, compliance monitoring or impact assessment. The design of programmes addressing multiple objectives of diverse nature are seldom attempted. Whitfield (1988) suggested that in order to cater for a broad range of information goals within one monitoring programme, each sampling point should be dealt with individually. Data collection strategies may therefore vary between sampling points depending on the information goals to be met at these sites .

2.3.3 Alternative strategies

Lloyd and Bartram (1991) suggested that the establishment of monitoring programmes in developing countries should be done by taking an incremental approach, beginning with pilot projects and moving to regional projects before national programmes are initiated. They further suggested that a diagnostic sanitary survey should be done to identify the potential sources of contamination and that water quality analysis should only be done thereafter in areas were there are indications of a possible health risk. The implementation of such a system for the microbiological testing of water would be an economical alternative in countries where funding is limited.

Ongley (1998) has suggested that some of the basic health related water quality monitoring should be decentralized to the local community level as they can respond far more rapidly to emerging problems than a centralized national agency. For this scenario the development of reliable field kits is of great importance.

2.3.4 Statistical approach

The use of various statistical approaches to decrease the uncertainty in the interpretation of water quality monitoring data has been well documented. Using basic statistical techniques, a number of procedures for the analysis of water quality data sets were proposed (Sanders *et al.*, 1983, Ward and Loftis, 1986, Harris *et al.*, 1987; Ward *et al.* 1988). The purpose of such an analysis is often to describe the status of water quality at a sampling point or for a specific water body (central tendency), to detect temporal changes in the quality (trend detection) and to detect outliers (exceeding of set standard or guideline values) (Ward and Loftis, 1986).

To determine the central tendency of a data set the arithmetic mean or geometric mean and confidence intervals or the median or mode and range could be determined. Apart from determining the central tendency of the data, the distribution of the data and any possible seasonal variations and serial correlations are also of importance. Some statistical tests assume that all observations are independent. The validity of the assumption of independence should be determined before selecting statistical test for further analysis of the data. Analyzing a historical data set in a similar way could assist the process of determining the most appropriate sampling frequency when designing a monitoring programme (Ward and Loftis, 1986).

A question that has raised considerable debate among the designers of monitoring programmes was how to best detect long term trends in water quality data sets. The major concerns during the selection of an appropriate statistical procedure are non-normal distribution and serial correlations often noticed for these variables. A number of researchers have proposed the use of non-parametric tests as the power of parametric procedures is low when applied to non-normal data (Sanders *et al,* 1983; Helsel, 1987). Tests such as the Wilcoxon test (Sanders *et al,* 1983), the seasonal Kendall test (Hirsch *et al.*, 1982) and modifications thereof (Hirsch and Slack, 1984), aligned rank methods (van Belle and Hughes, 1984) and the Mann-Kendall test (Harcum *et al.*, 1992) were proposed.

The statistical procedures for the analysis of data should be determined during the design of a monitoring programme and not after the programme has been in operation for a while and data have already been collected. The statistical methods selected should also match the information requirements of the programme and the people involved with data analysis should be familiar with the use of the proposed statistical techniques (Ward *et al.*, 1990).

2.3.5 Sampling site selection

The location of sampling sites is critical to the ability of any water quality monitoring programme in order to provide representative information and should be guided by the monitoring objectives (Sanders *et al.*, 1983; Bartram and Ballance, 1996). Of the three primary approaches to site location, viz. random, systematic or judgmental, the judgmental approach is the most widely used as it can easily be linked to the information objectives of the programme (Keith, 1990). In most cases the judgement for the selection of sites is based on historical data, preliminary field surveys or mathematical models as in the case of groundwater programmes (Sanders *et al.*, 1983; Ward *et al.*; 1990; Chapman1996).

Although most researchers provided general guidelines for site selection, procedures for the objective selection of both the macro and microlocation have received relatively little attention (Sanders *et al.*, 1983; Ward *et al.*; 1990; Chapman1996; Bartram and Ballance, 1996). Sanders *et al.* (1983) suggested the use of an index approach to quantify differences between catchments. The use of population numbers, industrial activities and agricultural use have been suggested for this index. Other approaches have been based on percentage areal coverage; population densities and stream networks (Sanders *et al.*, 1983) No procedure could be found for the objective selection of sites to specifically monitor the microbial quality of surface waters.

2.3.6 Conclusions

One of the major challenges to water quality monitoring at present is to improve the integration of water quality monitoring programmes to meet the full range of information required for the effective management of water resources. In order to meet the information requirements, the design of monitoring programmes should ensure the collection of accurate and representative data and allow for the generation of reliable information by selecting appropriate site selection, sampling, sample analysis, data storage and data analysis procedures. Only then would water quality monitoring play its rightful and intended in the protection of human health, preservation and restoration of the natural ecosystem and sustainment of a viable economy (United States Geological Survey, 1995b).

CHAPTER 3: METHODOLOGY AND RESEARCH APPROACH

3.1 INTRODUCTION

The Department of Water Affairs and Forestry acknowledged that the microbial quality of water resources is problematic and that data on the microbial quality of South Africa's water resources are required (Department of Water Affairs and Forestry, 1986; Department of Water Affairs and Forestry, 1991). To address this need, DWAF initiated the development of a national microbial monitoring programme in 1994. During the course of the next two years agreement was reached on the design and implementation framework for a national microbial monitoring programme. Terms of reference were established for the project of which the preparation and testing of a conceptual design, described in this chapter, formed an essential part.

During the discussions, the question soon arose whether the existing chemical surface water quality programme could be expanded to include microbial variables, as is the case in many countries, or whether a separate programme should be established. An important aspect that had to be taken into account was the fact that microbial variables demonstrate pronounced non-conservative behavior. Samples often taken at weirs or other convenient sampling locations as is often the case for the conservative chemical variables don't give a true reflection of the microbial quality at the point of use. The non-conservative behavior of microbial parameters also implies greater variability and a need for an increased sampling frequency compared to those presently used for the chemical monitoring programme. A separate monitoring programme would therefore be of benefit to cater for the unique temporal, spatial and logistic requirements associated with microbial water quality monitoring. The increasing importance of microbial water quality in South Africa, due in part to regular outbreaks of water-borne diseases, could certainly justify a separate national microbial water quality programme for the country.

Although information to assess the microbial quality of all water resources is needed, the design approach for a programme to monitor surface water would differ considerably from the approach to be followed for the design of a ground water monitoring programme. Surface water is more exposed to pollution sources and environmental influences resulting in greater variation in the microbial quality. Catchments are also used for the management of land use activities and their effect on microbial quality of surface water. The design of a ground water monitoring programme should rather focus on aquifers and the land uses which might have an impact on ground water quality. The conceptual design of the monitoring programme described in the present thesis will therefore only deal with the microbial quality of surface water. The microbial water quality programme might be extended to cover ground water in future.

An overview of the design framework established and approach followed during the study to develop the conceptual design and initiate the implementation of the national microbial monitoring programme for surface water in South Africa will now be given.

3.2 DEVELOPMENT OF THE MICROBIAL MONITORING PROGRAMME

3.2.1 Design and implementation framework (A)

3.2.1.1 Activities (A1)

The initial activity of the project was the development of the design and implementation framework (Figure 3.1). The framework consisted of seven distinct activities, marked from A to G. The project could be divided into two different phases viz. design and implementation. The first four activities are all related to the design phase of the programme and formed the basis of the present study. As part of the initial activity, the scope(A2), information requirements of possible end users (A3) and the approach to the spatial distribution of areas to be monitored (A4) were also determined (Figure 3.2). Once the design and implementation framework was finalized, the actual conceptual design (B) was developed, areas to be monitored were identified (C) and the monitoring network was evaluated by means of a pilot study (D).

Activities E and F (Figure 3.1) both formed part of to the implementation phase of the programme. Activity E dealt with the implementation the full-scale monitoring programme whereas activity F involved the continued operation and performance evaluation of the programme on a regular basis in order to ascertain whether the programme's objectives were

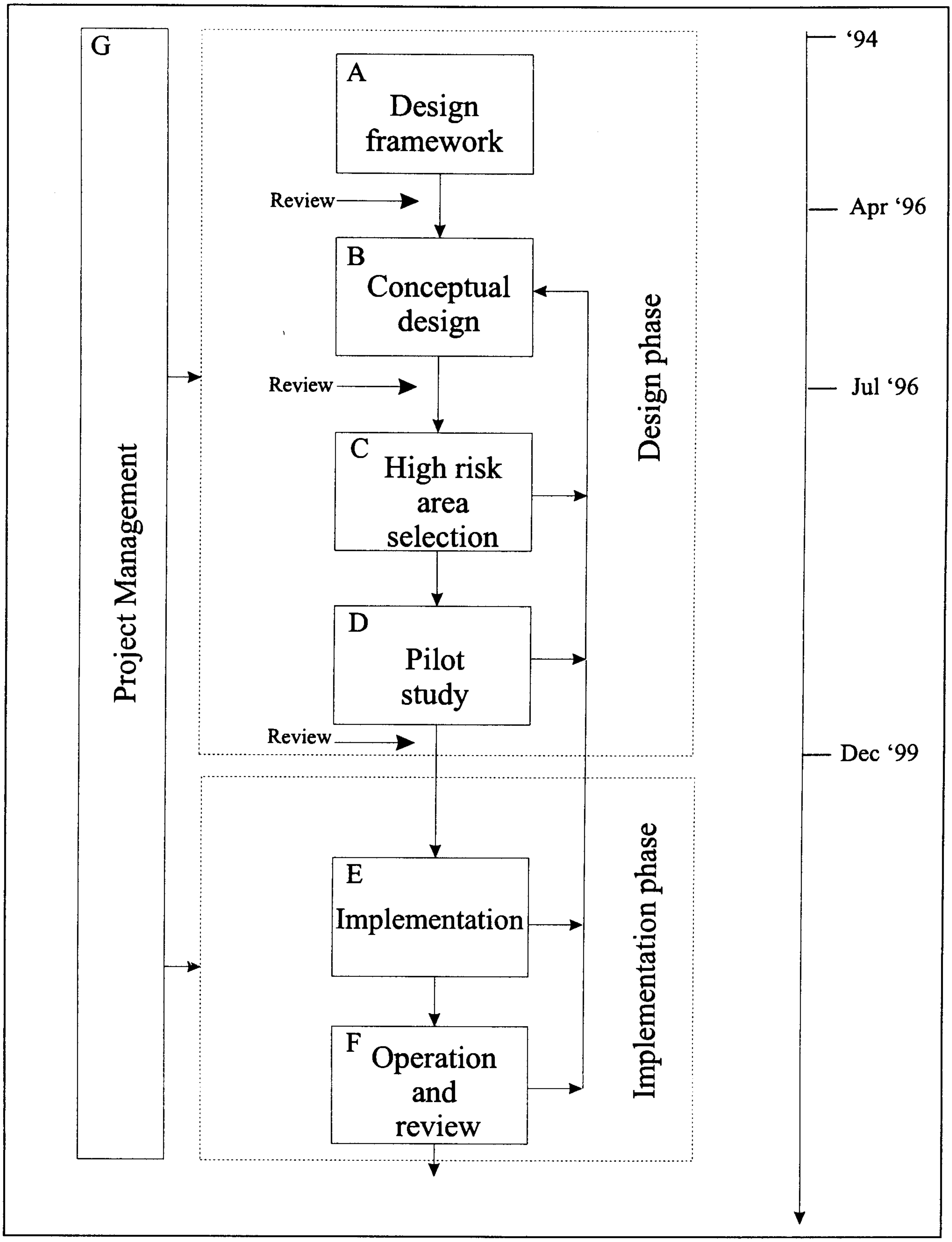


Figure 3.1 Flow diagram illustrating the framework established for the development of a national microbial water quality programme for surface water resources.

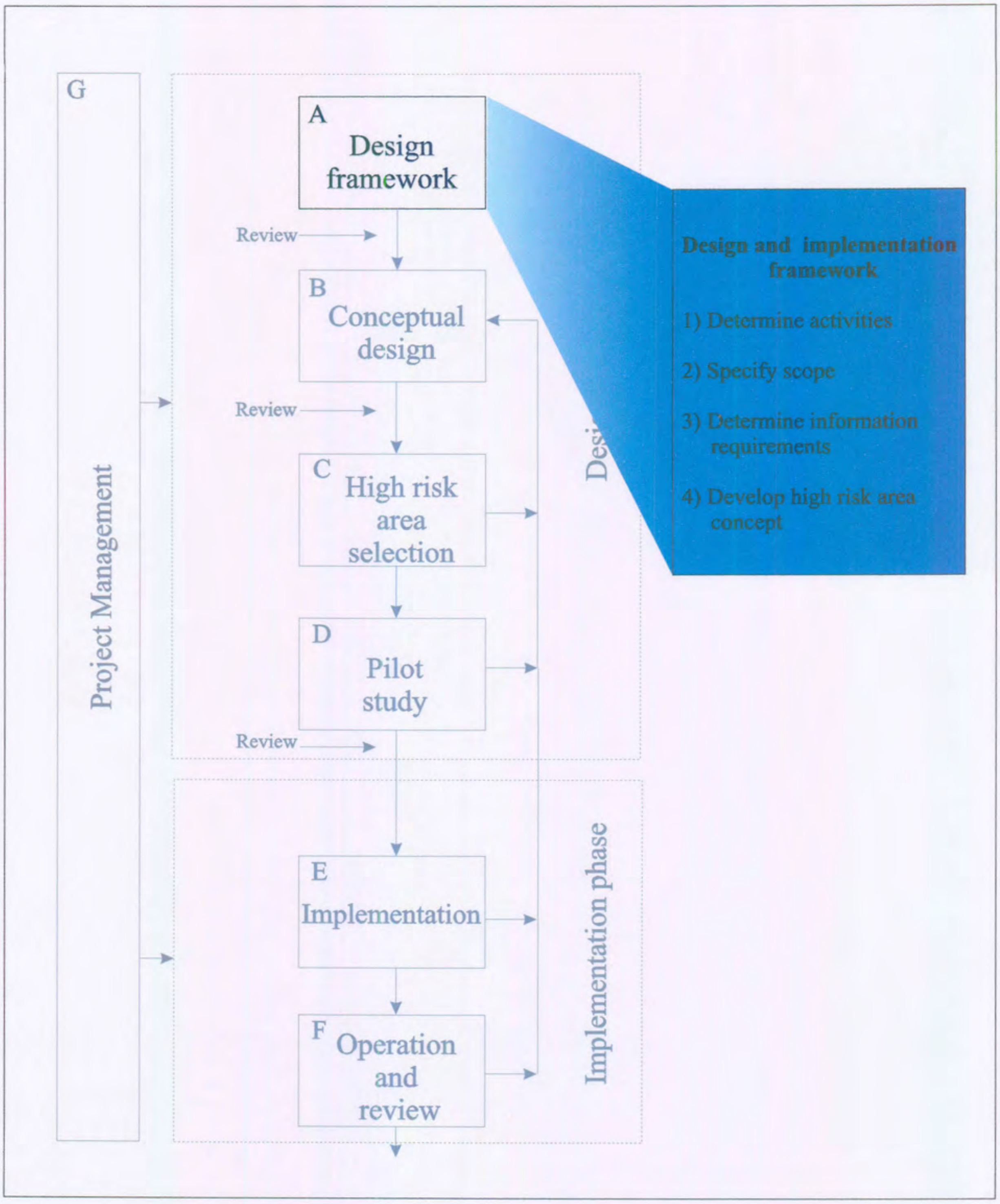


Figure 3.2 Flow diagram showing the tasks performed when developing the design and implementation framework for the microbial monitoring programme.

being met. The implementation of the programme did not form part of the scope of the research presented in the thesis and will not be discussed in detail.

The project management activity (G) spanned all phases of the project and dealt with the project management structures and procedures put into place to oversee the development and implementation of the national microbial surface water quality monitoring programme according to the requirements of DWAF.

3.2.1.2 Scope of the monitoring programme (A2)

Microbial monitoring data are used for a number of purposes such as resource management, assessment of health risk to consumers, compliance monitoring, or quality control as is the case with treated drinking water. The scope of the microbial monitoring programme was, however, restricted to the provision of information for resource management and the assessment of the health risk to various users. The programme was aimed at dealing with South Africa's surface water resources which are used for potable, recreational and certain irrigation purposes. Marine resources and ground water as well as fresh surface water resources, not used for the above mentioned purposes, were excluded from the scope.

3.2.1.3 Information requirements (A3)

The point of departure for the design of the national microbial monitoring programme was that the intent of the programme would not simply be to collect microbial water quality data, but that information based on the needs and requirements of the end user should be the overarching concern. The information needs of potential end users therefore had to be established before determining the specific objectives of microbial monitoring programme.

The information expectations of potential users of the monitoring programme were defined by interviewing key persons involved in water quality management. Water resource managers dealing with the quality of surface water resources were considered to be the principal information users and a number of them were interviewed. After completion of all the interviews, a summary of the expectations was prepared by the project team. Thereafter, the persons interviewed had an opportunity to approve the proposed summary as a reasonable reflection of their information requirements. The information requirements (Institute for Water Quality Studies, 1996a) were listed as:

1. Information required to identify and prioritize geographic areas in which the health risks related to faecal pollution of water resources are high, e.g number of people potentially exposed through "high risk" water uses, sources of faecal pollution, etc;
2. Status of and trends in microbiological water quality of water resources in high risk areas;
3. Status of and trends in effectiveness with which water bodies in high risk areas are protected against faecal pollution;
4. Status of and trends in the potential health risks, arising from faecal contamination of water resources in high risk areas. The assessment of the potential health risks are based on the status of and trends in effectiveness with which water resources are protected against faecal pollution and their microbial water quality.

3.2.1.4 Spatial distribution of areas to be monitored (A4)

Before initiating the programme's design selection criteria for the areas to be monitored had to be developed. From the onset, the severe constraints of human and financial resources were noted. The microbial monitoring programme will therefore not be in a position to provide information for all catchments in the country. Areas with severe microbial water quality problems and constant human exposure had to receive priority. A scientifically justifiable way to address the spatial distribution of sampling areas had to be developed.

Problem areas do not correspond to specific tertiary catchments. Such problem areas usually vary considerably in size. In some cases, a number of adjacent catchments could all severely impact the microbial water quality of a specific water body whereas in other cases it could be restricted to only one or a few quaternary catchments. The concept of high risk areas was therefore developed. In an initial attempt (Institute for Water Quality Studies,1996a) such an area was defined as one meeting the following criteria:

1. It encloses a water resource or part of it, e.g. a dam or a stretch of river, which is or could be directly impacted by significant point and /or diffuse sources of faecal pollution (land uses with an impact on microbial water quality);
2. The water resource is , or could potentially be, used by a significant number of people in

ways which would expose them to significant health risk if the water was contaminated by faecal pollution (water uses sensitive to microbial quality).

Focusing on relevant land and water uses, the high risk area concept was further developed to produce a procedure for the demarcation and selection of areas to be monitored during the actual design of the monitoring programme.

3.2.2 Conceptual design (B)

Based on the current understanding of the field, an approach similar to that described by Sanders *et al.* (1983) and further developed by Ward and co-workers (Ward *et al.*, 1986, Ward *et al.*, 1990) was selected for the development of the conceptual design. The approach followed during the conceptual design included the following tasks (Figure 3.3) :

1. Evaluation of information requirements and establishing of objectives;
2. Design of a monitoring network;
3. Documentation of data collection and management procedures;
4. Development of data assessment and reporting procedures;
5. Development of evaluation and implementation strategy.

During the first task, the information requirements as derived from the various interviews were evaluated in terms of the information that could be produced and thereafter converted to achievable objectives (B1) for the monitoring programme. Thereafter the design of the monitoring network (B2) was initiated. During activity B2 attention was given to the design of a procedure for the selection of high risk areas to be monitored and the selection of sampling sites. The variables to be monitored and the required frequency were also addressed. Two other tasks performed, were the description of procedures for sample analysis, data management, assessment, reporting and information dissemination (B3 and B4). Task B5 addressed a number of issues in need of attention during the development of an implementation strategy.

3.2.3 Selection of high risk areas (C)

As part of the monitoring network design (B2) a procedure for the demarcation and prioritization of high risk areas was developed. The selection of high risk areas is a crucial step in the design. The selection procedure was therefore conducted after completion of the design (Figure 3.4) and served as an opportunity for the evaluation of the proposed procedure and the results obtained.

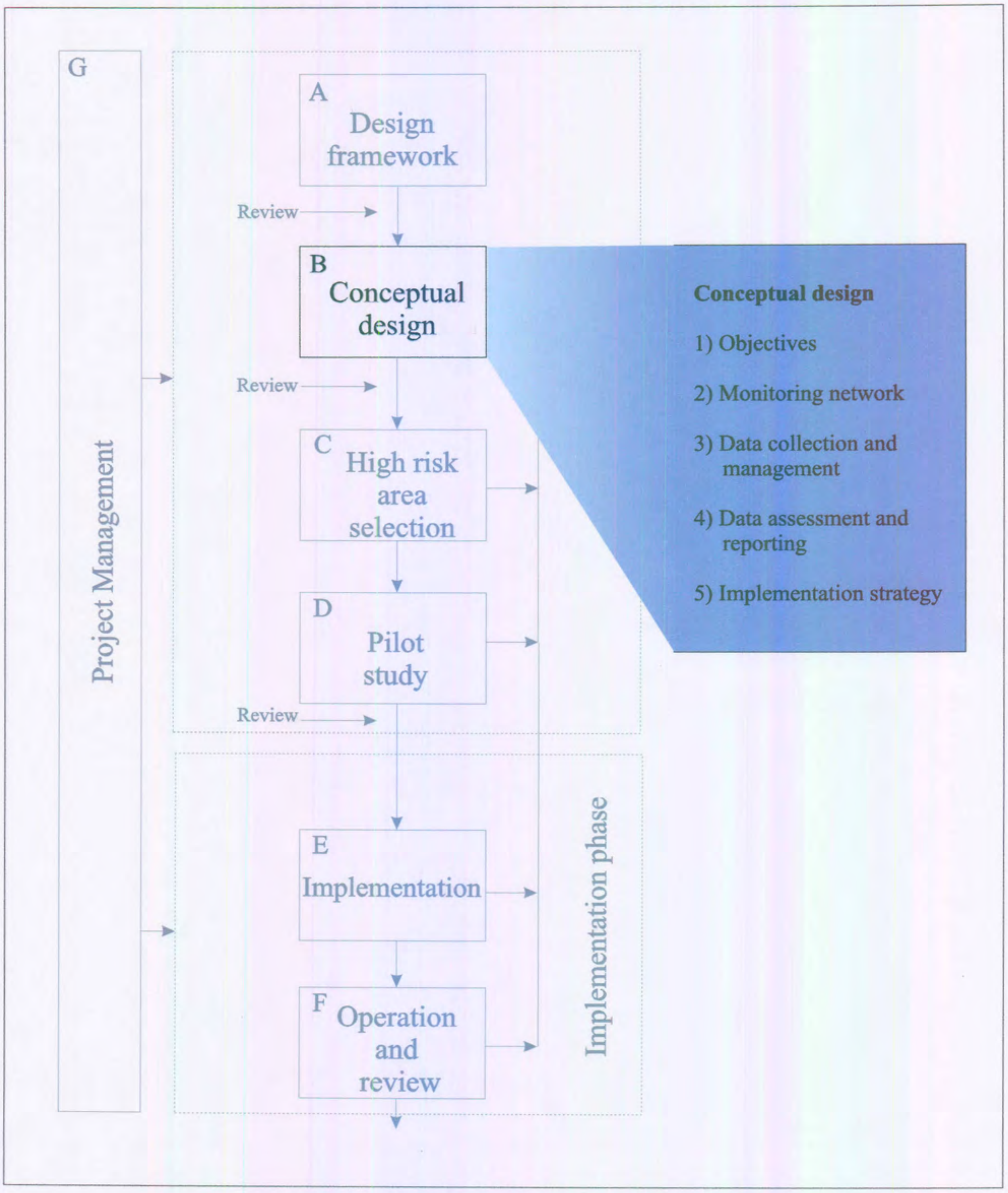


Figure 3.3 Flow diagram showing the tasks performed during the conceptual design of the microbial monitoring programme.

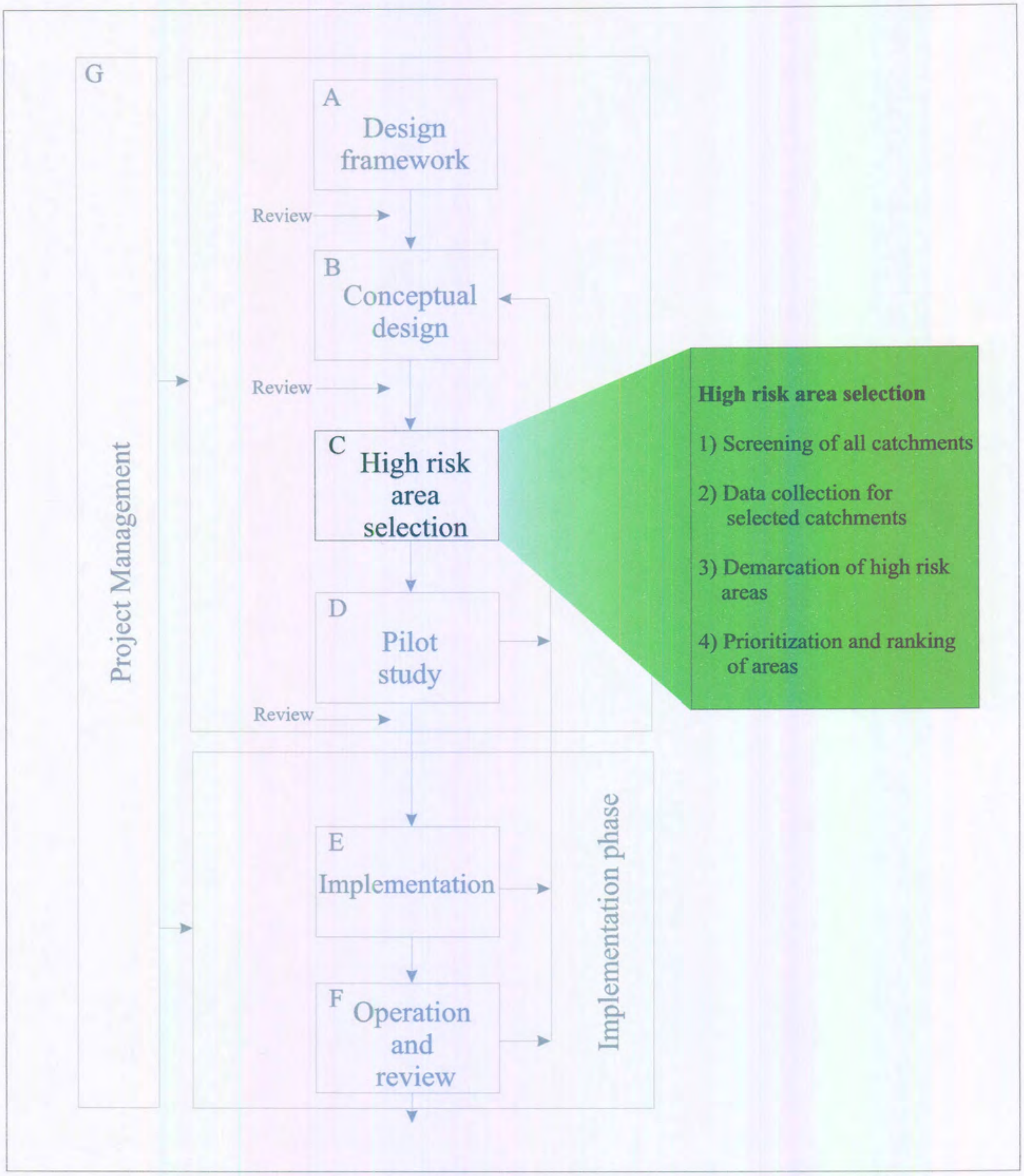


Figure 3.4 Flow diagram showing the tasks performed when the high risk areas to be included in the microbial monitoring programme, were determined.

The activity started with the screening of all tertiary catchments (C1) according to a set of criteria. The collection of the information (C2) required for all these catchments followed. Thereafter the demarcation of high risk (C3) areas proceeded, in part based on the collected data. Once the high risk areas were identified, they were prioritized and ranked (C4) according to the formulated procedure.

3.2.4 Pilot study (D)

Apart from the selection of high risk areas, other parts of the monitoring design also had to be evaluated. Evaluation was achieved by conducting a pilot study in two of the previously identified high risk areas. Umgeni Water and Rand Water, two of the main water suppliers in the country, were responsible for the actual monitoring of the microbial water quality over a period of one year. Issues such as sampling site selection, sample collection and analysis, implementation of data storage procedures and production of routine reports were addressed (Figure 3.5). After the evaluation was performed and the required changes were made, the design phase of the project was completed.

3.2.5 Implementation (E)

With the completion of the design phase, the implementation phase of the project was initiated. The implementation of the project did not form part of the conceptual design but will be briefly outlined. The approach followed was to first develop and document an implementation strategy (Murray, 1999). Thereafter implementation of the national programme was initiated during 2000 on the basis of the "Demonstration-for-Resource Allocation Spiral" approach previously used for the national biomonitoring programme (Roux, 1998). The spiral approach involved the selection of a few high risk areas for initial implementation. The idea was that successful implementation in these areas would result in the allocation of funds for expansion of the programme to other high risk areas. At present, monitoring has already been initiated in four of the identified high risk areas.

3.2.6 Operation and performance evaluation (F)

The operational activity would involve the coordination, execution and funding of the programme on a continuing basis. Once the national microbial monitoring programme is operational, its performance needs to be evaluated on a regular basis to ensure the continued

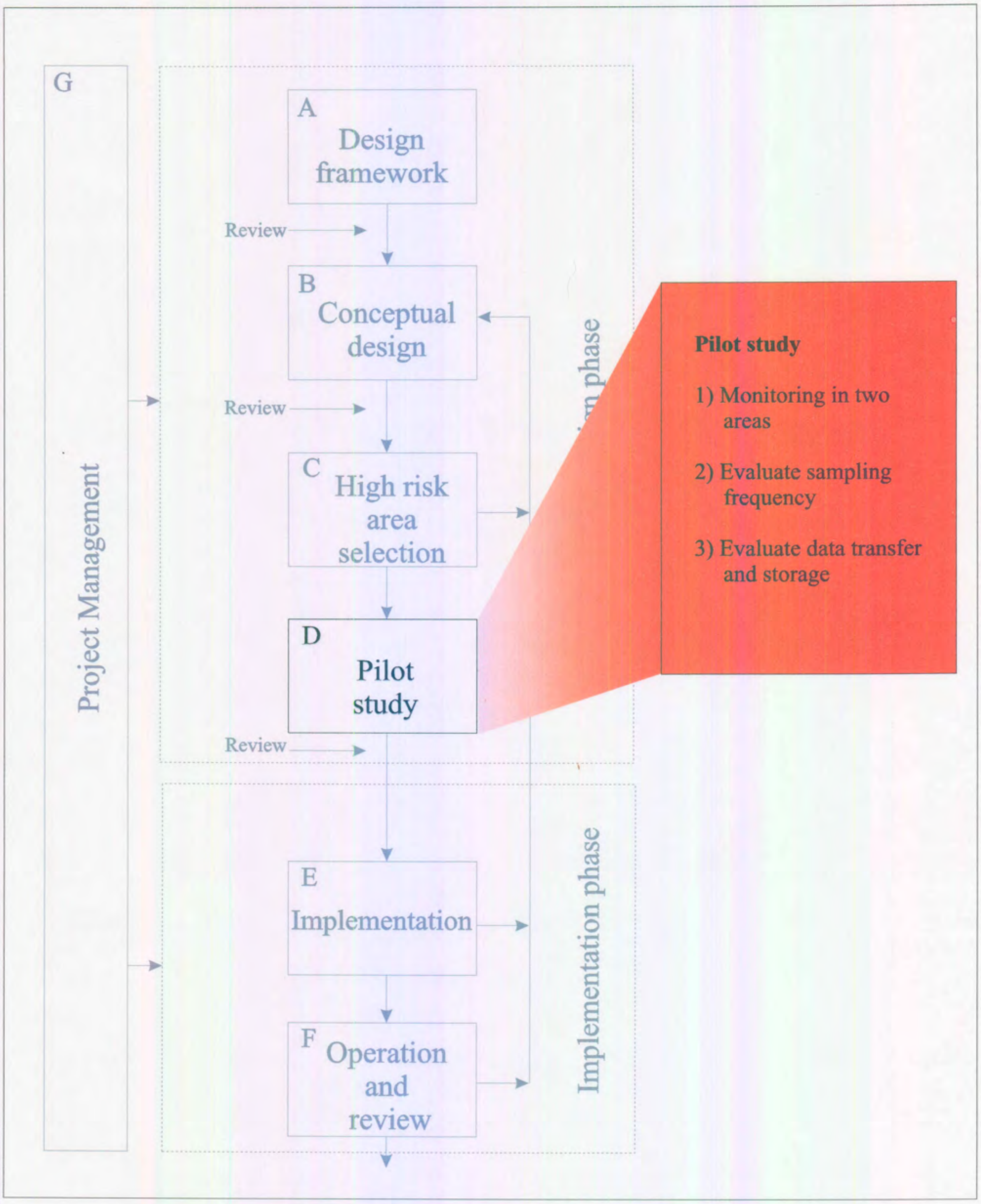


Figure 3.5 Flow diagram showing the tasks performed during the pilot study to evaluate aspects of the conceptual design of the microbial monitoring programme.

utilization of the information generated. The evaluation should measure how the set objectives are met, as measured by the response of information users. The conceptual design produced some recommendations which could assist during evaluation of the programme.

3.2.7 Overall project management (G)

An appropriate management process and structure had to be developed for the project to ensure that the needs and requirements of DWAF were addressed during the study. A technical committee representative of both the project team and DWAF was formed, which met on a regular basis to evaluate the progress of the project. DWAF was represented by technical staff from the Institute for Water Quality Studies (IWQS). IWQS is the institution where control of the programme would eventually be housed. The process agreed upon was interactive and allowed for regular input from DWAF members into the design process as well as feedback to ensure that the final conceptual design would meet the expectations of DWAF.

In the light of the fact that the proposed monitoring programme was to be a national programme, DWAF requested that the design should be subjected to formal external evaluation during the development of the programme. Evaluation took place after completion of each of the main activities (Figure 3.1). Participants involved with the formal evaluation varied according to the type of issues addressed in the design. In all cases both technical experts and potential end users were approached. At the completion of most of the activities, documents capturing the process and findings were prepared which facilitated the external review (Institute for Water Quality Studies, 1996a; Institute for Water Quality Studies, 1996b, du Preez *et al.*, 1999).

3.3 CONCLUSION

The framework and approach described above formed the basis for the conceptual design of a separate national programme to monitor the microbial quality of surface waters in South Africa. The programme will only focus on surface water and should provide information to assist in the management of the associated potential health risk. In the light of the extent of microbial pollution of surface water in certain areas and the limited resources available, the main focus of the programme will be on areas with a high possible human health impact. The decision to focus on potential high risk areas was taken in spite of the fact that the information to be generated might not give a true reflection of the overall status of the microbial water quality of surface waters in South Africa. The issues of better representation could be addressed once some of the existing problems have been identified or more resources have been made available.

The framework developed served as the basis for the design and implementation of the monitoring programme. The design phase responsible for the development and evaluation of the conceptual design formed the basis of the study covered in the next four chapters.

CHAPTER 4: CONCEPTUAL DESIGN OF THE MICROBIAL MONITORING PROGRAMME FOR SURFACE WATER

4.1 INTRODUCTION

A number of unique issues had to be addressed during the development of the conceptual design for a programme to monitor the microbial quality of surface water in South Africa. The documented monitoring design procedures available to date do not provide appropriate design criteria for the conditions addressed by this programme. The design procedures typically aim at the collection of physical, chemical or hydrological data or a combination of those parameters. Furthermore, for the intended programme to be successful, local environmental conditions as well as the political and governmental context in South Africa also had to be incorporated.

As discussed in Section 3.2.2 and shown in Figure 3.3, the design was based on the approach of Ward and co-workers (Ward *et al.*, 1986, Ward *et al.*, 1990) and consisted of the following five tasks:

1. Evaluation of information requirements and establishing of objectives;
2. Design of a monitoring network;
3. Documentation of data collection and management procedures;
4. Development of data assessment and reporting procedures;
5. Development of evaluation and implementation strategy.

Once the objectives were formulated (Section 4.2) the monitoring network had to be designed. A number of issues had to be addressed and are reported in Section 4.3. The design of a process for the selection of areas to be included in the monitoring programme was one of the main priorities. As stated in Chapter 3, when the research framework was discussed, the decision was made that the monitoring programme would focus primarily on areas where severe faecal pollution could pose a health risk to water users. Section 4.3.1 describes how the concept of high risk areas was developed and how the concept was applied towards the identification and prioritization of such areas. The second issue that impacted on the network design was the selection of sampling sites; this is addressed in Section 4.3.2. Section 4.3.3 deals with the selection of the water quality variables included as part of the monitoring programme. In Section 4.3.4 the issue of sampling frequency was examined, taking the programme's information objectives and the general financial and logistical constraints into account.

In Section 4.4 the design of a data handling and storage system and methods for the analysis and interpretation of the data are described. The proposed interpretation of data had to be consistent with local guidelines, standards and policies, as well as international practice.

The next section (Section 4.5) investigated options for the presentation and dissemination of the monitoring information among government employees, political role players, the scientific community and most important, the general public. For the success of any monitoring programme, it is essential that the information collected should be freely available. This is, however, not the only prerequisite. Information must be presented in such a manner that it is comprehensible for all parties. A strategy for the implementation of the conceptual design was required and the issues that might influence this process are dealt with in Section 4.6.

4.2 FORMULATION OF OBJECTIVES

4.2.1 Introduction

The first step in the design process was to evaluate the requirements of the potential users of the information produced by the monitoring programme. It is essential that the information requirements are addressed if the programme is to be cost effective and proceed beyond merely collecting microbial water quality data that are of limited benefit or use. Apart from the information expectations expressed by the potential users, the legal background and obligations of such a programme also had to be taken into account when formulating the objectives.

4.2.2 Information requirements

During the development of the design and implementation framework a number of key persons were interviewed to determine their information expectations. The final list of information expectations provided in 3.2.1.3 was the result of consensus reached by all parties involved in the interview process. In summary, data were needed to identify areas where a health risk to users exists due to high faecal pollution of surface water resources, to determine the status and trends of the microbial water quality in such areas and to evaluate the overall effect of possible management actions undertaken. Careful evaluation of the requirements led to the conclusion that theoretically all the information needs could be met. Limited financial resources and human capacity might, however, influence the degree to which the information requirements could be met by the implemented programme.

4.2.3 Legal requirements

The scope of the monitoring programme was not aimed at compliance monitoring and the only legal requirements that had to be met were the general specifications under the Water Act 54 of 1956 (Union of South Africa, 1956) which stated that DWAF was the custodian of all water resources and which required that it should be managed on a sustainable basis. In 1991 the Department updated their general water quality management policy (Department of Water Affairs and Forestry,1991) and care was taken that the proposed programme would fit into this policy framework. At the time of the design the new National Water Act was not yet promulgated.

4.2.4 Objectives

Once the legal and information requirements of the proposed monitoring programme were established the requirements had to be converted into obtainable objectives for the monitoring programme. The monitoring objectives formed the basis on which the conceptual design of the programme was based. The specific objectives of the national microbiological monitoring programme were formulated as follows:

- To locate, assess and prioritize those areas in the country where potential health risks related to faecal pollution of water resources are the highest;
- To provide information on the status of and trends in the extent of faecal pollution, in terms of the microbiological quality of surface water resources in the high risk areas;
- To provide information to help assess the potential health risk to humans associated with the possible use of faecally polluted water resources;
- To help assess the effectiveness of measures to protect water resources against faecal pollution in terms of trends in the microbiological water quality.

Because the monitoring programme was to be a national programme, the objective of the programme was, therefore, not to quantify or even isolate the effect of individual activities on the microbial water quality, or to determine the potential health risk to specific water users at specific points of abstraction or contact. The objective was rather to provide general information on the status and trends in the microbial water quality of high risk areas, as well as to give an indication of the potential health risk associated with the use of surface water in those areas. The data could also give some general indication of the effectiveness of measures taken to protect water resources against faecal pollution.

4.3 MONITORING NETWORK DESIGN

4.3.1 Selection of high risk areas to be monitored

4.3.1.1 High risk areas

Many of South Africa's surface water resources are severely impacted by microbial pollution. In order to save lives and improve the quality of life of many South Africans, the health impact of microbial pollution needs to be addressed urgently. During the development of the design framework for the proposed monitoring programme, areas of high human health impact was the primary focus. The selection of severely impacted areas could not be based on historical microbial water quality data due to the lack thereof in most catchments. The concept of high risk areas was proposed for the identification of impacted areas and a procedure for the calculation of priority values and ranking of high risk areas was developed.

For the purpose of the monitoring design, high risk areas were defined as all areas where conditions exist for severe microbiological water quality impacts and the water therefore poses a major risk to the health of a large number of users. A number of land uses could have a major impact on the microbial quality of the surface water in a catchment. Water uses, on the other hand, provide information on the possible risk associated with the use of microbial polluted water. Important land and water use activities, as shown in Section 2.1.3.2 and 2.1.3.3 could therefore be used to identify and rank high risk areas (Figure 4.1).

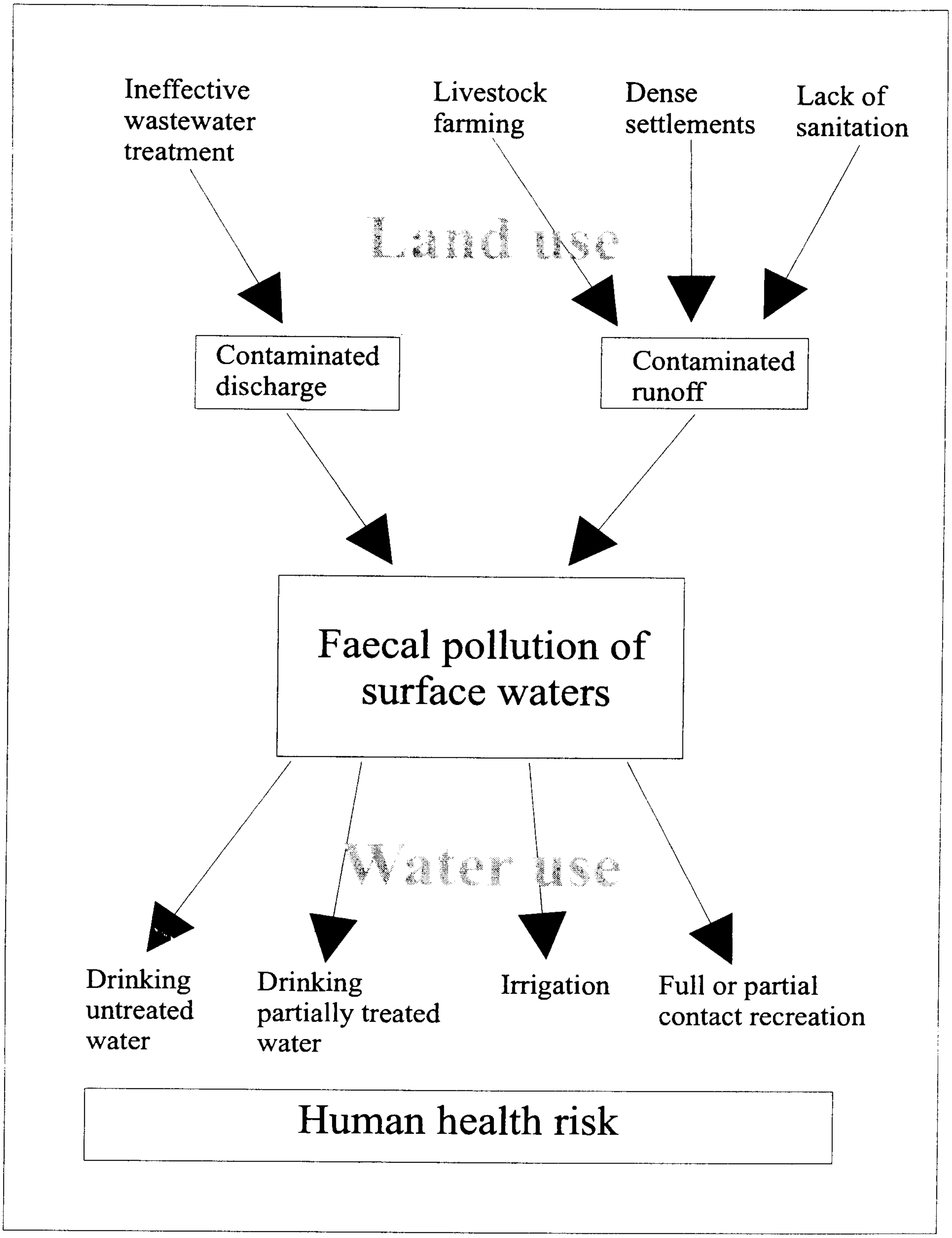


Figure 4.1 Diagrammatic representation of the suggested relationship between land use, water use and human health risk.

4.3.1.2 Land uses as possible sources of microbial pollution

In Section 2.1.3.2 it was clearly demonstrated that certain land use activities could severely impact the microbial quality of surface waters. Based on the information in the literature, various land uses were grouped according to their potential impact on the microbial water quality. The grouping was done according to the expected level of microbial pollutants and the effect of the type of microbial contaminants on human health (Table 4.1).

Table 4.1 Land uses grouped according to their possible impact on microbial water quality of surface water

Land use	Impact on microbial quality
Informal settlements Urban settlements Agriculture - Livestock	High
Agriculture - Aquaculture Industry Recreation Mining	Medium
Agriculture - Irrigation Forestry Natural environment	Low

The land uses associated with a high impact could be further defined in terms of more specific attributes. The specific attributes served as the basis for quantifying the impact of land uses on the microbial water quality and were described as follows:

- Households without sanitation infrastructure (Informal settlements);
- Inefficient, poorly maintained / operated or inappropriate sanitation infrastructure (Informal and urban settlements);
- Dense settlements and the associated surface runoff (Informal and urban settlements);
- Intensive farming with livestock (Agriculture - Livestock).

4.3.1.3 Water uses impacted by microbial water quality

Human exposure to water-borne diseases could be associated with a number of water use activities as was shown in Section 2.1.3.3. The route of human exposure is important when ranking water uses according to the possible health impact of the microbial quality of water. Ingestion is the most direct way of exposure and even low numbers of microorganisms could have a severe effect on human health. Apart from ingestion, skin contact and inhalation of aerosols could also affect human health. Using the information on the route and effect of exposure, water uses were grouped according to the possible human health impact of the microbial quality of water (Table 4.2).

Table 4.2 Water uses grouped according to the possible health impact of the microbial quality of water

Water use	Sensitivity to microbial quality
Domestic - Direct use and limited treatment Industry - Food and beverages Recreation- Contact Agriculture - Irrigation	High
Agriculture - Livestock Agriculture - Aquaculture Industry - Non-potable	Medium
Recreation - Non-contact Aquatic environment	Low

The water uses with high sensitivity could in some cases be further defined according to more specific attributes. The specific attributes can be used to quantify the possible human health impact of poor microbial water quality and are as follows:

- Drinking of untreated surface water (Domestic - Direct use);
- Drinking of surface water after partial treatment (Domestic- Partial treated);
- Full or partial contact recreation (Recreation- Contact);
- Irrigation of crops to be consumed raw (Agriculture - Irrigation).

4.3.1.4 Quantifying the impact of water and land uses

The selected water and land use attributes typically associated with high risk areas were used as the basis for the ranking of the high risk areas. A system to quantify each of these uses was needed for the calculation of priority values. To ensure that the prioritization process was objectively applied to all areas, land and water uses had to be characterised by means of measurable attributes that could be verified independently. Data collection should also be relatively inexpensive and the data should be easy to obtain. The ideal situation would be to make use of existing governmental databases.

In the case of most of the land and water uses, the magnitude of impacts could be measured by means of the number of affected individuals. Another possibility was to use the number of affected households because such data might be easier to obtain from local authorities. Using the number of households was, however, a less accurate option in the South African context. Large differences in the number of individuals per household were noticed between settlements but also within settlements, mainly due to socio-economic factors.

The number of affected individuals to quantify impacts could not be used to quantify all land and water use attributes and a measurement system or value function had to be developed for the following attributes:

- Dense settlements and the associated surface runoff;
- Intensive farming with livestock;
- Irrigation of crops to be consumed raw.

Surface runoff from dense settlements

Runoff from settlements has an impact on the microbial quality of surface waters. Due to the variability in runoff volume and the erratic occurrence thereof, it is not suited for comparison and use during prioritization. It would be far better to compare areas in terms of the potential for high volume surface runoff events. Initially, an estimation of the percentage surface area covered with infrastructure within a settlement was proposed as such a measure. Due to the positive correlation between the surface area covered and the level of surface runoff generated, the use of surface area coverage was further investigated. Satellite images to obtaining surface area coverage data was examined but the resolution and accuracy of the readily available data were not sensitive enough for this purpose. Another option investigated was the interpretation of aerial photographs which could provide accurate data but that was a labourious and very costly exercise. Surface run-off models were also found to be inappropriate for urban and peri-urban use without accurate data concerning a number of parameters which were unavailable. The final decision was therefore, to use the average population density of the settlements because population densities correspond well with the percentage of surface area covered by structures such as buildings and roads. In areas of lower density there would be a greater potential for rainwater to be retained and absorbed by the soil. Obtaining population densities also tends to be a rapid and inexpensive method based on readily obtainable data.

Livestock

The impact of intensive farming on surface water quality is governed by two factors, the first being the size of the units, but more important, the waste disposal practices in place. Farms where appropriate waste handling practises are in place with no chance of the effluent reaching surface waters would not form part of the prioritization process. For other farms, a measurement scale based only on the size of these units would be used. Dairy farming, pig farming, cattle feedlots, poultry and ostrich farming are all included whenever substantial capital and labour inputs per unit area are required. Information regarding their waste disposal practices is also needed. The most common animal production units linked to water pollution are cattle feedlots and piggeries. According to DWAF pollution control officers the following estimates could be used to group these units according to size:

- Small: Cattle feedlots: < 5 000 cattle ; piggeries: < 500 pigs;
- Medium: Cattle feedlots: 5 000 - 10 000 cattle ; piggeries: 500 - 2 000 pigs;
- Large: Cattle feedlots: > 10 000 cattle ; piggeries: > 2 000 pigs.

Irrigation

The water use for which a measurement system had to be developed was the irrigation of crops to be consumed raw. The main focus was on crops which are spray irrigated such as lettuce, tomatoes and grapes but data pertaining to these crops specifically was difficult to obtain. In many areas crops are rotated during the growing season and may differ from month to month. The measurement of use for irrigation of crops would therefore be based on the area in hectares. Based on production figures the estimate was that the produce from one hectare could be enough to affect up to 1000 people during a year. All areas where fruit or vegetables are cultivated and irrigation with surface water from the catchment is practised, are to be included. A people equivalent of 1000 would be assigned for each hectare under irrigation by surface water.

4.3.1.5 Identification and demarcation of high risk areas

Once the appropriate land and water uses were identified and measurement systems were developed for use during prioritization, a procedure for the identification and demarcation of high risk areas was developed. In order to minimize costs in terms of data collection, a three stage approach was proposed. The aim of the initial screening stage was to find catchments where faecal pollution posed a serious risks to human health and to eliminate the other catchments from the process. The initial screening was followed by the collection of data for all catchments retained after the screening. Finally the demarcation of high risk areas were performed based on the previously collected data.

Screening

The initial screening process had to be performed for all tertiary catchments (secondary catchments might also be applicable for some of the smaller areas) and their corresponding quaternary catchments. The use of catchments during this initial stage ensured total coverage of the country. The following screening criteria were used:

- Health impacts related to microbiological water quality experienced in catchment;
- A part of the population living in the catchment utilizes untreated or partially treated surface water from this catchment for domestic use;
- Parts of settlements in the area or upstream thereof, do not have the necessary or appropriate sanitation infrastructure;
- There is a high incidence of possible water-borne diseases in the community as indicated by data from hospitals, clinics and pathologists.

Catchments meeting any of the above criteria were selected for further investigation and collection of data.

Data collection

Once the relevant tertiary catchments were identified, the second stage focussed on the collection of the data needed for the identification and demarcation of high risk areas. The same data was later also used for the prioritization of these areas. Based on the identified land and water uses and their measurements systems, the following information had to be collected for each settlement within the selected catchments (In cases where the necessary information is not available estimates could be given):

a The number of affected individuals associated with human settlements that:
- do not have the necessary sanitation infrastructure;
- have the necessary infrastructure but it is in a poor condition;
- have sanitation infrastructure that is inappropriate for the situation;
- have sanitation infrastructure that cannot cope with the present increase in the population.
- are served by wastewater treatment works that do not meet the "relaxed" microbial effluent standard of 1000 *E. coli* / 100ml;

b An estimation of the average population density of the settlements;

c A list of intensive farming enterprises in the area with an estimation of their size and waste disposal practices. Dairy farming, pig farming, cattle feedlots and poultry and ostrich farming are to be included whenever substantial capital and labour inputs per unit area are required.

In terms of the water uses the following information had to be collected:

a The number of individuals without any appropriate or reliable water supply infrastructure and who use untreated surface water;

b Identification of human settlements or parts thereof (number of individuals involved) where untreated surface water is available as an alternative source of drinking water and the distance between communal taps and the majority of the households is more than 200 m, or where there are more than 25 households per standpipe;

c Identification of human settlements or part thereof (number of individuals involved) that rely on untreated surface water as an additional supply of water for household activities;

d The number of individuals supplied with surface water for domestic use after limited treatment (for example only physical treatment or chlorination);

e The maximum number of people per month that use surface water for full or partial contact recreational activities. This figure would typically be associated with summer. Other activities where people are in contact with the water such as the washing of laundry are also to be included in this figure;

f An estimation of the area (ha) under irrigation by surface water. This is restricted to irrigation methods where crops come into direct contact with the water.

Most of the information collected would be directly associated with settlements. When collecting this type of water and land use data, care should be taken to ensure that only data related to parts of the settlement which fall within the selected catchment boundaries are included.

Demarcation of high risk areas

Once all the above-mentioned data were collected, the next step was to identify high risk areas. The main aim during the identification of high risk areas was to select areas in the country where a high number of sensitive water users are exposed to water of poor microbial quality. A risk area may therefore consist of the whole catchment, a limited part thereof, or there may even be more than one risk area in a catchment. The specific demarcation of a risk area therefore depended largely on the unique situation in the catchment. The situation in the catchment can usually be judged best using maps of the catchments which indicate the major land and water uses. The following generic guidelines were established to assist with the demarcation process and included:

- Land and water uses should only form part of the same area if the land uses have an impact on the identified water uses;
- The distance between land uses and the impacted water uses downstream should not be more than 100 km. The criteria may, however, be changed according to the specific characteristics of a catchment such as topography, vegetation (eg. vegetated flood-plains) and flow patterns (eg. narrow fast flowing streams or impoundments and wetlands which limit water movement);
- In case where certain water uses occur upstream of the land use activities in the catchment, these water uses should not be taken into consideration during demarcation;
- The presence of large water impoundments such as dams often minimize the effect of upstream land use practices on water uses downstream of the impoundment and their possible effect should be taken into account.

At the end of the demarcation process, a list of high risk areas in the country could be compiled. The high risk areas were all selected on the basis that surface water of poor microbial quality are present and that a serious human health risk exists due to the number of water users in the area exposed to surface water.

4.3.1.6 Rationale for the calculation of priority values

The various land uses associated with high risk areas would each have a different impact on microbial quality of the surface water in the area. The impact of no sanitation would be much higher than the impact of normal surface runoff. The associated human health risk is also clearly linked to the type of water use. The same number of people drinking untreated water represent a far greater risk than when they are exposed to the same surface water in a recreational situation. The prioritization of high risk areas is clearly influenced by a number of different factors and the best answer would only be obtained when all these factors and their relative contributions are taken into account.

In recent years the development of models for decision making expanded dramatically. Various types of models were investigated for use as the basis for the prioritization process. A multi-criteria decision making (MCDM) model was found to be the best suited for the prioritization process as it allows for the simultaneous evaluation of the various factors and their contribution towards the final outcome. Two categories of MCDM models exists based on the requirement of a decision with either deterministic or stochastic outcomes. As the chosen attributes on which the catchment prioritization was based could be determined quantitatively, a deterministic type of model could be used. Offringa (1996) evaluated a number of MCDM models for the determination of water research priorities and found the SMART method described by Goodwin and Wright (1991) most suitable for his purposes. Based on the evaluation of Offringa's findings (Offringa, 1996) the SMART methods was also used. The SMART method is transparent and is therefore likely to lead to enhanced understanding of the problem, it is also robust and easy to apply.

The SMART method (Goodwin and Wright,1991; Goodwin and Wright,1999) requires the identification of the main attributes on which selection (prioritization) should be based. In the case of prioritization of high risk areas the two main attributes were land and water use. Land and water use were each then further divided into a number of sub-attributes as was described in Sections 4.3.1.3 and 4.3.1.4. Once the sub-attributes were identified each had to be weighted according to the sub-attribute's relative importance, a process that could be very subjective when based on the opinion of a single person. To minimize the problem of subjectivity, the relative weights were assigned to the attributes based on the consensus opinion of a team of technical experts.

The team of technical experts consisted of microbiologists, water quality managers and an environmental engineer. According to consensus opinion of the team the most important factor affecting the microbial quality of surface water would be when no sanitation infrastructure is present. The attribute of "no sanitation" was therefore assigned a value of 100. The contribution of inefficient sanitation infrastructure was rated as 60 when compared to no sanitation infrastructure. The above approach was followed to until relative weights were assigned to all the attributes. The assigned values were then normalized so that their sum equalled 100 (Table 4.3). The same procedure was followed for the subset of water use attributes (Table 4.4)

Table 4.3 Land use attributes and assigned weights

Land use attributes	Original weight	Normalised weight
No sanitation infrastructure	100	53
Poor sanitation infrastructure	60	43
Intensive animal farming enterprises	6	3
Average population density	2	1

Table 4.4 Water use attributes and assigned weights

Water use attributes	Original weight	Normalised weight
Drinking untreated water	100	50
Full or partial contact recreation	50	25
Irrigation of crops	30	15
Drinking after limited treatment	20	10

The prime objective of the prioritization process was to locate, assess and prioritize high risk areas in the country where potential health risks related to faecal pollution of water resources are highest. As each of the selected attributes represented a separate aspect of the problem the priority value for an area was calculated by using an additional model. First the total value for land or water use was calculated by adding the separate normalised values in each category. The prime focus was to find areas where people are at risk and the water use information therefore received greater emphasis during the final calculation of the prioritization value. An overall weight of 60 was given to the combined value of these attributes in comparison to the 40 given to the combined attributes dealing with land use.

4.3.1.7 Calculation of priority value

According to the approach followed during the design of the monitoring programme, areas with the highest potential risk should be monitored first. A priority value was therefore determined for each of the identified high risk areas. The priority value consisted of the sum of two components, the land and water use value. Normalisation of the land use attributes were performed according to the values shown in Table 4.3. and that of the water use attributes according to the values shown in Table 4.4. The land use value (LUV) was the sum of the normalised attributes which were calculated as follows:

a N x 0.53 - where N is the number of individuals with no sanitation infrastructure within the high risk area;

b M x 0.43 - where M is the number of individuals within the high risk area with sanitation infrastructure that is either inefficient, poorly maintained or operated or generally inappropriate;

c P x 0.01 - where P is the average population density of all settlements within the high risk area;

d Intensive livestock farming is measured according to the size (Section 4.3.1.5) of the unit which does not have waste handling practices in place:

Small scale unit = 5000 x 0.03 = 150

Medium scale unit = 7500 x 0.03 = 225

Large scale unit = 10 000 x 0.03 = 300.

The water use value (WUR) is the sum of the normalised attributes which were calculated as follows:

a Q x 0.50 - where Q is the number of individuals within the high risk area without appropriate or reliable water supply infrasructure and who rely on untreated surface water for drinking water;

b R x 0.1 - where R is the number of individuals supplied with surface water for domestic purposes after limited treatment. The water has to be abstracted from within the high risk area;

c S x 12 x 0.25 - where S is the maximum number of people per month that have full or partial contact with surface water in the high risk area;

d T x 1000 x 0.15 - where T is the area in hectares with vegetables that are spray irrigated with untreated surface water from the high risk area.

The overall priority value (PV) was used to rank areas and was calculated as:

PV = 0.4 x (LUV for the area) + 0.6 x (WUV for the area).

Once a priority value was calculated for each of the high risk areas, it was used as a mean of ranking areas from the highest to the lowest priority. This information was used to determine the high risk areas where monitoring should be initiated.

4.3.2 Water quality variables

The main purpose of the proposed monitoring programme is to assess and manage the health risk to water users due to faecal pollution of water resources. The health risk to water uses could be defined best if information on the occurrence and levels of pathogens could be determined. The routine monitoring of water for all possible water-associated pathogens is, however, impractical. Apart from the number of tests that would be involved, many of the methods are complex and time-consuming. When present, pathogens usually occur at low levels relative to the natural microbial population present in the water. The presence of pathogens at low levels also limits the likelihood of detecting these organisms quantitatively on a routine basis. For a general indication of the level of faecal pollution, indicator organisms are commonly used. Based on the information provided in Section 2.1.4 a number of potentially useful indicator organisms were selected (Table 4.5).

Table 4.5 Indicator organisms commonly used in water quality monitoring

Indicator organisms	Relevance to microbiological water quality
Total coliforms	Indicator of the bacteriological water quality (possible faecal pollution)
Faecal coliforms	Indicator of probable faecal contamination of the water
Escherichia coli	Indicator of faecal contamination of the water
Faecal streptococci / enterococci	Secondary indicator of probable faecal contamination of water (less sensitive but more resistant than coliform bacteria)
Clostridium perfringens	Indicator of remote faecal pollution
Standard plate count / heterotrophic plate count	Indicator of the general bacteriological water quality
Coliphages	Indicator of possible faecal pollution and the presence of pathogenic viruses

The focus of the monitoring programme is to assess the impact of faecal pollution and the faecal (thermotolerant) coliform group or *E. coli* would be the most appropriate indicator. The faecal coliform group is at present still one of the most widely used indicators of faecal pollution and remains the organism of choice in South Africa. The use of the faecal coliform group in the assessment of water quality is also widely accepted in the world (World Health Organization, 1996b). The concentrations of faecal coliforms are, under most circumstances, directly related to that of *Escherichia coli* , one of the organisms that comprise the faecal coliform group.

Escherichia coli was reported to be a more reliable indicator of human faecal pollution than the faecal coliform group (Olivieri, 1982). At present the information gained from using *E. coli* instead of the faecal coliform group does not, however, justify the extra time and cost associated with detecting *E.coli* in water. The standard methods of detecting *E. coli* still require an additional confirmation step. The development of rapid techniques such as defined substrate technology, could however make the detection of *E. coli* an economically viable alternative in future. Another reason for selecting the faecal coliform group was that more information is available for the interpretation of the faecal coliform data in terms of the potential health risk to the various water uses (Canadian Council of Resource and Environmental Ministers, 1987;

Department of Water Affairs and Forestry, 1996a; Department of Water Affairs and Forestry, 1996b; Gardiner and Zabel, 1989).

The faecal coliform group would, therefore, at present be the only microbial variable determined during the execution of the monitoring programme. The validity of the decision to only use the faecal coliform group was evaluated using microbial water quality data collected between 1991 and 1993 in a peri-urban area in Gauteng (Venter *et al.*,1996). During this study, apart from faecal coliforms, the levels of a number of microbial pathogens and indicators (enetric viruses, Cryptosporidium, Giardia, coliphages and enterococci) were determined in a number of samples. The data collected during the Gauteng study clearly demonstrated that although, as expected no clear correlation between these parameters existed, the faecal coliform group was always present in high numbers at sampling stations where pathogens were detected.

Testing for one indicator organism simplifies the sampling logistics and laboratory analysis. Savings incurred by the decision to test only one microbial variable could be used to finance more sampling points in an area or the monitoring of other high risk areas. If water quality programmes exist which also monitor for the presence of selected pathogens, links between the national programme's data base and these other data sets should be created as the other monitoring programmes could provide valuable additional information.

Attention could be given to chemical and physical variables which may provide information on environmental conditions which may either enhance or decrease the survival of microorganisms in surface water. In general pH, nutrient supply, temperature and solar radiation are considered to be the most important factors affecting microbial decay (Bowie *et al.*, 1985; Crane and Moore, 1986). Temperature, pH and turbidity could be measured on-site at little extra cost, but the value and reliability of the these analyses needed further investigation.

The collection of stream flow data was also investigated as flow data could help with the interpretation of the data. As previously reported (Venter *et al.*, 1996) obtaining accurate flow data for most of the sampling points is very difficult. Many of the streams do not have weirs where flow readings could be taken accurately. The use of the stage-discharge relationship method was investigated but was not accurate during high or very low flow conditions, often the prevailing conditions in South African streams. The instream velocity sampling method was also evaluated but was too labour intensive for regular use in a national monitoring programme. The determination of flow measurements was therefore not included as part of the monitoring programme.

4.3.3 Selection of sampling sites

The location of sampling sites is a critical step in the design of water quality networks (Sanders *et al.*, 1983). All the information required to meet the specific monitoring objectives is derived from samples collected at the designated sampling sites. The broad objectives of the proposed monitoring programme were to determine the status and trends in the microbial quality of surface water and to assess the potential health risk associated with the use of the polluted water source. Status and trend information would primarily be used by managers for the development of water quality management policies. Other uses would be for operational purposes such as the development of catchment protection plans and the allocation of resources to improve water supply and sanitation services. The proposed programme is a national programme and the objective is not to quantify the effect of each of the individual land use activities on the microbial water quality or to determine the potential health risk to each of the water uses at the specific point of abstraction or contact. The objective of the programme is rather to describe existing conditions in selected areas with respect to faecal pollution.

Ideally the programme should be able to provide information on the general status of a high risk area as well as locations of specific concern. Under certain circumstances these two issues could be conflicting. Funding for the implementation and operation of the monitoring programme would in most cases be limited and one of the above information needs may have to receive priority. From a managerial perspective greater importance should be placed on sites where a number of selected water uses (drinking with limited or no treatment, contact recreation or irrigation) may occur because the real risk to human health manifests at such points. Preference was therefore given to an approach where the initial sampling sites would be located in areas with the largest number of identified water uses. Additional funds could later be used to ensure better representation of sampling sites.

High risk areas often cover a large geographical area and the conditions in such an area cannot be represented accurately by less than three sampling points. For very large areas the minimum number of sampling points required might be higher. There is no upper limit on the number of sampling points to be included, although at some level, additional points may not contribute any new information. The optimal number of sampling points would largely depend on the individual circumstances in the high risk areas.

The selection of sampling sites is to be approached at two levels. First the macrolocation of the sampling sites should be identified. In view of the abovementioned discussion, the final selection of the most appropriate river reaches should be guided by the land and water use data already collected for the areas. The focus would be *inter alia* on areas with no sanitation where people still use the water for a number of domestic purposes, or where polluted surface water is abstracted for limited treatment before distribution to a large section of the population. The number of macrolocations would be determined by the size of the high risk area and the number of sampling points that could be supported by the available budget. If funding for enough sampling points would be available, a procedure such as the one proposed by Sharp and modified by Sanders and coworkers (Sanders *et al.*, 1983) could be employed. Using this procedure the river network could systematically be subdivided into a specified number of equal portions based on a selected factor of interest, such as the number of tributaries or pollution sources. The macrolocations to be sampled would then correspond to each of these portions. With this approach, results obtained would be more representative of the general status of the area and could at the same time be used to indicate areas of concern.

The second level of sampling site selection would be to determine the specific location of a sampling site or microlocation. This would be determined by the spatial and temporal variation of the microbial water quality within the area. A preliminary investigation to determine the variation in quality in the area might be required before the final position of a sampling site is determined. In some areas, information on the variability in the microbial water quality may already be available from previous monitoring efforts in the area.

The specific location of sampling sites would be determined by the local conditions prevailing in each of the selected sections to be monitored. The importance of site visits in the final selection of sampling sites cannot be over emphasized. Apart from the site observations the selection of sampling sites could also be base on the following guidelines:

- The sampling site should provide information characteristic of the conditions in the section of the high risk area it represents;
- Sites close to an identified point of water use should receive preference;
- The site should be located where the microbial water quality is independent of the depth and lateral location in the stream's cross section, e.g. complete mixing could be assumed;
- The site should be accessible to the technical personnel for the collection of samples.

4.3.4 Determination of sampling frequency

4.3.4.1 Introduction

The sampling frequency is primarily determined by the information requirements of the monitoring programme. Operational constraints such as sampling procedures, transport and analysis costs and the capacity of the laboratories to handle the given number of samples, could however, also play an important role as estimates show that a large portion of the sampling cost directly relates to the frequency of sampling (Sanders *et al.*, 1983). The main objectives of the proposed monitoring programme were to determine the status and trends (also seasonal variation) in the microbial quality as well as to determine the potential health risk to water users based on the measured microbial water quality data.

In contrast to irrigation and contact recreation, the direct use of untreated water for domestic purposes (the most sensitive water use) is not tied to seasonal activities and information regarding the potential health risk for this use should be collected on a constant basis throughout the year. The sampling frequency should therefore be constant throughout the year and sampling should not only be focussing on specific seasonal effects.

4.3.4.2 Data analysis protocol

To specify the optimal sampling frequency during the design of the programme, a number of historical data sets were obtained and analysed. Analyses were performed using the Statistica (Ver.5) software. The data sets were selected on the basis of the consistency of the sampling frequency interval. For most of the sets, data were collected at weekly intervals.

Estimates of missing values had to be supplied in order to perform time series (serial correlation) analysis. When less than three consecutive values were missing, these values were estimated by linear interpolation between the adjacent existing values. When more values were missing, random observations were generated from a normal distribution with the mean and standard deviation of the natural log of all the other observations at the specific sampling point.

The first analysis was to test whether the data came from a normal distribution. The assumption is often made that microbial data would resemble a log-normal distribution and therefore each set was transformed by taking the natural logarithm of each measurement. Data were plotted as a normal probability plot and the Chi Square Goodness of fit test was performed to determine if the distribution was significantly different from a normal distribution.

The data sets were also evaluated for the presence of trends. Once any noticeable trend was detected, the trend value was subtracted from each log transformed value resulting in a stationary (the mean is equal for any subset of the data) data series. Based on the evaluations performed up to this point, a decision was made whether the assumptions of normality and the presence of a stationary trend could be still be used. Data sets that reasonably fitted these criteria were used to determine serial correlation among observations at the same sampling point.

If observations are made at short time intervals between sampling, their values may be correlated and some redundancy in the successive observations would exist. To determine the presence of any such dependance, the auto-correlation function was calculated. This function gives an indication of any dependence structure in the data by comparing sample values at increasing time periods. For example, lag one analysis compares a data point with the next observation made and lag two compares measurements with one intervening time period. The information obtained from the correlograms were used to determine the ideal sampling ferquency.

4.3.4.3 Analysis of data sets

The historical data sets were obtained from a number of institutions (University of Pretoria, Rand Water, Johannesburg City Council and DWAF) which are involved in monitoring on a full time or *ad hoc* basis. The sets mainly represented urban and peri-urban areas situated in the Gauteng area which is in the summer rainfall area of the country. One data set represented an area from the Western Cape which falls within the winter rainfall area. The data sets differed in sampling frequency (mostly weekly), coverage and period covered (from two months to 7 years).

The data sets used for the initial evaluation indicated that in most cases the data correlated poorly, even at a lag of one week. For one of the more extensive data sets, covering a period of 156 weeks, a statistically significant correlation coefficient at lag one was observed, but not at the other lags. The implication of the analysis of all the sets was that data should optimally be collected on a weekly basis. A monthly sampling frequency would miss substantial changes in the data and many high risk events may not be reported. In most cases, the historic sampling frequency was limited to a weekly basis and no evaluation could be performed on more frequent sampling regimes.

4.4 DATA COLLECTION AND MANAGEMENT

4.4.1 Introduction

A crucial aspect in the success of any monitoring programme is the proper administration and control of the sample collection, analysis and data storage processes. Standardisation of data collection and management of activities is of even greater importance when a number of agencies are involved in the collection of the data, as is foreseen in the case of the national microbial monitoring programme. To ensure the overall reliability of the collected data and comparison of data sets from different institutions, procedural guidelines, quality control and staff training are needed.

4.4.2 Sampling and methods of analysis

The collection, handling, transport and storage of samples are critical in any monitoring programme as the results of water quality analyses can be influenced by all these aspects. These are even of greater importance when determining the microbial quality of the water. Sampling procedures for microbial water samples have been described on a number of occasions (Bordner and Winter, 1978; Eaton *et al.*, 1995, Bartram and Ballance, 1996). This information can easily be incorporated in a standard operating procedure (SOP) custom made for the needs of this programme. The proposed SOP document should deal with issues such as suitable containers, labelling and washing procedures for containers, physical collection of the samples, measures to avoid contamination of the sample, as well as information of the handling of samples such as cooling, storage and transport, and maximum time lapse between sampling and analysis.

The faecal (thermotolerant) coliform group was selected as the microbial variable to be determined in this study. Two methods for the determination of faecal coliform levels in water are widely used in South Africa, i.e. the most probable number (MPN) method (in samples with a high turbidity) and the membrane filter technique. The membrane filter technique, using commercial m-FC agar would the method of choice for this monitoring programme. The advantages of this method are that results are available within 24 hours and the preparation and analysis procedures are less time consuming than for the MPN method. The MPN method should only be used for analysis when laboratories in an area are not equipped to perform the membrane filtration method. Both these methods are well described in Standard Methods (Eaton *et al.*, 1995) and in the SABS method 221-1990. Analysis should be performed according to these specifications.

In view of the high variability of microbial water quality data and difficulty in testing the validity of values, laboratories performing the analysis should implement the necessary quality control measures to ensure the validity of the data.

A few laboratories in South Africa use methods for the quantitative detection of *E. coli* and not faecal coliforms. The use of these methods for the analysis of any sample pertaining to the national monitoring programme should be discouraged to promote greater uniformity among the data sets. The programme will, however, have to rely heavily on voluntary participation of institutions. Data obtained by means of a different method as recommended in the design, should not be excluded from the programme. Such cases should be clearly indicated when registering the sampling sites as well as on the yearly reports. Comparisons with other areas where different methods or indicator organisms are being used should, however, be performed with caution.

The staff involved in the collection and analysis of the samples should have a clear understanding of their role in the monitoring programme and therefore they would receive the necessary training as well as a copy of the relevant SOP document.

4.4.3 Data collection and storage

The collection and storage of the monitoring data would be a vital link in the functioning of the programme. The Institute for Water Quality Studies (IWQS), DWAF is responsible for the operation of a number of national monitoring programmes and would have the function of coordinating the collection of data of the proposed microbial monitoring programme. This institute has developed the Water Management System (WMS) to assist in the operation and management of monitoring programmes. The WMS has a link to the Hydrological Information System - Quality Databank (HIS-QDB) on which the data would be stored. WMS is to provide a customized interface between the monitoring programme and the databank. WMS also allows for the automation of certain monitoring management functions e.g. sampling schedules and bi-monthly sampling progress reports. which would indicate outstanding and missing data.

For the optimal use of the WMS, each programme should give an indication of its specific requirements. The basic requirement which the systems should fulfill would be the registration of a unique microbial monitoring programme and the associated sampling points. The following information with regard to the sample point would be mandatory for registration:

- Location (latitude and longitude);
- High risk area and general description of land and water uses;
- Institutions responsible for sampling and analysis;
- Analytical methods used for sample analysis
- Variables and sampling frequency.

The system should be able to provide a format for the electronic transfer of data as this would help to minimize introduced errors due to repeated transcription of the data. A master file with limited access, should also be maintained to avoid the loss of data due to accidental erasure of data. Care should be taken that this file would be updated on a regular basis. WMS could also issue reports to the participating laboratories to confirm that their data have been received and processed.

Existing microbial water quality programmes, operated by other institutions, may also monitor for the presence of selected pathogens at the same sampling points. WMS should be able to link this type of information to the prescribed data collected for the specific sampling point.

With the possible involvement of a number of institutions in the microbial monitoring programme, a national coordinator will have to be appointed to control the flow of data from the various participants. An interruption in the flow of incoming data could be an early sign of sampling and analysis problems. The WMS could be of valuable assistance to the coordinator by creating reports on outstanding and missing data. WMS reports would alert the coordinator to contact the responsible laboratories to obtain the data and rectify any problem experienced.

Microbial data are often characterised by wide variability. Counts of organisms from samples collected in ambient water typically range over several orders of magnitude. The coordinator or a microbiologist assigned to the task would have to check the data on a regular basis to detect unusual or unlikely values.

To enhance cooperation between institutions and to demonstrate the government's policy of transparency, the monitoring data should be freely available for use. WMS should therefore facilitate data access by institutions and regional DWAF personnel dealing with microbial water quality management.

4.5 Data assessment and presentation

4.5.1 Introduction

One of the major reasons for the failure of monitoring programmes to improve water quality and the public's perception thereof, is the fact that collected data are seldom transformed into useful management information (Ward *et al.*, 1990; Ward, 1996). In some cases the collection of data has even been the sole purpose of the monitoring effort (Sanders *et al.*, 1983). The design and specification of data assessment methods is an important part of the process to achieve the monitoring objectives and should be established and agreed upon as part of the conceptual design.

The main objectives of the national microbial monitoring programme require that the data collected should provide information on the status of and trends in the extent of the faecal pollution of surface water resources in high risk areas and that an assessment should be given of the potential human health risk associated with the use of the water. Another objective requires that the data should be used to assess the effectiveness of any measures implemented to protect surface water against faecal pollution. Methods for data presentation (Section 4.5.2) and assessment (Section 4.5.3 and Section 4.5.4) are given to satisfy these goals.

As described in Section 3.2.1.3, the main users of the information derived from this programme, would be water resource managers who are responsible for the protection of the quality of South Africa's water resources. Some of these managers would be responsible for the general water quality within a specified catchment and would mainly be interested in data for their own area. Others are involved at a national level and would be more interested in the comparison of different areas. Reporting of the information as described in Section 4.5.5 was therefore designed to provide for the different needs in terms of the type and frequency of reporting.

4.5.2 Data representation

The incorporation of accurate statistical analyses on yearly data, as part of the preparation of reports, was considered but it was decided to limit it to the minimum during the preparation of general reports. The main reasons for this were the possible limits of statistical expertise within the implementation agency, the time involved, and the level of understanding of such analyses among the information users. The final decision was therefore to concentrate on a graphical presentation of the data.

The status of faecal pollution in a high risk area could be more clearly understood if the summarized data for each of the sampling points is presented separately. For this purpose, box and whisker plots would be most suited (Ward *et al.*, 1988). These plots (Figure 4.2) give a visual representation of the range, median and skewness of the data. Due to the variability present in microbiological water quality data, it would be better to use the log transformed values for the preparation of all box and whisker plots.

Apart from the graphical display, the values should also be summarized by their geometric mean. This value would be used as it is useful for the estimation of the central tendency of values which range over orders of magnitude (Sanders and Ward, 1993). None of the values should have

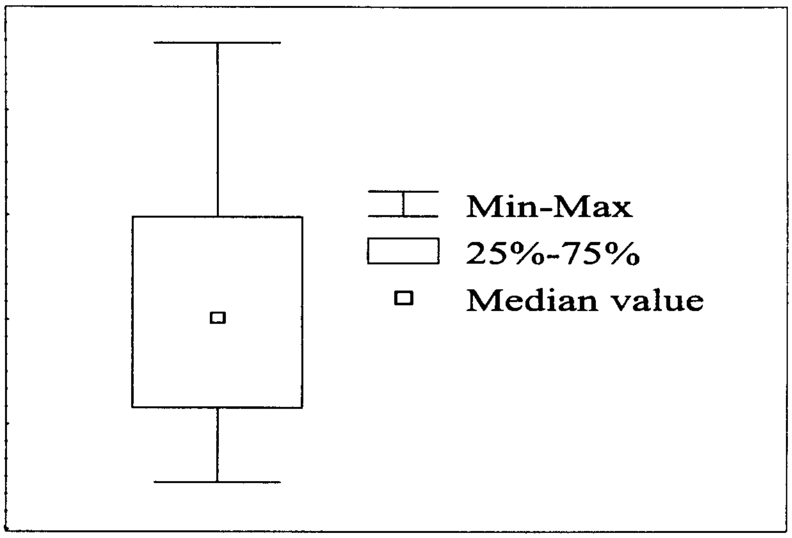


Figure 4.2 An example demonstrating the various components of a box and whisker plot.

a zero value when calculating the geometric mean. If a zero value is reported it should be eliminated from the data set before the calculation of the geometric mean. Although elimination of zero values will increase the uncertainty of the resultant value, it would be a rare situation. The faecal coliform count of heavily polluted rivers would seldom have a zero value. Should it not be the case the median could be used in stead of the geometric mean.

Initially the data sets will be limited in size and the only trends that could possibly be detected would be seasonal variation. As in the case of the entire data set, box and whisker plots might provide enough information to detect meaningful trends. The data set should be split into two, representing the main high and low flow periods. For the purpose of the programme, values collected between October and March would be considered to form part of the high flow period and those collected during the other six months to be part of the low flow period. In the case of winter rain i.e. Western Cape, the high flow period would be between April and September.

For the initial determination of trends, yearly box and whisker plots could be used. A graph showing the yearly data collected at a specific point, would give a suitable visual indication of possible trends. The detection of statistically significant trends should in most cases, where dramatic changes have not been noted, be attempted after having collected about three or more years of data. For the detection of statistically significant trends the combined data set should be log transformed, visually inspected for multiple trends and divided into subsets if necessary. The next step would be to test the set for normality, deseasonalise the data and perform a linear regression to determine the slope of the trend. If the data set does not follow a normal distribution, the original data could be submitted to a Kendall's Tau test for a trend and the slope could be determined using Sen's Estimate (Ward *et al.,* 1988).

Statistical analysis could detect the effectiveness of implemented measures to improve the microbial water quality. For the detection of effective measures taken, the data should be divided into two sets, one containing the values determined before implementation of the measures and the other consisting of all the measurements made thereafter. Comparison of data sets should only be attempted when both data sets would be large enough to allow for meaningful analysis. For data from a normal distribution a Student's t test could be performed. If the non-parametric approach is necessary due to the non-normal distribution of a limited data set, the median can be compared using the Mann-Whitney test (Ward *et al.*, 1988).

4.5.3 Assessment of the potential health risk

The following methods are suggested for interpretation of the faecal coliform data in terms of the potential health risk to each of the four selected water uses. The criteria for the categories of direct use of untreated water for domestic purposes and full or partial contact recreation were based on the latest edition of the South African water quality guidelines (Department of Water Affairs and Forestry, 1996a; Department of Water Affairs and Forestry, 1996b). The values for the irrigation of edible crops was based on the Canadian water quality guidelines (Canadian Council of Resource and Environment Ministers, 1987) and the values for the interpretation the data in terms of domestic purposes after limited treatment was based on the British standards (Gardiner and Zabel, 1989).The criteria are summarized in Table 4.6. Care was taken to ensure, where ever possible, that the criteria corresponded with the existing South African guidelines to avoid any conflict when the assessments would be reported.

During the assessment, each individual measurement would be scored for each of the four water uses, as representing a high, medium or low risk on the basis of the values reported in Table 4.6. Those data are used for the calculation of the potential health risk index of a specific high risk area as described in Section 4.4.4. A yearly assessment, based on the geometric mean of the annual data at each sampling point, would also be performed for each of the four water uses, based on the geometric mean of the yearly data.

Table 4.6 Potential health risks associated with the use of surface water based on the level of faecal coliform bacteria in the water

	Potential Health Risk		
	Low	Medium	High
Water uses	Faecal coliform count (CFU/100ml)		
Drinking untreated water	0	1 - 10	>10
Drinking water after limited treatment	<2 000	2 000- 20 000	> 20 000
Full or partial recreation	<600	600 - 2 000	> 2 000
Irrigation of crops to be eaten raw	< 1 000	1 000 - 10 000	> 10 000

4.5.4 Development of a health risk index

One of the biggest challenges faced during the development of assessment methods was how to present the information obtained from the data collected, in a format that would allow for the rapid comparison of high risk areas. The calculation of a potential health risk index (PHRI) was proposed. Calculation of an index allows for the consolidation of the information, obtained for several uses as measured at a number of sampling points, into one value. One of the advantages of this approach is that it has the ability to convey complex data to non-technical users. The disadvantage of such an approach is the loss of detailed information. To overcome this draw-back, the summarized raw data would always be presented on the yearly reports as was indicated in Section 4.5.2.

Various approaches have been suggested for the design of multiplicative water quality indeces (Dinius, 1987) which combine a number of water quality parameters. A need exists for an index to represent information on the potential health risks associated with the use of microbially polluted water. Because of the involvement of only one variable, a more simplified approach was justified. The PHRI was therefore based on the percentage of incidents where high risks were reported for all uses, everywhere in the high risk area, during that specific year. The number of high risk incidents reported for an area are calculated using the data for all the sampling sites in the area as well as the interpretation for all four of the water uses as show in Table 4.6.

The calculation is as follows:

$$PHRI = 100 \times \frac{\text{(Total number of high risk occurrences reported for all uses)}}{\text{(total number of assessments made for all uses)}}$$

The following guidelines should be used for the interpretation of the potential health risk index. PHRI values between 0 - 30 % would indicate limited pollution of the surface water and the risk would mainly be confined to the direct use of untreated water. Values of 30 - 60 % would represent moderate pollution with the risk mainly concerned with the direct use for domestic, recreational and irrigation purposes. Percentages of 60% and higher would indicate heavy microbial pollution of the surface water and a subsequent increase in the risk to human health.

4.5.5 Report formats

4.5.5.1 Technical reports

Yearly technical reports would be prepared to communicate the information of the microbial monitoring programme. For the wider communication of the programme's findings, two types of yearly reports would be prepared. The aim of the first type of report would be to give interested parties an overview of the current situation in South Africa. The second report would be issued for each of the high risk areas that were monitored and would aim at the stakeholders directly involved in the management of microbial water quality within that area.

The overview report would consist of a geographical display of the country which would indicate all the high risk areas sampled during the year and the microbial water quality in each area would be presented by the overall potential health risk index for the area.

As suggested in Sections 4.5.2 - 4.5.4 the detailed report on a high risk area would consist of the following information:

- A map of the area showing settlements, rivers or streams as well the location of all the sampling points in the high risk area;

- A description of the area including information on the general status of land and water uses in the area;
- A box and whisker plot depicting the annual microbial water quality measured at each sampling point;
- The geometric mean of the annual data for each sampling point and its assessment in terms of the potential human health risk to the four groups of identified uses;
- The potential health risk index as calculated for the high risk area;
- Trend analyses including seasonal box and whisker plots and if possible the comparison of the annual data of each sampling point;
- If required, a comparison of the data collected before and after the implementation of any specified measures to improve the microbial water quality in the area.

The information should be presented in a user friendly manner. The use of easily recognisable images representing the different water uses is to be encouraged and colour coding of the values of the potential health risk index should also be considered. The use of such measures would be standardised throughout the entire monitoring programme and if at all possible also between the other monitoring programmes operated by DWAF.

Water resource managers in the national DWAF office often deal with the national situation and would receive both the overview report as well as all the detailed reports on the high risk area monitored. If required, the data and assessments of the various high risk areas could be combined into a single report which would facilitate comparisons between the various high risk areas.

There is, also a need for more frequent reports. Regional water quality managers of DWAF or their staff, are usually involved in the day to day management of water resources in a specific catchment area. For the management of the potential health risk in an appropriate timeframe, information on the situation in the catchment is needed on a regular basis. For this purpose monthly or bi-monthly reports would be prepared. These reports would contain the raw data and would only be for limited distribution. The raw monitoring data for the last six months as well as the criteria specified in Table 4.6 for the assessment of health risks would be provided. Although these reports are for limited distribution within the Department, copies would be provided to participating institutions in the cases where the Department is not responsible for the actual monitoring. These reports would also assist local coordinators of the monitoring programme to ascertain whether all the data were received by the Department and where problems in sampling or analysis may have occurred. Once the monitoring programme is fully operational, the suggested bi-monthly reporting could easily be automated. Apart from the reports depicting the monitoring data and assessments, a report on the prioritisation process should also be compiled every time the prioritization process has been performed.

The above mentioned reports would fulfill all of the objectives set for the microbial monitoring programme. The prioritization report would provide information on the areas in the country where the faecal pollution of the surface water would be the highest. The detailed annual reports of the high risk areas would provide information on the status of and trends in the extent of the faecal pollution of surface waters in those areas. It would also provide information on the potential health risk to humans associated with the use of these contaminated water sources. If any measures were implemented to improve the microbial quality in an area, the detailed report would also provide some information to assess its effectiveness. As soon as the monitoring programme is implemented in selected high risk areas, the acceptability of the reports proposed in this section will have to be evaluated in terms of their format and the information provided.

4.5.5.2 Reports to the public

Monitoring programmes are often directly or indirectly funded by public money and the data created should not only be used to provide technical and management information but also be aimed at providing the public with comprehensible information. Developing such a reporting system would however, require exceptional skills because it would have to take the diverse needs and complexities of the South African society into account, including the recognition of the 11 official languages in the country..

The United States Environmental Protection Agency has made great progress in providing examples of reports aimed at the general public such as the full and summary report on water quality for 1998 to the US congress (United States Environmental Protection Agency, 2000a, United States Environmental Protection Agency, 2000b). To produce similar reports in South Africa would be very difficult due to financial constraints and the diverse needs of the public.

The areas most severely affected are rural and peri-urban areas where many of the people are often illiterate. The people living in rural and peri-urban areas would not gain any benefit from the above mentioned type of reports. The needs of rural and peri-urban communities are usually centred around education to create a basic understanding of the concept of microbial water quality and the creation of an awareness of the risks involved in utilizing untreated surface water.

There is however, still a keen interest among certain environmental groups within the South African society for more detailed information on the microbial quality of surface waters. Other users of the information include farmers as well as international and non-governmental organisations providing assistance and services to developing and rural communities. The information requirements of these groups should not be overlooked as their general support for programmes for the improvement of water supply and sanitation services as well as the improvement of surface water quality are invaluable. Special interest groups could also assist in the dissemination of the finding of the programme to the wider public.

The provision of information to the South African public should be addressed at two levels, namely a technical and a more social level. The need for technical information could be addressed by creating a website where interested parties could obtain background information on the national programme, descriptions of the various sampling points as well as the microbial water quality measured at a specific site. The information that should be released would typically be of the same format as suggested for the yearly high risk area reports as described in Section 4.5.5.

At the second level the focus would be on general communication to the people living in identified high risk areas which are being sampled. The purpose of such efforts would be to inform and make the public aware of the various risks associated with water use and to promote efforts to improve the situation within the community. Communication of the potential risks could be incorporated in the activities of existing water committees or programmes run by non-governmental organisations within these communities. The risk communication and dealings with the communities should be overseen by persons skilled in sociology or community participation approaches.

4.6 Implementation

4.6.1 Introduction

Without proper consideration and development of an implementation strategy, even the best designed and motivated monitoring programme might fail in practice. Attention needs to be given to the development of appropriate logistical, financial and coordination structures. Evaluation of the programme should also be addressed. The implementation of national monitoring programme would be carried out in two phases. Phase one would involve the development of an implementation strategy and accompanying documentation as well as the actual implementation of the programme in a few key areas. The development of the implementation strategy would be followed by phase two which would allow for a fully operational programme and provide for the appropriate co-ordination and execution of the programme on a continuing basis. Performance evaluation should also take place during this phase of the project. Dealing with the implementation of the programme separate from the design phase does not imply that important implementation issues of concern should not receive attention during the conceptual design phase. The purpose of the following sections is to highlight such issues.

4.6.2 Implementation strategy

As part of the conceptual design of the microbial monitoring programme, a number issues were identified which need to receive attention during the development of an implementation strategy. The most important issue was that of national and local coordination. Other issues include general awareness among stakeholders and users, quality control, training and funding.

4.6.2.1 Co-ordination

According to the legislation DWAF is the custodian of South Africa's water resources and is required to establish national water quality monitoring systems. A single person within the Department should therefore take the responsibility for the national co-ordination of the microbial monitoring programme. Without such a dedicated person within the Department, the national programme would be difficult to implement. Ideally the person should form part of the IWQS, an institute within DWAF which has the mandate to initiate such projects. The national co-ordinator would facilitate implementation of monitoring programmes in high risk areas according to the requirements of the national programme as would be prescribed in the implementation document. The person should also oversee data storage and assessment as well as the dissemination of the reports and information. Apart from the national coordinator, regional or area specific coordinators should also be appointed to ensure the day to day running of the monitoring programme. The implementation document should clearly spell out the duties and responsibilities of the various types of coordinators.

4.6.2.2 Quality assurance and training

The development of quality assurance and quality control measures should also be emphasised in the implementation document. The main purpose of such measures would be to provide trust in the data and information produced by the programme. The findings and recommendations of the programme should in no way be compromised by unreliable results. Guidelines similar to those usually specified in DWAF tender documents would be used for the appointment of regional analytical laboratories. These guidelines include issues such as the demonstration of analytical performance, the use of recognised and well documented methods, supervision by a qualified microbiologist and whether or not the laboratories have received accreditation. The analyses performed by these laboratories would also be guided by the standard operating procedures suggested in Section 4.4.2.

The implementation document to be prepared should also address the training needs that may exist among the various parties involved. If necessary, workshops or courses could be developed for the training of staff. Such training might assist staff to clarify their role and importance in the operation of the national programme and would also form part of quality assurance measures.

4.6.2.3 Funding

One of the major restrictions on the implementation of the national microbial monitoring programme is the availability of funds. Funding should receive urgent attention to ensure the sustainability and success of the programme. A number of approaches to improve funding exist and need to be further investigated during the implementation phase of the programme.

The one approach would be for DWAF to obtain the necessary funds for the monitoring programme from internal or external sources. Reallocation of internal sources would be difficult to justify since large amounts are at present spent on the provision of basic water supply and sanitation services. Projects to supply water and sanitation infrastructure have a direct impact on the quality of life of thousands of people and can also have a positive impact on the microbial quality of surface water resources. External funding such as donor aid could be a possible source of funds. The type of project and the long term commitment needed for monitoring programmes could, however, fall outside the scope of some of most of the donor aid programmes as they might only be interested in short term projects with a high visibility.

The second approach with a higher chance of success would be to obtain the involvement and long term commitment of other institutions such as water boards and local authorities, through negotiations and the creation of common goals. Involving other institutions does not imply that DWAF would be the only party to benefit from the cooperation. DWAF could on their behalf provide technical and management information and resources to assist these organisations in dealing with microbial water quality problems experienced in areas under their control.

In order to create the interest of other institutions the initial implementation of the programme in a few selected areas should also be used to demonstrate the need and use for such a programme. Regular communiques should be prepared to inform water quality managers about the progress and success of the programme. Areas with the necessary infrastructure, resources and capacity should initially be targeted. Once the programme is successfully implemented in a number of key areas, the available funding could be improved through cooperation with institutions that have noticed the benefits of the programme. The implementation document should provide information on how this process would be approached.

The performance of a cost / benefit analysis may be an additional tool that could assist in the process of obtaining increased funding or cooperation of other institutions. The basic approach of such a study is to relate and express the merits of the project to basic economic terms and concepts and to determine whether these benefits are in excess of the basic costs (Griffin 1998).

4.6.3. Performance evaluation

When an attempt is made at the evaluation and revision of a monitoring programme, the response of the primary information users (eg. water quality managers) towards the information provided by the programme should be determined. A number of approaches to obtain this feedback have been suggested (Ward *et al.*, 1990). In the case of a national programme, formal surveys should be conducted. Personal contact with the participants should be encouraged as it allows for clarification of comments and would assist in determining whether the information requirements have changed substantially. The necessary changes should be implemented as soon as possible to ensure that the monitoring programme remains relevant and of national use.

4.7 SUMMARY

During the conceptual design of a national microbial monitoring programme the following issues were addressed and decisions taken:

- The information expectations of potential users were evaluated and used to formulate the objectives of the monitoring programme;
- The concept of high risk areas was developed;
- A novel prioritization approach was developed for the selection of high risk areas;
- Land and water use information was proposed as the criteria for the selection and prioritization of areas to be monitored;
- The faecal coliform group was selected as the single microbial variable to be monitored, and based on historical data, a weekly sampling frequency was proposed;
- To ensure uniform sampling and analysis, the preparation of standard operation procedures were proposed as part of the data collection specifications. The data would best be managed through the Water Management System developed by of DWAF;
- A health risk index based on the assessment of the actual monitoring data was developed to indicate the potential health risk associated with water uses in an area. The distribution and preparation of both technical reports and those aimed at the general public were proposed;
- Programme coordination, quality control and funding was highlighted as issues to be addressed during the implementation of the national monitoring programme.

The conceptual design of the national microbial monitoring programme was followed by the next part of the design phase described in Chapter 5 and 6, which addressed the identification and ranking of high risk areas and the conducting of a pilot monitoring study.

CHAPTER 5: SELECTION OF HIGH RISK AREAS

5.1 INTRODUCTION

Many of South Africa's surface water resources are severely impacted by microbial pollution. During the development of the design framework for the proposed monitoring programme, areas of high human health impact was the primary focus. As a result the concept of high risk areas was proposed for the identification of impacted areas and a procedure for the calculation of priority values and ranking of high risk areas was developed.With the completion of the conceptual design, the next action was to evaluate and if necessary revise specific aspects of the design before initiating the implementation of the national programme. Conducting and evaluating the procedure for the selection of high risk areas were essential steps in the process to targeted areas with severe faecal pollution and constant human exposure and needed to be completed before any monitoring could take place.

As proposed in the conceptual design, the procedure for the selection of high risk areas consisted of a number of steps. In order to identify possible areas of high risk, all catchments were subjected to a screening process. The screening was followed by the collection of the prescribed land and water use data for all catchments retained after the initial screening. The next steps were the demarcation of high risk areas and the calculation of a priority value for each of the identified high risk areas. The process and its finding were evaluated by investigating alternative approaches.

5.2. SCREENING PROCEDURE

5.2.1 Approach

The initial screening was conducted during 1997 and members of the Institute for Water Quality Studies, DWAF assisted in the collection of data. Contact was made with the regional offices of DWAF and most of the information was obtained from either Water Quality Managers working in the regions or the Deputy Director, Water Quality Management of each region. Screening was done on a tertiary catchment scale for all catchments listed in Table 5.1 according to the procedure described in Section 4.3.1.6. Catchment locations are shown on the map in Figure 5.1. A few catchments e.g. A10, B20, Q70, R10, were screened on a secondary catchment level due to their small size.

5.2.2 Results

Of the 270 catchments initially screened, 123 were eliminated. They were mostly situated in the drier areas of the country where flow is often intermittent and/or where ground water is the predominant source of water. Examples are D57, E30, J21 - 25 and N 11 - 14. Other catchments eliminated were small, sparsely populated costal catchments such as F60, G50 and H90. The 147 catchments selected for further evaluation are shown in Figure 5.2 and listed in Table 5.2

5.3. DATA COLLECTION

5.3.1 Approach

The required land and water use data were collected for the 147 catchments listed in Table 5.2. Most of the data were obtained from DWAF's Water Supply and Sanitation database. The database did not contain information on recreational activities, irrigation and the presence of feedlots and this information had to be obtained from others sources such as regional Water Quality Managers and Water Boards.

For a number of water and land uses, the database did not differentiate between the attributes as proposed in Sections 4.3.1.3 and 4.3.1.4. No separate data were available on the number of individuals with sanitation infrastructure that is either inappropriate, inefficient, poorly maintained or operated or on the number of individuals supplied with surface water for domestic purposes after limited treatment. In most cases, these individuals were grouped under the broad category "*below the basic level of water supply or sanitation*" as measured by the Reconstruction and Development Programme (RDP) standards (African National Congress, 1994). To get a detailed break down of the data would have been very time consuming and the decision was taken not to include the abovementioned two categories in the calculations during the present prioritization exercise. In addition as an additive model was used for calculation of priority values, interaction

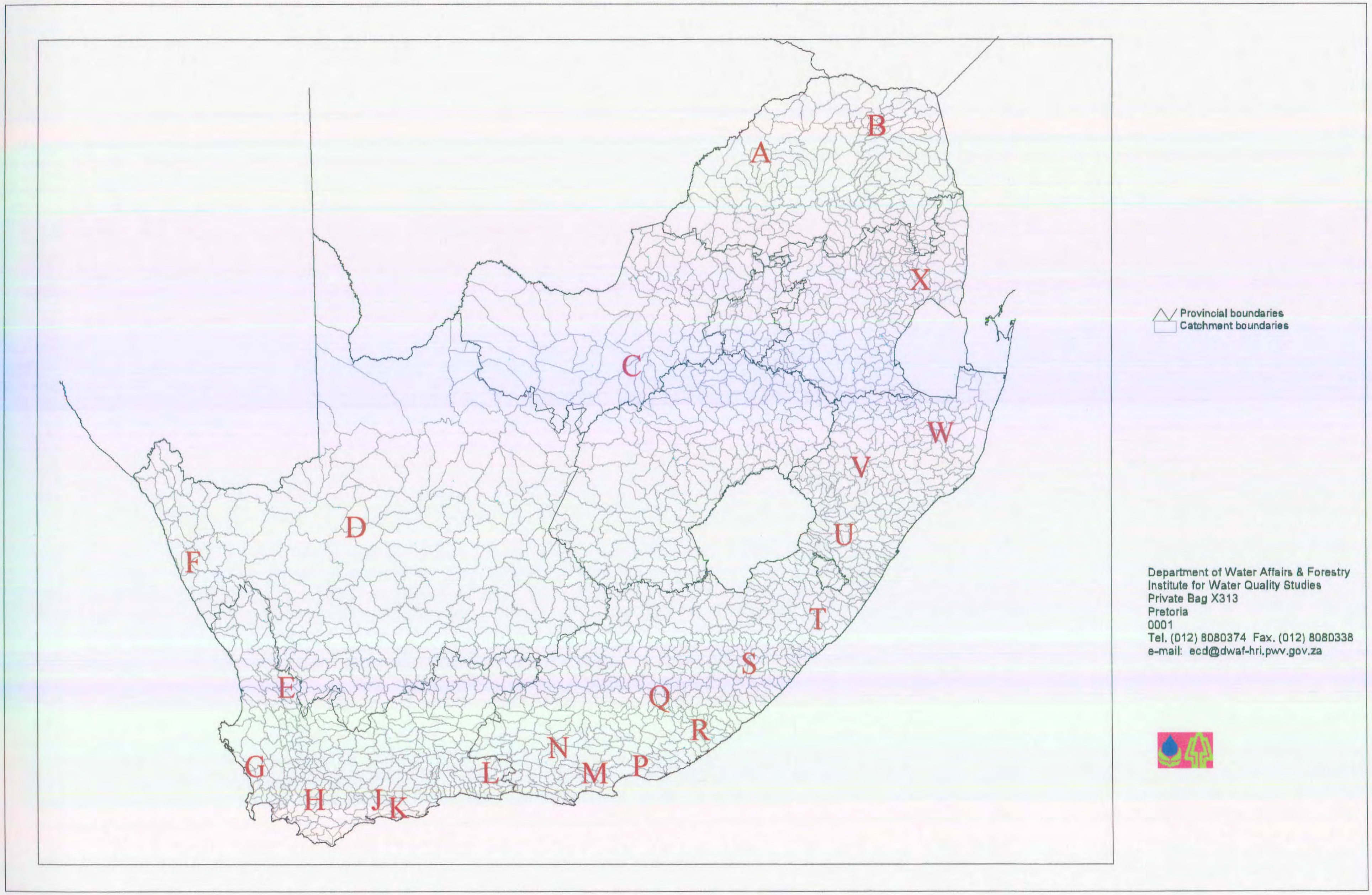


Figure 5.1 Map indicating catchments included in the screening process.

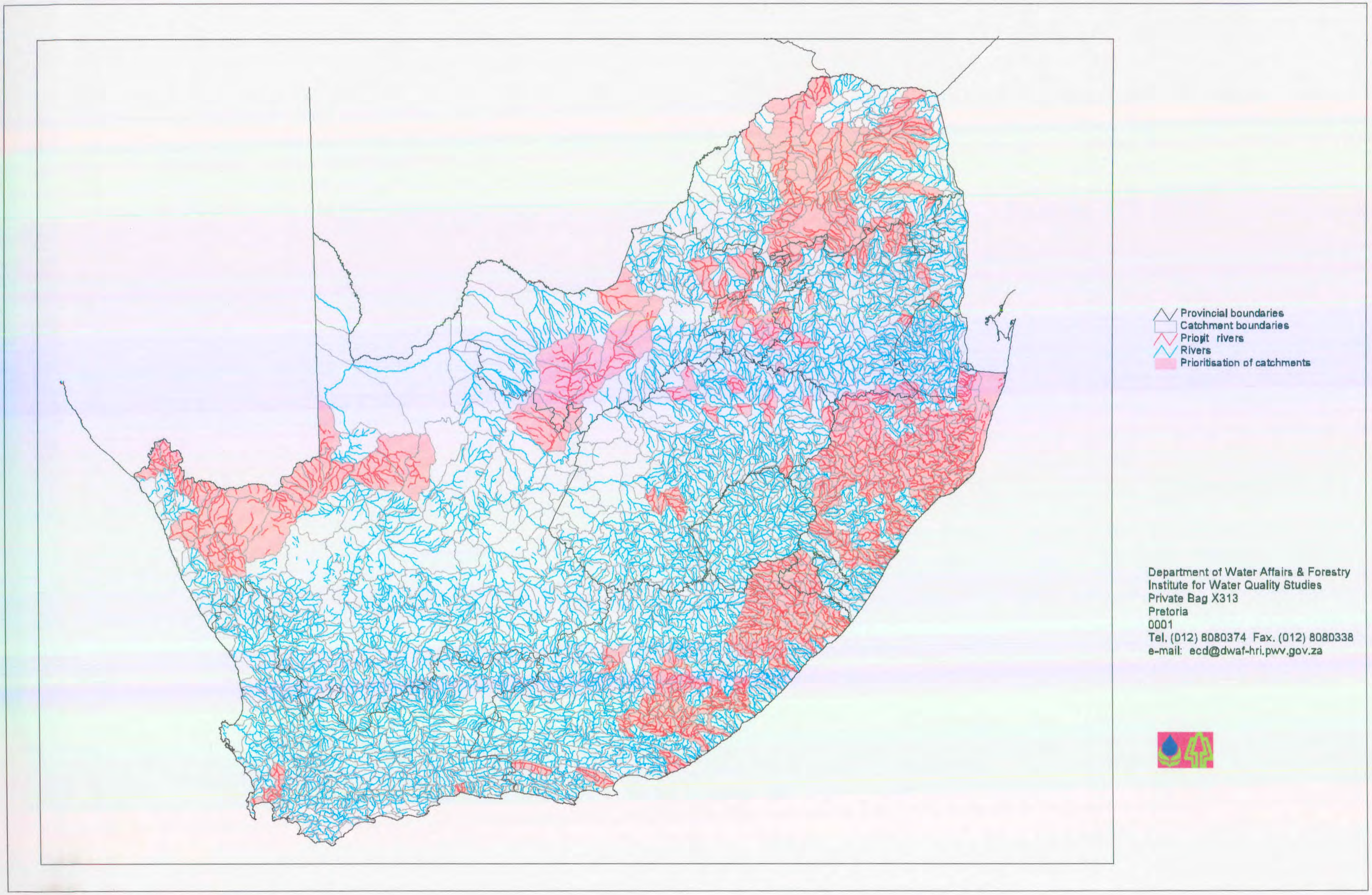


Figure 5.2 Map indicating catchments retained after the initial screening.

Table 5.1 Tertiary catchments within the boarders of the Republic of South Africa included in the initial screening process

Primary drainage area																					
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**J**	**K**	**L**	**M**	**N**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	**X**
10	11	11	12	10	10	10	10	11	10	11	10	11	10	11	10	10	11	10	11	11	11
21	12	12	13	21	20	21	20	12	20	12	20	12	20	12	20	20	12	20	12	12	12
22	20	13	14	22	30	22	30	13	30	21	30	13	30	13	30	31	13	30	13	13	13
23	31	21	15	23	40	30	40	21	40	22		14	40	14	40	32	20	40	14	21	14
24	32	22	18	24	50	40	50	22	50	23		21		21	50	40	31	50	20	22	21
31	41	23	21	31	60	50	60	23	60	30		22		22		50	32	60	31	23	22
32	42	24	22	32			70	24	70	40		23		30		60	33	70	32	31	23
41	51	25	23	33			80	25	80	50		24		41		70	34	80	33	32	24
42	52	31	24	40			90	31	90	60		30		42			35		40	41	31
50	60	32	31					32		70		40		43			36		50	42	32
61	71	33	32					33		81				44			40		60	44	33
62	72	41	33					34		82				50			51		70	45	40
63	73	42	34					35		90				60			52			51	
71	81	43	35					40						70			60			52	
72	82	51	41											80			70			53	
80	83	52	42											91			80			54	
91	90	60	51											92			90			55	
92		70	52											93						56	
		81	53											94						70	
		82	54																		
		83	55																		
			56																		
			57																		
			58																		
			61																		
			62																		
			71																		
			72																		
			73																		
			81																		
			82																		

Table 5.2 Tertiary catchments selected for further evaluation

Primary drainage area																			
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**K**	**L**	**M**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	**X**
21	11	12	21	10	30	10	10	10	11	10	40	13	10	31	11	10	11	11	11
22	12	13	22			21	30	30	12			30	20	32	20	20	12	12	12
23	20	21	23			22	40	60	81			44	30	40	31	30	13	13	13
24	31	22	24			40	50	90	82			50		60	32	40	14	21	14
31	32	23	41									70		70	33	50	20	22	21
32	41	31	42									92			34	60	31	23	22
41	42	32	53									94			35	70	32	31	23
42	51	33	73												36		33	32	24
50	52	52	81												60		40	41	31
61	60	60	82														50	42	32
62	71	70															60	44	33
63	72	81															70	45	40
71	73	82																51	
72	81	83																70	
80	82																		
91	83																		
92	90																		

between values for attributes could overemphasize the real contribution of these attributes. The assessment was therefore based on the information contained in the database and no distinction was made between individuals with no treated water and those with inadequately treated water.

Apart from the required data, an estimation of the proportion of people dependent on ground water was also required. The focus of the programme is only on surface water and people using untreated ground water as an alternative source of drinking water should not be included in the data. In catchments where this was applicable, the water use data was adjusted using the obtained estimates to exclude the fraction of people dependant on ground water alone.

5.4. DEMARCATION OF HIGH RISK AREAS

5.4.1 Approach

Selection of areas where a high number of sensitive water users are exposed to water of poor microbial quality was carried out. After appraisal of the land and water use data collected, another 49 catchments were eliminated from the demarcation process. Although these catchments that were eliminated were selected based on the general criteria used for the screening process, as described in Section 4.2.1.3, the land and water use data suggested that only a limited number of people in these areas are affected by poor microbial quality of surface water. A typical example would be catchment E10 where it was estimated that less than 500 people might be using untreated surface water for domestic purposes, or H 30 where most people already have access to treated water. The catchments that were further investigated for the demarcation of high risk areas are given in Table 5.3

Table 5.3 Catchments investigated for the demarcation of high risk areas

A	B	C	D	F	G	K	L	M	P	Q	R	S	T	U	V	W	X
21	11	12	41	30	10	30	11	10	40	13	10	32	11	10	12	11	12
22	20	13	73		22		12			70	20	40	20	20	13	12	14
23	31	21	81				81			92		60	31	30	14	13	24
50	41	22	82									70	32	40	20	21	
61	51	31											33	60	31	22	
62	52	32											34	70	32	23	
63	60	33											35		33	31	
71	71	52											36		40	32	
72	81	60											60		50	41	
91	82	70													60	42	
92	90	81													70	44	
		83														45	
																70	

5.4.2 Results

A total of 119 high risk areas were identified in the remaining 98 catchments listed above. The specific demarcation of a risk area depended largely on the unique situation in the catchment. In a number of cases more than one tertiary catchments were combined into one high risk area. An example of such a combination is found in the T drainage area were catchments T 31 -T36 were grouped together. These rural tertiary catchments are located north of Umtata in the Eastern Cape province. In the abovementioned rural area, sanitation infrastructure is lacking and most of the communities still rely on untreated surface water for domestic purposes. Land uses (mostly small rural villages) which have an impact on the microbial water quality were in close proximity to sensitive water uses throughout the area and there was no indication that these tertiary catchments could be separated from each other.

In most of the catchments, the whole tertiary catchment or certain parts thereof were incorporated into a single high risk area: e.g. in catchment S40 only the d ,e and f quaternary catchments were included. The a, b and c quaternary catchments are sparsely populated and minimal risk to downstream users occurs. Lastly, in some of the tertiary catchments more than one high risk area could be identified; e.g. catchment C60 where quaternary catchments d and j were identified as two separate high risk areas. These areas are more than 80 km apart and are separated by a sparsely populated farming area known for maize production.

The final list of high risk areas are given below:

Catchment A: 21c-h, 21k, 22f, 22h, 23jf, 23k, 50gh, 61-63, 71a-h, 72a, 91a-h, 92a-d

Catchment B: 11k, 20a-c, 31d-j, 41d-k, 50, 60, 71g, 72k-j&73c, 81c-d, 82d-h, 90b-d, 90f

Catchment C: 12d, 12h, 13c, 13g, 21b, 21d-f, 22, 31-33, 52b-d, 52f, 60d, 60j, 70a, 70c, 70k, 81f, 83g-h

Catchment D: 41a, 73d-f, 81-82

Catchment F: 30a-g

Catchment G: 10c-d, 22d, 22e-h, 22g

Catchment K: 30c, 30d

Catchment L: 10, 81

Catchment M: 10

Catchment P: 40

Catchment Q: 13, 70, 92, 94

Catchment R: 10, 20d-e, 20f, 20g

Catchment S: 31d-f, 32, 40d-f, 60, 70

Catchment T: 11, 20ab, 20c-g, 31-36, 60a, 60b-d, 60e-g, 60j

Catchment U: 10, 20g, 20j, 30a, 30c-d, 30e, 40d-j, 60c, 60d, 60e, 60f, 70b-d, 70f

Catchment V: 12&14e, 13a-e, 14cd, 20hj, 31-33, 40, 50, 60, 70a-c, 70de

CatchmentW: 11a-c, 12ab, 12c-j, 13ab, 21d-l, 22b-l, 23a-d, 31&32ab, 32c, 32de, 32h, 41e-g,42a-m, 43f, 44b, 45ab, 70

Catchment X: 12h-k, 14e-g, 24 a-c

5.5 PRIORITIZATION

5.5.1 Approach

Priority values were calculated for the high risk areas to allow ranking of the areas. The same data as used during the demarcation process was utilized. As mentioned before, data in DWAF's Water Supply and Sanitation Database, which was used as the main source of information, were not always differentiated according to the same categories as proposed for the prioritization process. In most of the cases the information was included under the broad categories of "no sanitation" or "no water supply" which were based on the standards as described in the RDP document (African National Congress, 1994).

No attempt was made to split the data into the various categories. The land use value of an area was calculated based on the individuals without sanitation and the category dealing with sanitation infrastructure that was either inappropriate, inefficient and poorly maintained or operated was not dealt with. Information on population density and livestock farming was used for the calculation of the land use value. The same approach was followed for the water use value where no value was calculated for the category of people receiving surface water for domestic purposes after limited treatment. The implication of this decision was discussed in Section 5.6.2.

The priority value of an area was calculated as described in Section 4.3.1.8. Values for the various land and water use attributes were aggregated within each high risk area to determine their land and water uses values. These two values were thereafter used to determine the final priority value. The data used for and calculation of the priority values are shown in Table 5. 4.

5.5.2 Results

The priority values calculated for the various high risk areas are presented in Table 5.4. A list of the areas ranked according to their priority values are given in Table 5.5 and the geographical locations of the areas are shown in Figure 5.3.

5.6 EVALUATION OF THE PRIORITIZATION PROCESS

5.6.1 Data collection

The availability of data used for prioritization and the cost involved in its collection is one of the major issues of concern. During the first prioritization process, most of the data were obtained from the DWAF Water Supply and Sanitation Database. Collection of information not contained in the DWAF database (recreation activities, irrigation, feedlots) was a tedious process as contacting people with detailed knowledge of the catchment is often very difficult. If the DWAF database is continuously updated the same database could be used in future when the prioritization of areas is to be repeated. At present the supply of water and sanitation services is considered to be one of the key performance areas of the government and the database is used to measure its performance (Department of Water Affairs and Forestry, 1999). If water supply and sanitation data are not readily available in future the whole approach for the selection of areas to be monitored should be reconsidered.

5.6.2 Attributes used

The database did not contain separate information on some of the proposed attributes related to the maintenance and efficiency of water supply and sanitation services and these attributes were excluded from the prioritization process. The exclusion of these attribute does not imply that they were not accounted for during prioritization and that the quality of prioritization process would be negatively affected. In most cases the information was included under the broad categories of "no sanitation" or "no water supply" in the database. The question arose whether these attributes should not all together be eliminated from the prioritization process. After careful consideration

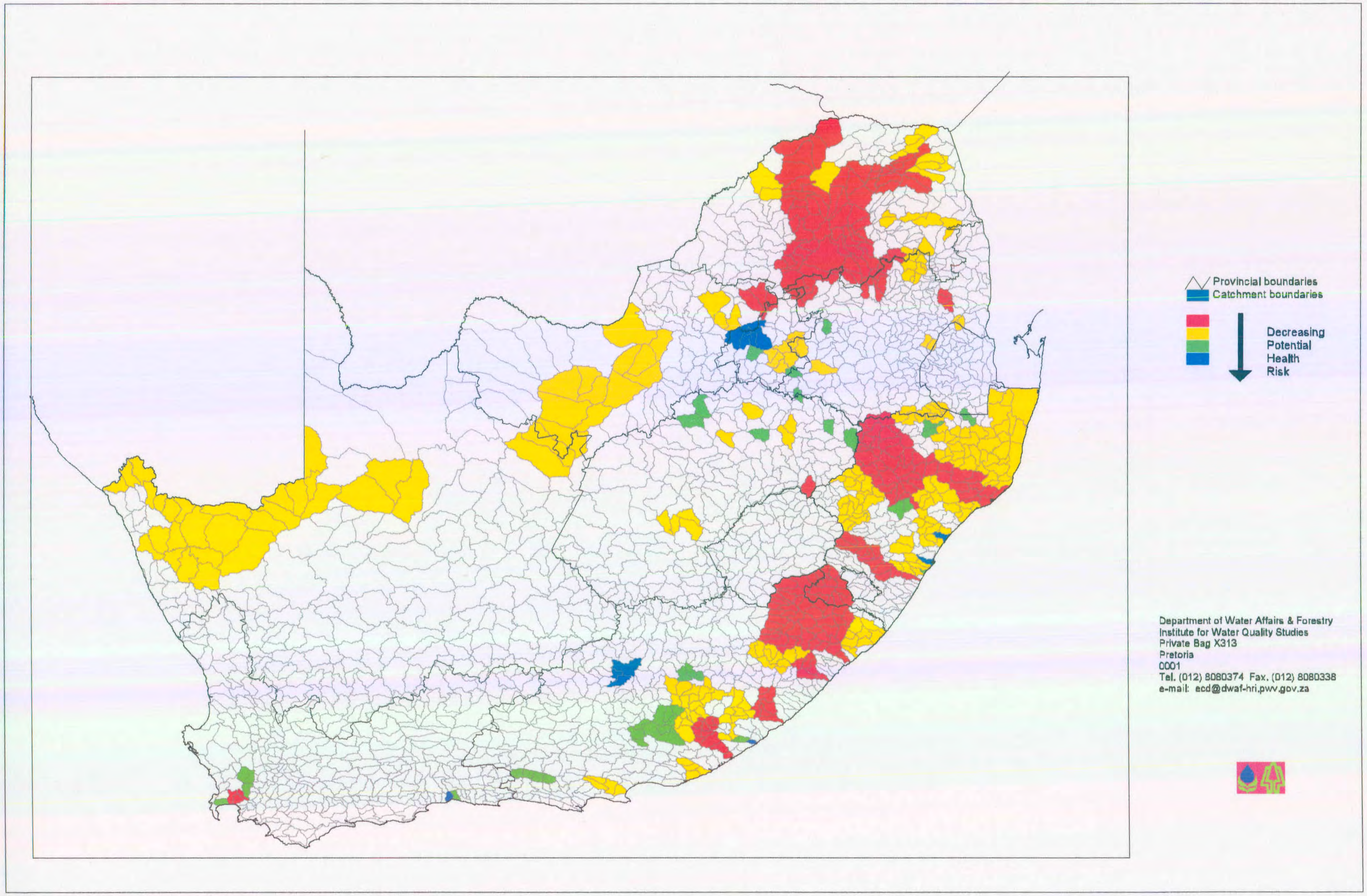


Figure 5.3 Map indicating the selected high risk areas grouped according to their assigned priority values.

Table 5.4 Summary of priority value calculations for all identified high risk areas

Risk area	Sanitation needs (N)	Population density (P)	Intensive farming	Land use value	Water needs (Q)	Recreation (S)	Irrig. (T)	Water use value	Priority value
	# of people	People / km^2	# of animals		# of people	people/month	ha		
T31-T36	1447258	1907		306826	1080571			324171	630998
B50	1037676	3140		220000	845374			253612	473612
A23k	279603	3950		59292	493479			148044	207335
A23jf	351985	4155		74637	371135		75	118091	192728
B31d-j	535962	3324		113637	192123		12	58717	172354
B82d-h	441485	4465	1500 cattle	93673	222277			66683	160356
C81f	496067	3435		105180	166610			49983	155163
V31-V33	285292	1131		60486	290598			87179	147666
W21d-l	272420	1315		57758	273872			82162	139920
X24a-c	313280	6009		66439	225870	100		67941	134380
T20c-g	269822	6363		57228	220178		112	76133	133361
U10	253200	1316		53684	265519			79656	133339
B41d-k	252950	2208	200 000 cattle	53994	149523		364	77617	131611
W12c-j	185450	1092		39320	287598			86279	125599
R10	227288	1580		48191	156472		150	60442	108633
S70	238662	2083		50605	188357			56507	107112
A61-A63	423455	3102		89785	50833			15250	105035
A91a-h	417035	3426		88425	51253			15376	103801
A71a-h	423169	3945		89728	43161			12948	102676
G22e-h	179993	7359		38188	212639			63792	101980
V60	146670	737		31097	235806			70742	101839
C52b-d	344504	2345	640000 chickens	73044	48250	625		15600	88644
T11	198179	1143		42019	155357			46607	88626
W22b-l	98660	1379		20921	216598			64979	85901
V12+V14	163728	668		34713	164458			49337	84050
C31-C33	252510	2974		53544	99354			29806	83350
V50	150575	706		31925	150960			45288	77213
T60e-g	156691	2379		33228	141508			42452	75680
T60b-d	151069	1536		32033	132277			39683	71716
U40d-j	137032	767		29054	131320			39396	68450
X14e-g	124700	9495		26474	109100			32730	59204
W31-W32	52053	639		11038	148212			44464	55501
V40	107478	465		22787	106492			31948	54735
B81c-d	127713	6382		27101	63303		80	26191	53292
S32	123205	1916		26127	70174		30	23752	49879
B60	113003	6919		23984	78361			23508	47493
W23a-d	80502	906		17070	98400			29520	46590
U30a	91290	951		19357	87870			26361	45718
T20ab	102874	1773		21816	65667			19700	41516
W12ab	80890	776		17152	79140			23742	40894

Table 5.4 (cont) Summary of priority value calculations for all identified high risk areas

Risk area	Sanitation needs (N) # of people	Population density (P) People / km²	Intensive farming # of animals	Land use value	Water needs (Q) # of people	Recreation. (S) people/month	Irrig. (T) ha	Water use value	Priority value
C12d	2400	7725		540	131600			39480	40020
W45ab	81008	141		17174	75604			22681	39855
F30a-g	12042	8451		2587	444		400	36133	38720
V13a-e	74670	540		15832	73686			22106	37938
W70	71620	108		15184	70008			21002	36186
D41a	154122	2370		32683	11637			3491	36174
P40	17863	2792		3798	13510	100	305	31683	35481
V70de	68850	1881		14604	68810			20643	35247
R20d-e	96542	1769		20474	47120	50		14226	34700
W11a-c	41024	1023		8701	84562			25369	34070
B90b-d	61887	3862		13135	69624			20887	34023
A92a-d	138435	4039		29364	14226			4268	33632
M10	24903	4871		5299	11919		260	26976	32275
C22	148495	15000		31541	1739			522	32063
B72k-jB73c	69146	4605		14677	42424		50	17227	31905
U30cd	62260	459		13201	62260			18678	31879
A22f	85390	3068		18115	40710			12213	30328
W13ab	14790	3830		3151	78479			23544	26695
V70a-c	52050	887		11038	52050			15615	26653
C52f	79950	5747		16972	23400		3	7290	24262
T60a	56845	1859		12059	39784			11935	23994
U70b-d	16180	373		3432	64880			19464	22896
B90f	52705	2282		11183	35752			10726	21908
W42a-m	3168	401		673	70719			21216	21889
B71g	42399	9698		9027	41919			12576	21603
A21k	19470	2239		4137	57258			17177	21314
U60c	85800	834		18193	8000			2400	20593
C21def	54181	15000		11546	107		100	9032	20578
S40d-f	42543	1161		9024	37422			11227	20250
W43f	36961	94		7836	37166			11150	18986
T60j	36802	1510		7808	32286			9686	17494
U20g	42890	694	22000 cattle (x3)	9455	26133	100		8020	17475
A72a	66746	2447		14160	9719			2916	17076
U20j	23480	1641		4984	30600	1000		10980	15964
D73d-f	26424	9955	4700 cattle	5642	32131	100	2	9999	15641
A22h	11830	3041		2520	12017		100	12605	15125
X12h-k	33440	3045		7101	24720			7416	14517
C83g-h	33970	6144		7226	24158			7247	14474
Q94	36474	1513		7739	22167			6650	14389
U60e	300	778		67	45130			13539	13606

Table 5.4 (cont) Summary of priority value calculations for all identified high risk areas+

Risk area	Sanitation needs (N)	Population density (P)	Intensive farming	Land use value	Water needs (Q)	Recreation (S)	Irrig. (T)	Water use value	Priority value
	# of people	People / km²	# of animals		# of people	people/month	ha		
U60d	30000	883		6364	19900			5970	12334
C60d	55860	4856		11862	1398			419	12281
A50gh	50300	5881		10687	3124			937	11624
W32de	3080	2494		663	36492			10948	11611
S60	5781	1164		1230	3532		100	10060	11290
C70c	34602	8860		7371	12396			3719	11090
D81-D82	15355	7164		3284	25970			7791	11075
B20a-c	4712	14689	100 cattle	1058	1700		100	9510	10568
C70k	45435	9300		9669	0			0	9669
U70f	0	1161		5	31000			9300	9305
B11k	15000	17645		3251	15000		10	5400	8651
V14cd	16030	628		3401	15900			4770	8171
C12h	9752	4541		2086	19600			5880	7966
G22d	31500	18797		6753	3400			1020	7773
V20hj	0	489		2	23280			6984	6986
C60j	22950	15227		4926	5850			1755	6681
C13g	24500	11358		5239	3500			1050	6289
W32h	12060	3080		2569	12060			3618	6187
W44b	0	585		2	20000			6000	6002
R20f	12495	6160		2794	7497	100	1	2519	5313
C21b	16445	15000		3546	3795			1139	4685
W41e-g	0	509		2	13050			3915	3917
C70a	18000	6734		3843	0			0	3843
S31d-f	8456	1642		1799	6480			1944	3743
Q92	8270	2844	200 cattle	1765	4479			1344	3108
G10c-d	10902	4200		2328	788			236	2564
C13c	0	4263		17	7500			2250	2267
W32c	0	827		3	4750			1425	1428
G22g	6004	6285		1298	0			0	1298
Q70	3297	1418		705	1927			578	1283
L81	2490	1068		532	1992			598	1130
K30d	0	12784		51	3360			1008	1059
L10	2254	3592		492	1803			541	1033
R20g	1484	2763		326	1373			412	738
A21c-h	200	667		45	1100			330	375
K30c	1500	8480		352	30			9	361
U30e	200	249		43	200			60	103
Q13	26	308		7	211			63	70
U60f	0	1793		7	0			0	7

Table 5.5 List of high risk areas ranked according to their priority ratings

Ranking	Area	Ranking	Area	Ranking	Area	Ranking	Area
1	T31-36	31	X14e-g	61	T60a	91	B11k
2	B50	32	W31-32	62	U70b-d	92	V14cd
3	A23k	33	V40	63	B90f	93	C12h
4	A23fj	34	B81c-d	64	W42a-m	94	G22d
5	B31d-j	35	S32	65	B71g	95	V20hj
6	B82d-h	36	B60	66	A21k	96	C60j
7	C81f	37	W23a-d	67	U60c	97	C13g
8	V31-33	38	U30a	68	C21d-f	98	W32h
9	W21d-l	39	T20ab	69	S40d-f	99	W44b
10	X24a-c	40	W12ab	70	W43f	100	R20f
11	T20c-g	41	C12d	71	T60j	101	C21b
12	U10	42	W45ab	72	U20g	102	W41e-g
13	B41d-k	43	F30a-g	73	A72a	103	C70a
14	W12c-j	44	V13a-e	74	U20j	104	S31d-f
15	R10	45	D41a	75	D73d-f	105	Q92
16	S70	46	W70	76	A22h	106	G10c-d
17	A61-63	47	P40	77	C83g-h	107	C13c
18	A91a-h	48	V70de	78	X12h-k	108	W32c
19	A71a-h	49	R20de	79	Q94	109	G22g
20	G22e-h	50	W11a-c	80	U60e	110	Q70
21	V60	51	B90b-d	81	U60d	111	L81
22	C52b-d	52	A92a-d	82	C60d	112	K30d
23	T11	53	M10	83	A50gh	113	L10
24	W22b-l	54	C22	84	W32de	114	R20g
25	V12&V14e	55	B72k-&73c	85	S60	115	A21c-h
26	C31-33	56	U30cd	86	C70c	116	K30c
27	V50	57	A22f	87	D81-82	117	U30e
28	T60e-g	58	W13ab	88	B20a-c	118	Q13
29	T60b-d	59	V70a-c	89	C70k	119	U60f
30	U40d-j	60	C52f	90	U70f		

of the situation they were retained. More and more communities are being supplied with water and sanitation services but concern exists whether the communities or the responsible local authorities would be in a position to maintain and effectively operate these services. Attributes such as inappropriate, inefficient, poorly maintained or operated sanitation systems and the supply of surface water for domestic purposes after limited treatment could therefore increase in importance during the next two decades.

5.6.3 Relative weight of land and water use data

The robustness of the process was assessed by evaluating the effect of changes in the relative weight assigned to land and water uses on the prioritization process was evaluated. Six high risk areas from the T drainage area with different priority values were selected for the sensitivity analysis. All the data for the T drainage area come from the same source and would have the same reliability. A summary of the raw data are given in Table 5.6. Figure 5.4 shows the results of the sensitivity analysis. For the analysis the contribution of the land use value (LUV) to the priority value was varied between 0 to 100% and the contribution of the water use value (WUV) was adjusted accordingly. Any change in ratios assigned to land and water use would not have had a major impact on the priority value of these high risk areas. None of the lines representing the six different areas cross at any time which also indicate these areas could be rated on water or land use data alone.

Table 5.6 Data used for the sensitivity analysis

Area	Ranking	Land use value (LUV)	Water use value (WUV)
T31 - 36	1	306 826	324 171
20c-g	11	57 228	76 133
T11	23	42 019	46 607
T20ab	39	21 816	19 700
T60a	61	12 059	11 935
T60j	71	7 808	9 686

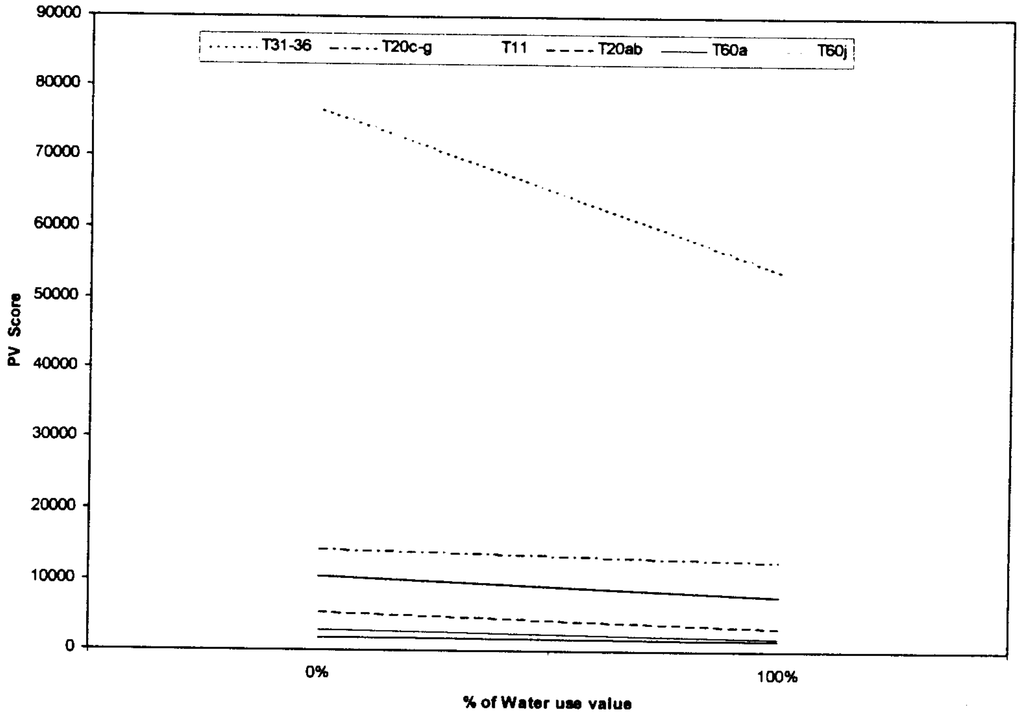


Figure 5.4 Sensitivity analysis performed on water use data.

Based on the results of the initial sensitivity analysis, another breakdown of the data was performed. During this analysis the effect of only using the LUV or WUV for prioritization was investigated. For both scenarios, 17 of the initial 20 top ranking areas would still form part of the 20 highest ranking areas. When performing the same analysis on the 60 highest ranking areas 11 of the areas would have been excluded using LUV values but only three areas when using WUV values alone. Using WUV alone represents an error of between 5 and 18%. The lower error associated with the use of water use information alone is to be expected as the WUV already constitute 60% of the priority value.

5.6.4 Size of high risk areas

During demarcation of high risk areas no attention was given to the size of the areas. Demarcation was solely based on the possible health effect of upstream land use on water use in an area. Focusing only on the possible health effects has led to the delineation of high risk areas of considerable size differentiation. Concern were expressed that the larger areas might have received higher priority values due to the cumulative effect of land and water uses in these areas. To address the concern that area size might influence the priority values of high risk areas, two analyses were performed. The priority list was investigated to determine whether larger areas consistently scored higher than smaller high risk areas and the effect of normalizing priority values by expressing the priority values as a value per km^2 was determined.

The relationship between the total area of the catchment and the priority value given to that area was investigated by ranking the high risk areas according to the size of the catchments as is shown in Table 5.7. The fact that the two highest ranking areas were also among the 10 largest areas created a perception that there was a bias towards the larger areas. The data also showed that 75% of the areas included in the top half of the priority list were also included in the top half when ranked according to their size (km^2) value . Closer inspection of the data did not however, provide direct evidence of a bias towards the larger areas. Only three of the top ten areas ranked according to size ranked among the top 10 priority areas. The largest area had a priority ranking of 26 and the second largest ranked at 87. Kendall's rank correlation coefficient also indicated that no significant correlation existed between these two data sets.

Although no clear indication of a significant bias towards larger areas was noted, an additional test was performed to investigate the effect of area size on the priority ranking. The additional test was done by normalizing the priority values. Normalization was performed by dividing the original priority value of the high risk area by the area's total surface area. The normalization resulted in a priority value expressed per km^2. The result of the ranking based on these new values is shown in Table 5.8. Although 73% of the areas retained their position among the top half of the high risk areas, the actual ranking changed considerably. Only three areas remained among the top ten with the top ranking area moving to position 47 and the second highest to position 23.

Analysis found that the surface area normalization procedure created a bias towards smaller areas. Most of the areas that showed a dramatic increase in their ranking were among the smallest when considering the surface area of the catchments involved. Of the 10 highest ranking areas 8 came from the lower half when the areas were grouped according to size. Some of these areas belonged to the coastal catchments on the east coast of South Africa. Although a definite risk of water-borne diseases exists in these areas, the number of people exposed is limited. People in the surrounding areas are not exposed due to the isolation of these catchments. The value as expressed per km^2 does not give an indication of the true extent of the problem. The purpose of the prioritization process

Table 5.7 Priority areas ranked according to the size of the catchments included

Area	Size ranking	Priority ranking	Area	Size ranking	Priority ranking
C31-C33	1	26	A91a-h	31	18
D81-D82	2	87	T11	32	22
T31-T36	3	1	V12+V14	33	25
A61-A63	4	17	B72j-k B73c	34	55
D73d-f	5	74	S70	35	16
L10	6	113	A92a-d	36	52
V31-33	7	8	C52b-d	37	23
F30a-g	8	43	A72a	38	73
B50	9	2	W45ab	39	42
A71a-h	10	19	U40d-j	40	30
W31-W32	11	32	B90b-d	41	51
C22	12	54	Q94	42	79
B31d-j	13	5	T20c-g	43	11
U10	14	12	A22f	44	57
D41a	15	45	C21def	45	67
S32	16	35	V40	46	33
W41a-m	17	64	M10	47	53
W21d-l	18	9	V50	48	27
V60	19	21	V13a-e	49	44
A23fj	20	4	T60b-d	50	29
B82d-h	21	6	S60	51	85
Q92	22	105	W12ab	52	40
W22b-l	23	24	W32h	53	98
B41d-k	24	13	B20a-c	54	88
A21c-h	25	116	C83g-h	55	77
W12c-j	26	14	L81	56	112
B60	27	36	W23a-d	57	37
A50gh	28	83	P40	58	47
R10	29	15	A23k	59	3
W70	30	46	T60e-g	60	28

Table 5.8 Ranking of areas according to their priority value as calculated per km^2

High risk area	New priority ranking	Old priority ranking	High risk area	New priority ranking	Old priority ranking
C81F	1	7	B41d-k	31	13
A23k	2	3	A91a-h	32	18
U70f	3	90	R10	33	15
X24a-c	4	10	W23a-d	34	37
G22e-h	5	20	U40d-j	35	30
U30a	6	38	V40	36	33
X14e-g	7	31	V70a-c	37	59
V70de	8	48	W11a-c	38	50
B71g	9	65	T11	39	22
T20c-g	10	11	W21d-l	40	9
B81c-d	11	34	C52f	41	60
U30cd	12	56	U20g	42	72
T60e-g	13	28	B31d-j	43	5
R20d-e	14	49	V12+V14	44	25
U60d	15	82	G22d	45	93
T60j	16	71	W12AB	46	40
V50	17	27	T31-T36	47	1
U60c	18	68	P40	48	47
A23fj	19	4	U10	49	12
T60b-d	20	29	W43f	50	70
W31ab	21	58	V13a-e	51	44
S70	22	16	U70b-d	52	62
B50	23	2	V60	53	21
U60e	24	80	B90f	54	63
T20ab	25	39	A22h	55	76
B82d-h	26	6	W22b-l	56	24
C12d	27	41	A21k	57	66
T60a	28	61	B11k	58	91
C52b-d	29	23	M10	59	53
W12c-j	30	14	U20J	60	75

is to provide an indication of areas where a large number of people are at risk due to faecal pollution of surface water. The surface area normalization approach clearly does not improve the existing prioritization process and the decision was taken to retain the initial proposed method for prioritization of high risk areas.

Care should also be taken not to complicate the process by unnecessary calculations and a requirement for extra input data. The collection of extra data, which are not readily available might put an extra financial burden on the programme. Prioritization only gives an indication of the areas which should be monitored. The true value of the national microbial monitoring programme will be experienced once the programme generates data for assessment and comparison. Most of the resources should be targeted towards achieving this goal.

5.7 CONCLUSIONS

It was demonstrated that a microbial monitoring programme could be designed by focusing on potential high risk areas. The feasibility and effectiveness of the procedure to identify and rank such areas was also demonstrated. The system was shown to be robust and could cater for a variety of conditions that might prevail in South African catchments. Future changes in the water supply and sanitation services levels might have a marked effect on the type of areas to be included in the national monitoring programme and it is suggested that if possible the same system should be used for prioritization. The analyses described above have shown that if data are not readily available, one could focus only on the collection of water use data for the selection of the areas to be monitored.

After finalizing the prioritization process the remaining question was whether this approach yielded relevant information in terms of the potential health risk to water users in the area. The direct evaluation of the outcome of this approach was very difficult. Epidemiological data was not available at the catchment level. Comparison of the microbial water quality in all of these areas could be used as an alternative approach. Microbial water quality comparisons will, however, involve an expanded sampling programme, something that was ruled out due to the costs, at the initiation of the programme. Such data will also only answer part of the question as it cannot provide any indication of the exposure level of consumers. The approach to select high risk areas could therefore only be evaluated indirectly on the basis of inferred evidence whenever such data became available.

The best evaluation of the process came during an outbreak of cholera in the KwaZulu-Natal province which started during August 2000. All the areas where cases of cholera were reported (National Disaster Management Centre, 2001) were included among the 30 highest ranking high risk areas and those areas where a substantial number of cases (> 5 000 cases) were reported formed the top ranking high risk areas for the province. Although this only provided indirect evidence from a geographically limited area, the strong correlation between the outcome of the prioritization process and the cholera data was considered to be indicative of the success of the approach.

CHAPTER 6: PILOT MONITORING STUDY

6.1 INTRODUCTION

Without proper consideration and development of an implementation strategy, even the best designed and motivated monitoring programme might fail in practice. Attention needs to be given to the development of appropriate logistical, financial and coordination structures. This is often best performed during a pilot study and the final step in the design phase was therefore to conduct a pilot monitoring study. The pilot study aimed at the evaluation of the conceptual design under different field conditions.

The help of two of the main water suppliers in the country was obtained to perform the actual monitoring and data collection during the pilot study in the two selected high risk areas. Umgeni Water was responsible for the monitoring of water quality in a predominantly rural area at five sampling points, whereas Rand Water monitored the quality in a peri-urban catchment at three selected sampling points.

A number of implementation issues and certain of the design issues was assessed by this study. The implementation issues that were addressed formed the basis for the preparation of an implementation manual to be used during the second phase of the project. Issues addressed included the monitoring design (site selection, coordination with laboratories, selection of samplers), the management of the programme (scheduling, equipment control, quality assurance/quality control procedures, registering of areas and sites on WMS), as well as the collection and assessment of the monitoring data. After completion of the pilot study this part of the work was summarized in the implementation manual (Murray, 1999).

Issues such as the logistics of sample collection and analysis, data storage and assessment as well as the compilation of routine reports that still required clarification were also addressed. The data collected were used to further investigate sampling frequency and the selection of suitable parameters to be included in the monitoring programme. These two factors could impact the conceptual design and are therefore covered in detail in this chapter.

6.2 WATER QUALITY VARIABLES

During the conceptual design of the national microbial monitoring programme the monitoring of the faecal coliform group as well as temperature, pH and turbidity were proposed. The non-microbial variables were suggested on the basis that they may provide information on environmental conditions which may either enhance or decrease the survival of microorganisms in surface water.

The data for pH, temperature and turbidity were investigated for correlations with the faecal coliform data. No statistically significant linear relationship could be found between any of the variables. The same result was reported by Venter *et al.* (1996) for monitoring data which covered a period of three years. The poor correlation between faecal coliform data and turbidity might suggest that high levels of faecal coliform bacteria present in surface waters in South Africa are not necessarily the result of surface run-off and that other pollution sources might be of greater importance. Based on the poor correlations between the values it is therefore suggested that these measurements should only be taken in cases where it does not increase the cost of the monitoring.

6.3 SAMPLING FREQUENCY

6.3.1 Background

During the conceptual design of the monitoring programme, a statistical approach was utilized to determine the ideal sampling frequency (Section 4.3.4). On the basis of the analysis of historical data, a weekly sampling regime was recommended. Because the initial analysis was based on data sets mostly representing urban areas, this aspect of the conceptual design had been revisited once the data of the pilot study for both urban and rural areas became available.

The proposed programme would rely heavily on the voluntary participation of institutions for the supply of data. These organisations would also have to provide the logistical support for sampling, which could be a substantial addition to their budgets. During discussions with possible participants many indicated that they might not be able to afford the financial burden implied by weekly sampling. A compromise between the statistical and economical factors needs to be made. This is an issue often experienced when designing monitoring systems (Ward and Loftis, 1989).

6.3.2 Approach

The effect of changing the proposed frequency should however, be thoroughly investigated in order to understand the implications of such a decision. The two data sets obtained during the pilot study were used to examine the possible effect of a reduction in sampling frequency on the monitoring programme. Two analyses were performed, the one investigated the effect of a reduction of sampling frequency on the data produced, whereas the other investigated its effect on the health risk index and reporting.

6.3.3 Appropriate sampling frequency

Following the same data analysis protocol as was previously used (Section 4.3.4), the two data sets were analysed. Some weak auto-correlation was evident in the weekly data collected in the rural area but minimal dependance was observed for the data from the peri-urban area. Even for daily samples, no relationship between adjacent samples was observed. A weekly sampling frequency was therefore again recommended. The lack of autocorrelation in daily samples, even indicated that more frequent sampling may be ideal. The temporal patterns observed were not strong enough to allow extending the sampling interval.

6.3.4 Sampling frequency and data distribution

The data sets produced during the pilot study contained measurements taken on a weekly basis. For the purpose of the analysis two subsets of data were created from each of the original sets. One of the newly created subsets contained data taken on the first date of sampling and continued on a 14-day interval. The other subset started at the second date of sampling (one week later) and also continued on a 14-day interval. The same approach was followed to evaluate the effect of sampling every three or four weeks. The results of the data manipulation for the rural and peri-urban areas sampling points are presented in Figures 6.1 to 6.9 as box and whisker plots.

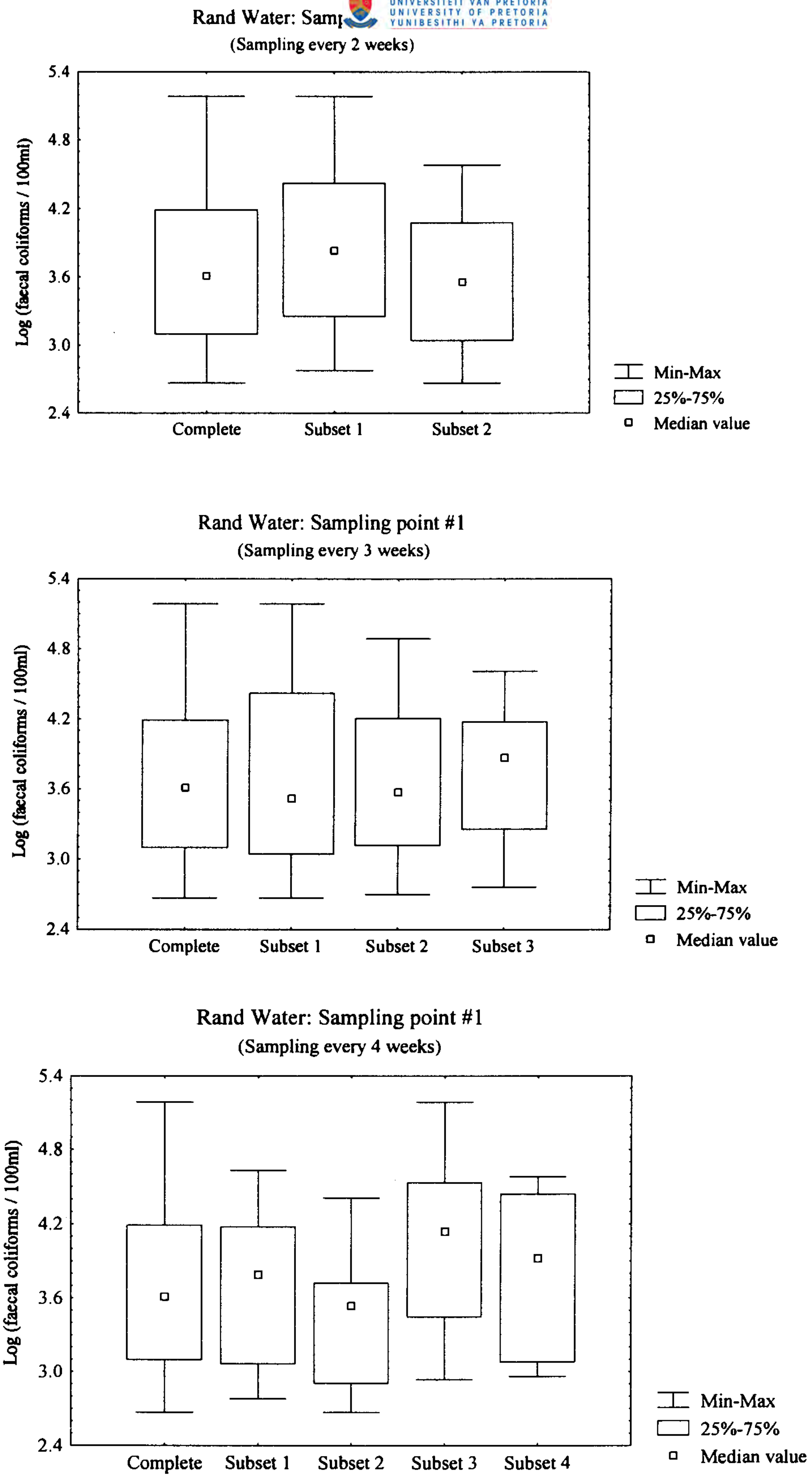


Figure 6.1 Box and Whisker plots showing the effect of different sampling frequencies on the data to be reported for sampling point 1 of the peri-urban area.

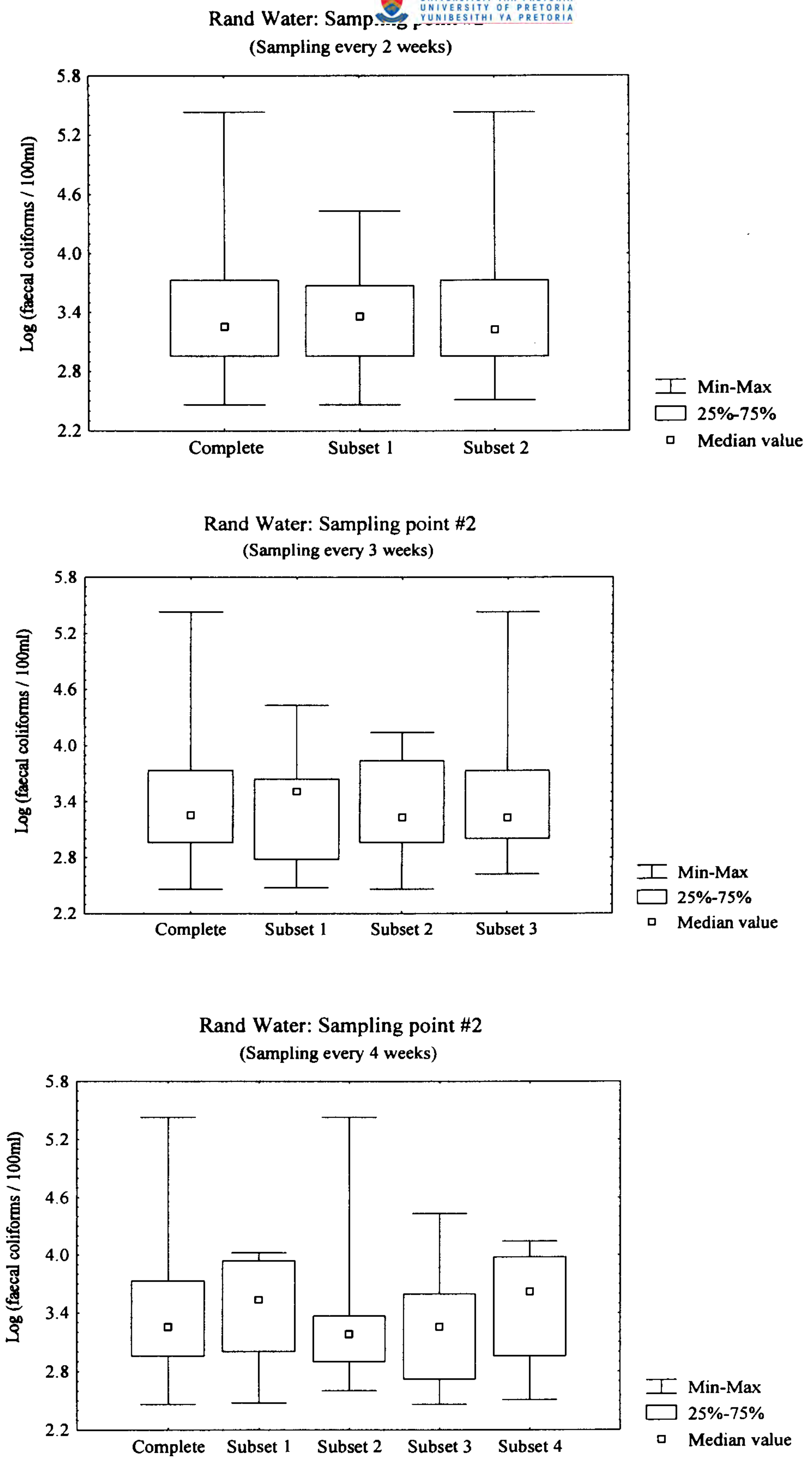
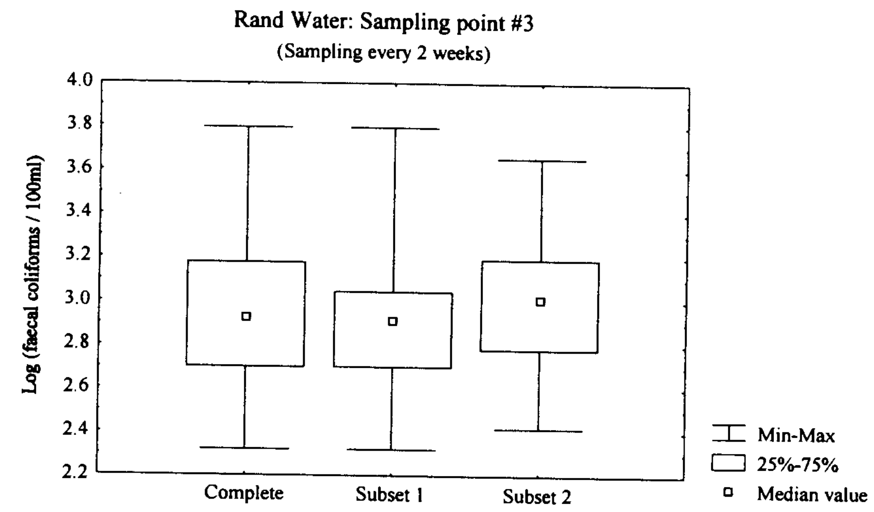
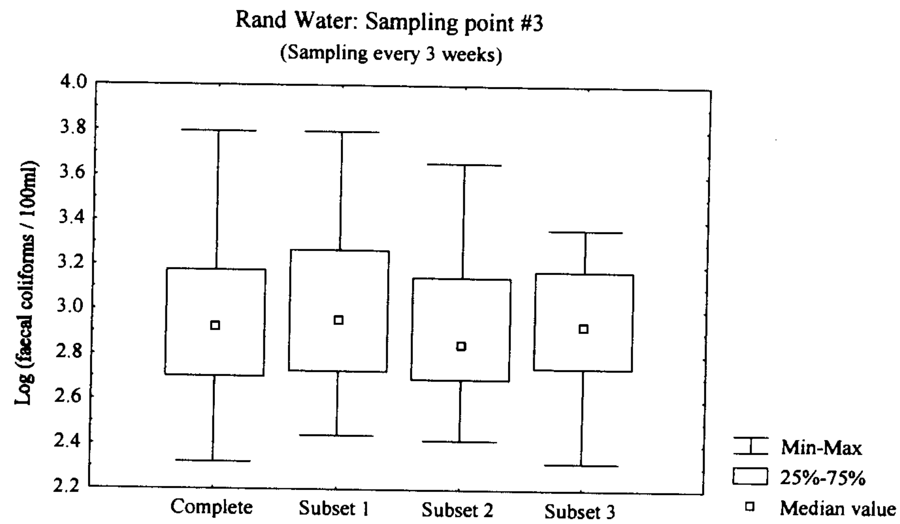


Figure 6.2 Box and Whisker plots showing the effect of different sampling frequencies on the data to be reported for sampling point 2 of the peri-urban area.





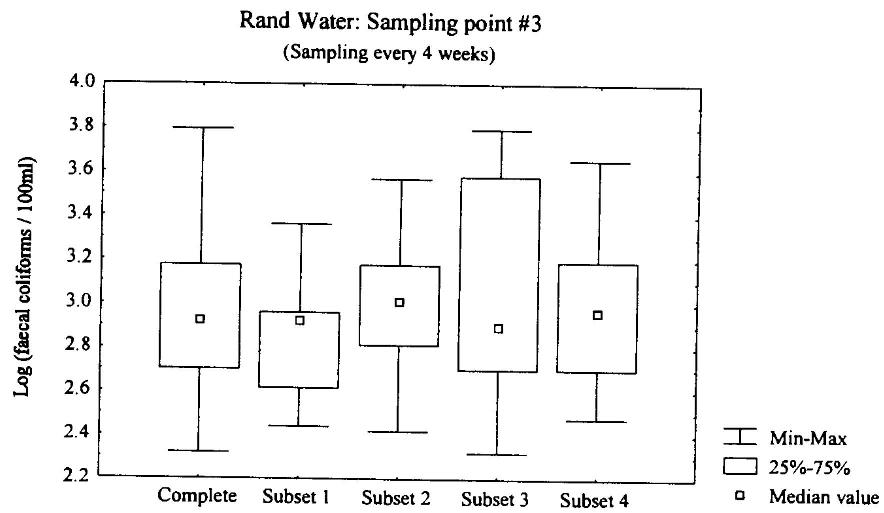


Figure 6.3 Box and Whisker plots showing the effect of different sampling frequencies on the data to be reported for sampling point 3 of the peri-urban area.

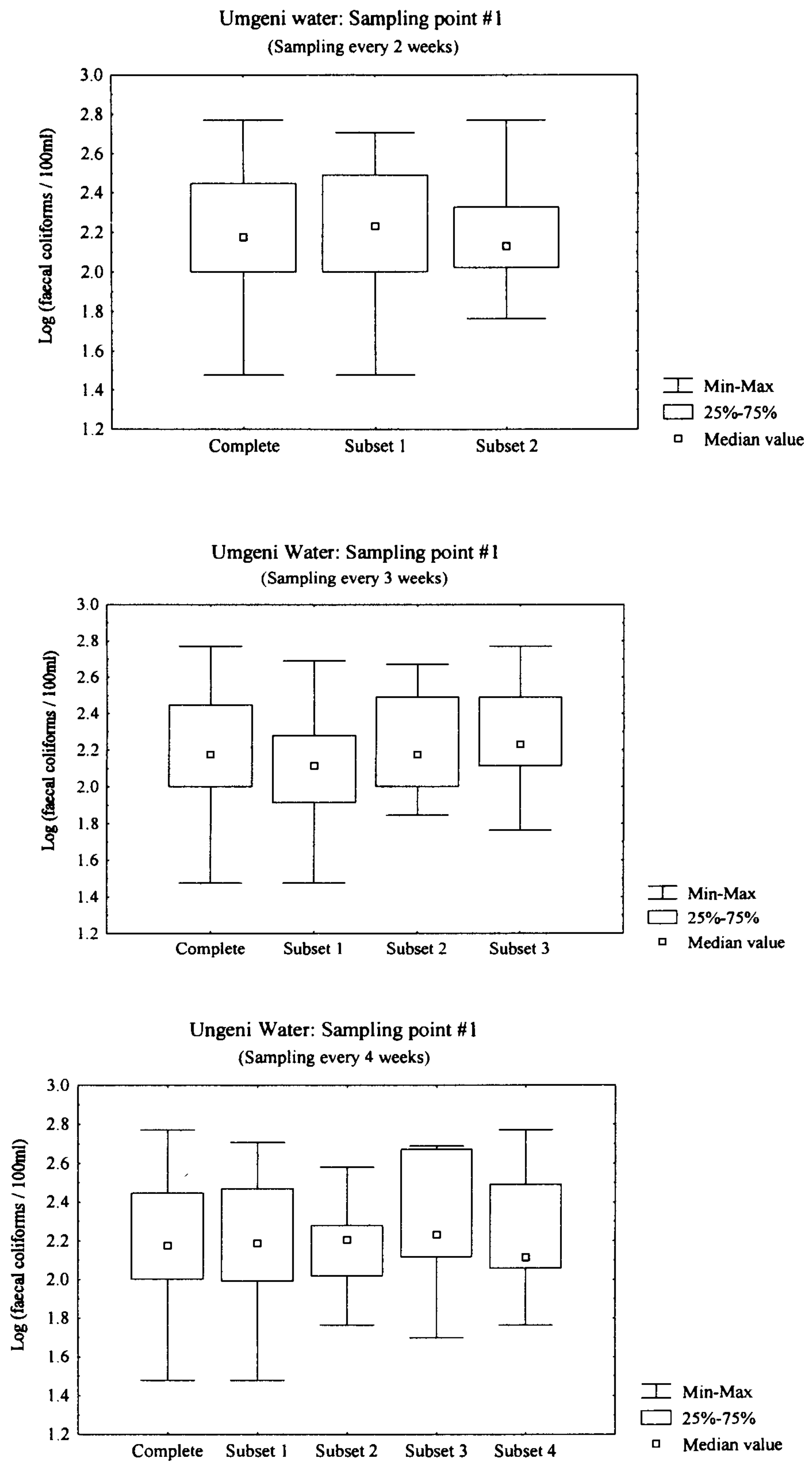
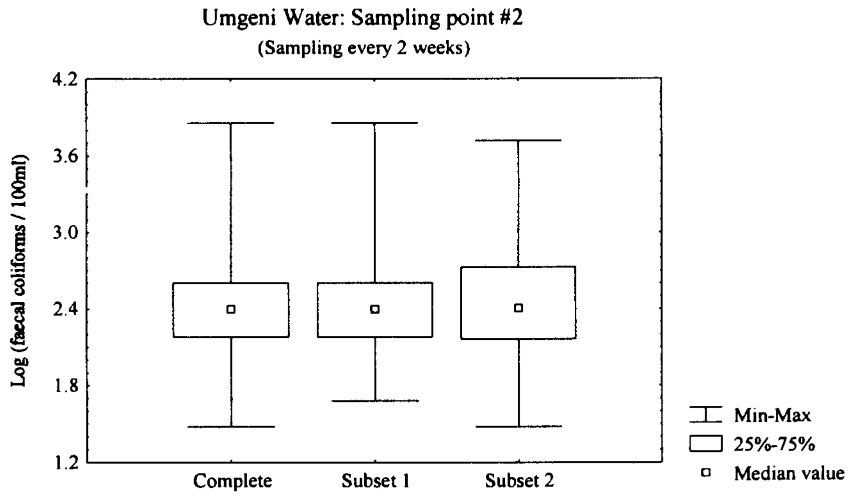
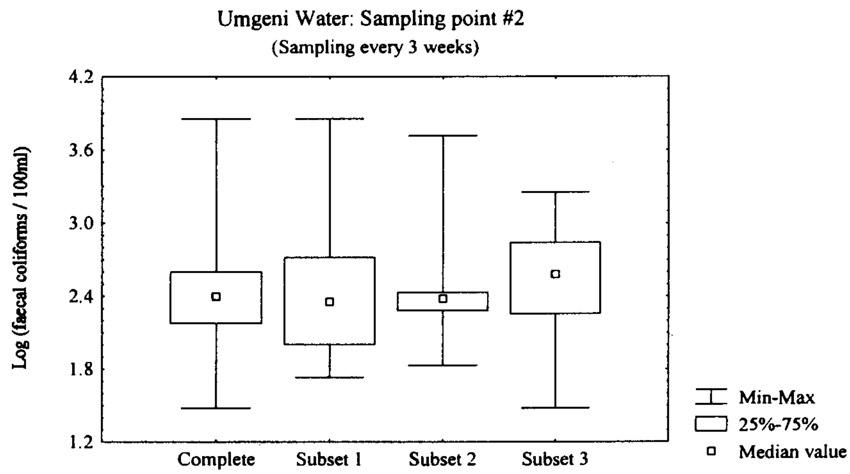


Figure 6.4 Box and Whisker plots showing the effect of different sampling frequencies on the data to be reported for sampling point 1 of the rural area.





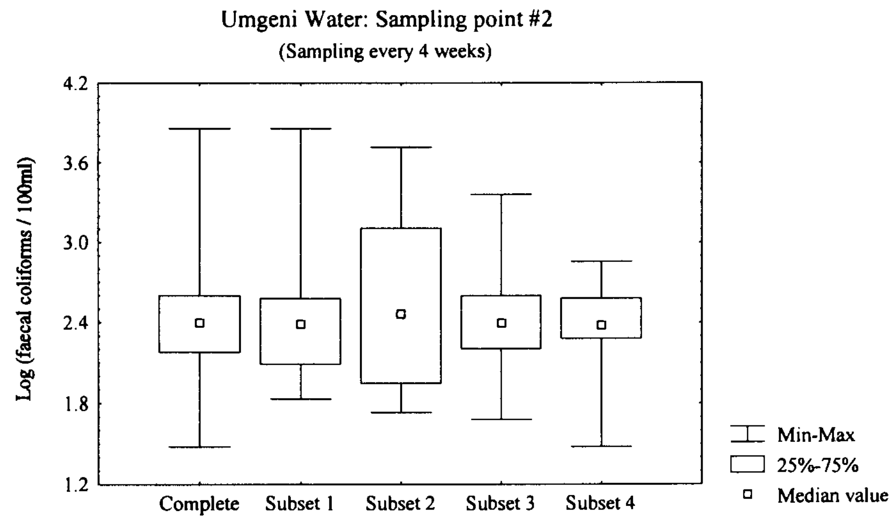


Figure 6.5 Box and Whisker plots showing the effect of different sampling frequencies on the data to be reported for sampling point 2 of the rural area.

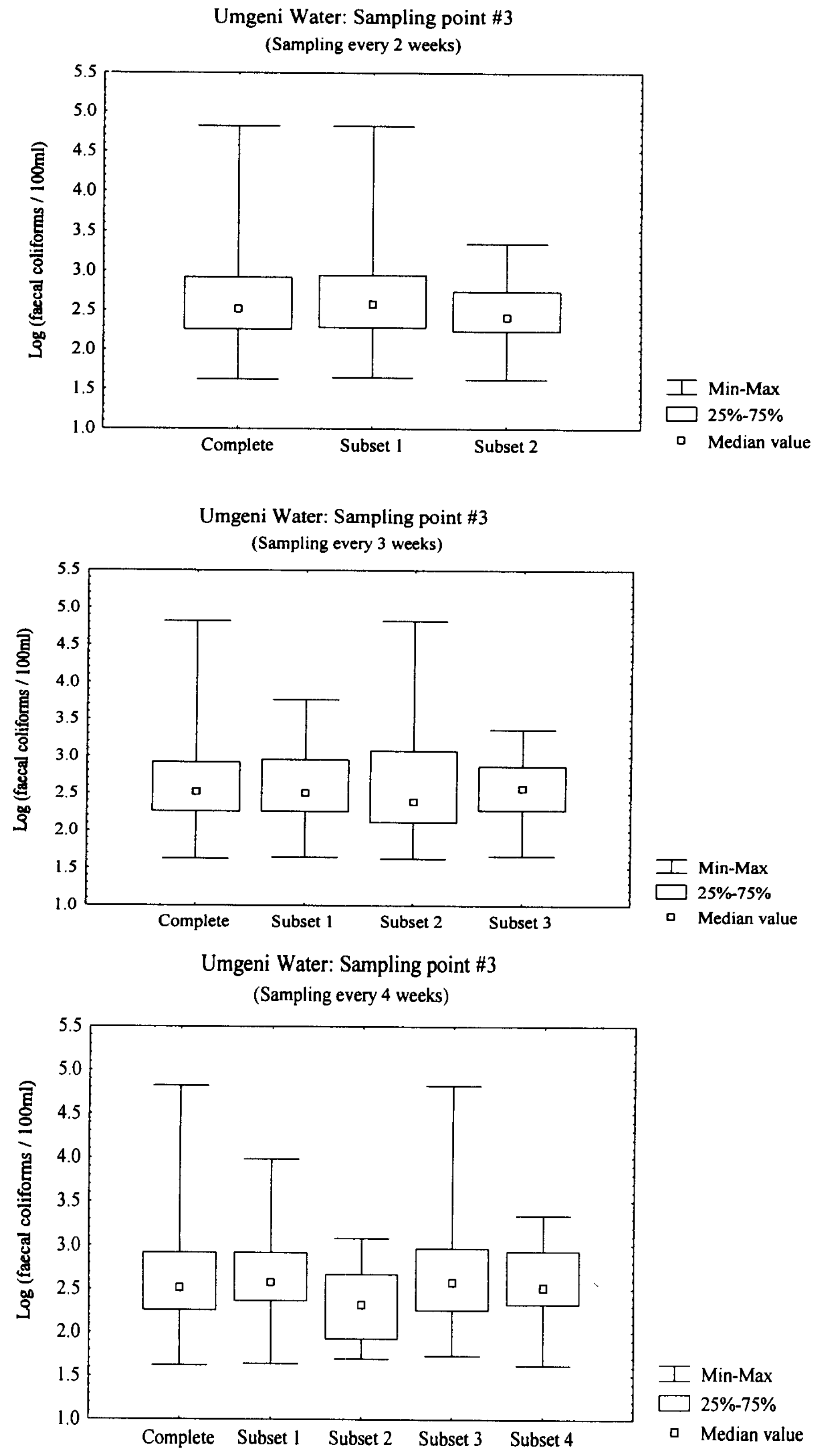
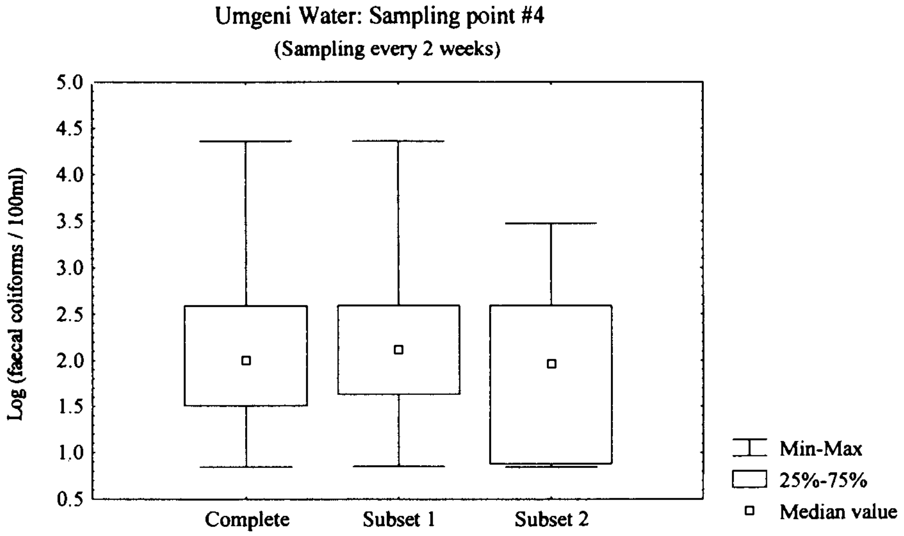
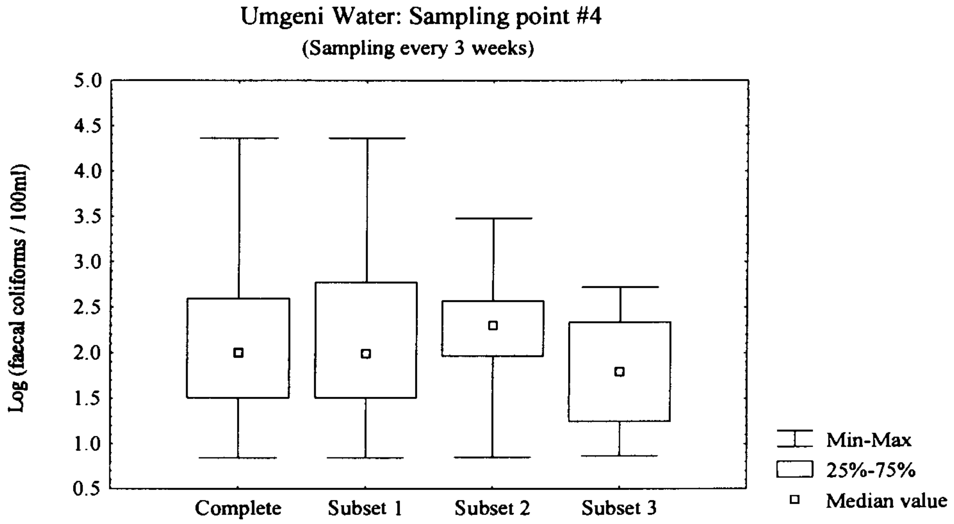


Figure 6.6 Box and Whisker plots showing the effect of different sampling frequencies on the data to be reported for sampling point 3 of the rural area.





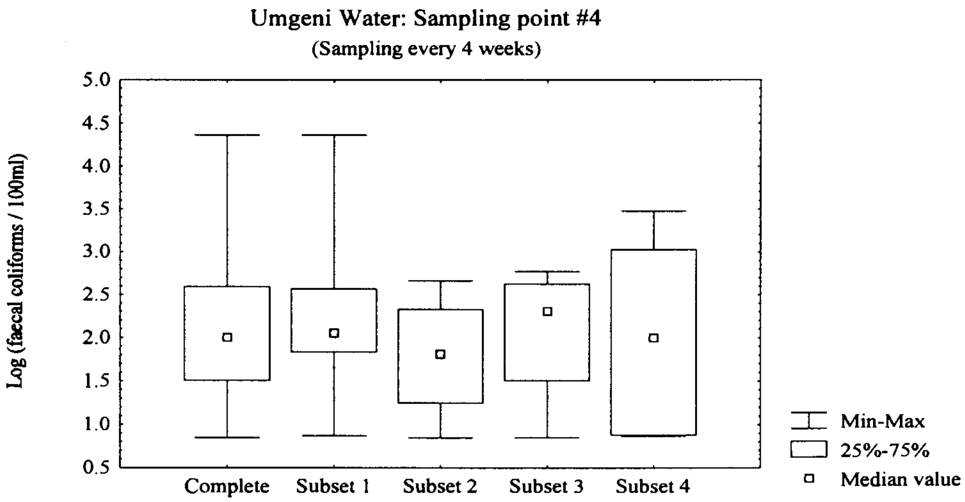
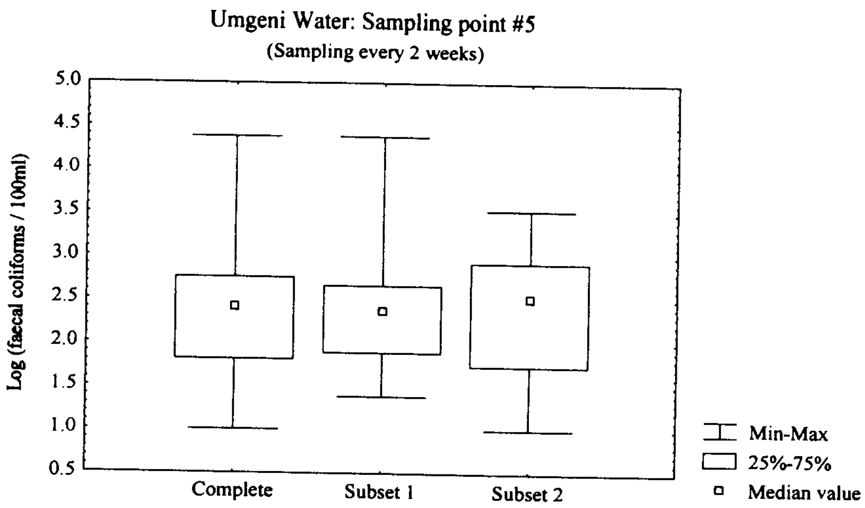
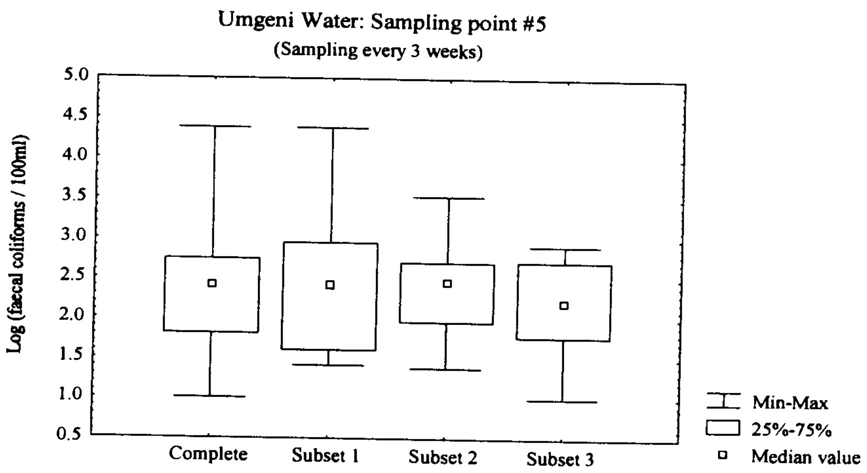


Figure 6.7 Box and Whisker plots showing the effect of different sampling frequencies on the data to be reported for sampling point 4 of the rural area.





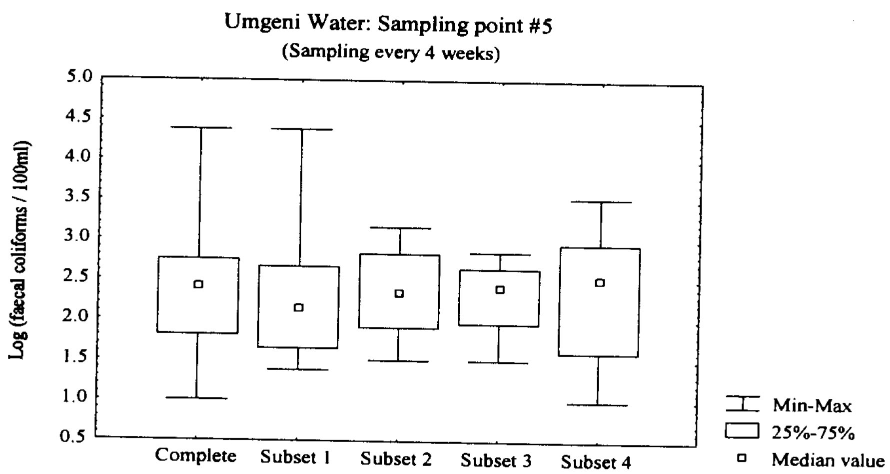


Figure 6.8 Box and Whisker plots showing the effect of different sampling frequencies on the data to be reported for sampling point 5 of the rural area.

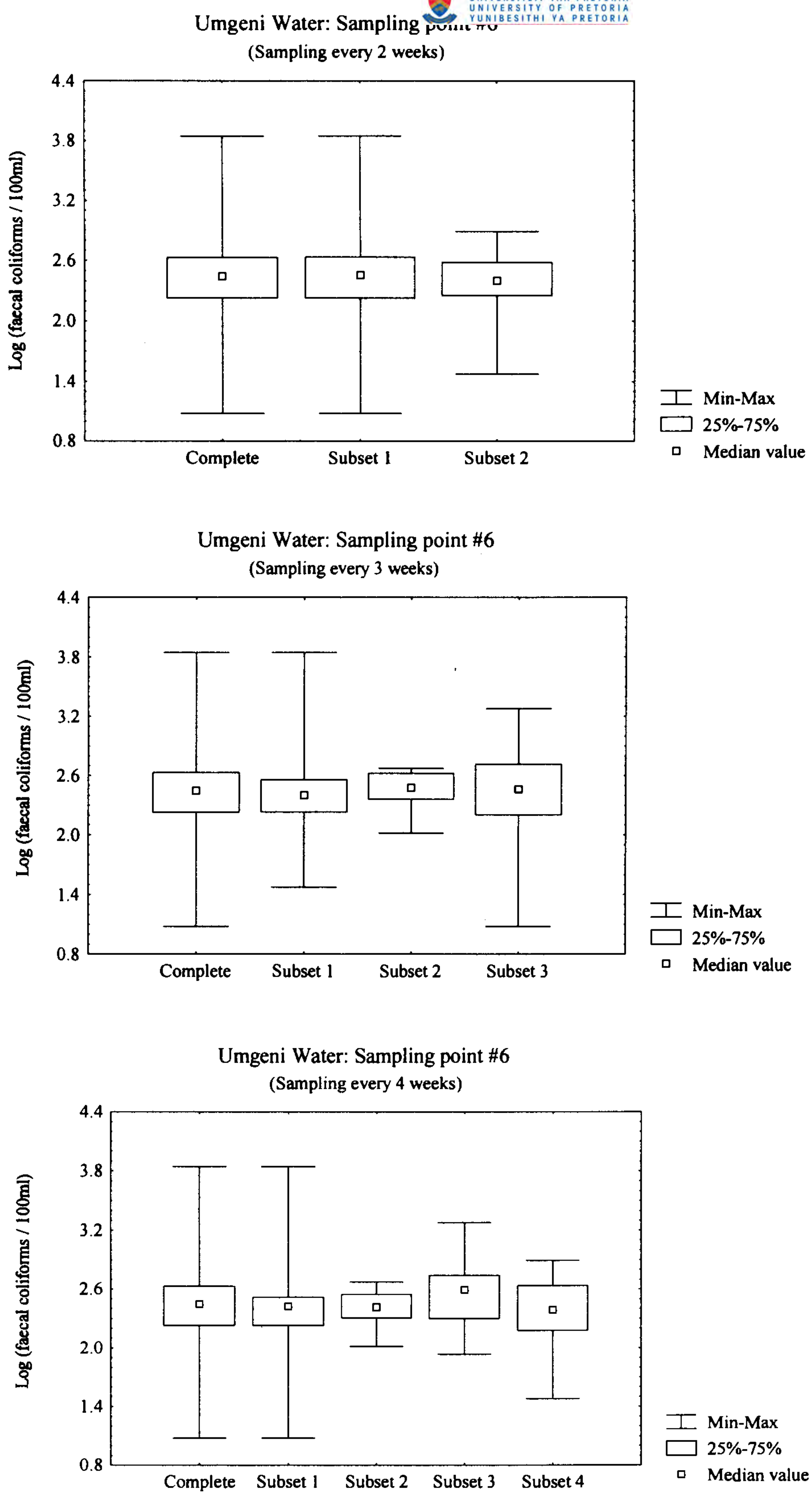


Figure 6.9 Box and Whisker plots showing the effect of different sampling frequencies on the data to be reported for sampling point 6 of the rural area.

The data presented show that at a fortnightly sampling frequency there could be a dramatic difference between the two subsets compared to each other as well as to the data set containing the weekly measurements. In most cases, one of the subsets contained all of the high values and the range of measurements were markedly different between the two subsets. Sampling on a fortnightly basis could therefore lead to a misrepresentation of the real quality of the surface water. Sampling every three or four weeks showed even greater differences among subsets and in comparison with the original data set. In most cases the greatest variation in values were noted for the upper quartiles. Variation in the upper values is particularly of concern because the high values represent incidents of high risk water use and one would not like to create a situation where there could be a serious underestimation of the risks involved. The evaluation of the different subset indicated that if at all possible, the weekly sampling frequency should be maintained.

6.3.5 Sampling frequency and the health risk index

As mentioned above, decreasing the sampling frequency could have an effect on the data used for the annual reporting of the potential health risk to water users. The weekly and fortnightly data from two of the data subsets (Figure 6.2 and 6.5) were used to investigate the effect of decreased sampling frequency on the value of the health risk index and the interpretation that would be given to these values.

The health risk index was 46.0 as calculated for the peri-urban sampling point 2 when using the complete data set collected on a weekly basis. Using the two subsets of data based on fortnightly sampling, the potential health risk index values obtained were 47.7 and 44.3. When making the calculations based on the data collected at sampling point 3 in the rural area, a value of 28.8 for the complete data set and 32.5 and 25.0 were obtained for the subsets. When reducing the sampling frequency to once every three weeks values of 26.7, 27.1 or 34.6 were obtained for the same sampling point.

As mentioned in Section 4.4.4 the health risk index values should be interpreted according to the following guidelines. Values between 0 - 30 % would be indicative of limited pollution of the surface water and the risk would mainly be confined to the direct use of untreated water. Values of 30 - 60 % would represent moderate pollution with the risk mainly concerned with the direct use for domestic, recreational and irrigation purposes. Percentages of 60% and higher would signify heavy microbial pollution of the surface water and a subsequent increase in the risk to human health.

From the values and the interpretation thereof a similar general interpretation of the risk would result, but there are also noticeable differences between the calculated health risk index values. Differences of as high as 7.5 were observed when health risk index values were calculated for the separate subsets. These differences relate to an over- or under-representation of nearly 7 to 8 high risk incidents per year. The fact that the greatest variation in faecal coliform values was noted between the upper quartiles of data sets implies that risk incidents associated with high faecal coliform counts could be under reported in cases such when the water is used for irrigation or for drinking after limited treatment. Decreasing the frequency to once every three weeks will even further increase the range of potential health risk values that could be calculated for the same sampling point.

6.3.6 Conclusions

The implication of a decrease in the sampling frequency will be twofold. The data collected on a fortnightly basis may not give an accurate reflection of the prevailing microbial water quality, especially in terms of the occurrence of high risk incidents. The sensitivity of the health risk index will also be affected. Under these circumstances values differing as much as 7 to 8% may not necessarily reflect a significant difference in the microbial water quality at different sampling points. Further decreases in the sampling frequency will result in even smaller data sets and an increase in the level of uncertainty. Weekly sampling is therefore recommended wherever possible. Due to economic constraints weekly sampling may not be a feasible option in some of the areas. In these cases the sampling frequency should not be reduced to less than fortnightly sampling and the interpretation of the results should be done with greater care.

6.4 SUMMARY

With the completion of the last step of the design phase described above, the end of this phase of the project to establish a national microbial monitoring programme for surface water was reached. The pilot study provided an ideal opportunity to evaluate specific aspects of the conceptual design and showed that no major changes to the design were required. The pilot study also formed the basis for the development of the implementation phase of the project.

After completion of the design phase an implementation strategy was developed and an implementation document was prepared addressing most of the issues raised during the conceptual design (Murray, 1999). A national coordinator has been appointed who is working closely with all parties involved. Implementation of the national programme was initiated during 2000 and monitoring was initiated in four of the identified high risk areas. Plans to increase the number of high risk areas monitored are progressing well.

CHAPTER 7: THE EFFICACY OF THE CONCEPTUAL DESIGN TO DEAL WITH IMPLEMENTATION CONSTRAINTS AND EMERGING ISSUES

7.1 INTRODUCTION

A water quality monitoring programme cannot be designed and operated in isolation from the broader environment and society in which it has to function. The possible impact of economic, technological, social and political factors on the validity of the objectives and the details of the monitoring activities has to be considered during the design. Because the present world is very dynamic and characterized by rapid change, many of these factors are also subject to constant adaptation. The success of any monitoring programme design should be described not only in terms of its ability to meet the set information objectives, but should also take into account how flexible the design is in dealing with factors that might impact the operation of the programme.

During the design phase a number of factors were identified which could impact on the success of South African monitoring programmes in general and the microbial monitoring programme specifically. For the purpose of the present study the impacting factors were broadly grouped into two categories viz. implementation constraints and emerging issues. Once the major factors which might restrict the full-scale implementation of the programme were identified, the conceptual design was developed with these issues in mind. Dealing with emerging national and global issues when designing a monitoring programme is far more difficult as a result of the wide range of the nature of some of these issues. At best, the designer can take note of possible trends in order to create a flexible monitoring design that would be able to accommodate likely changes should these changes occur. In this chapter an attempt was made to assess the conceptual design's ability to address these types of issues.

7.2 IMPLEMENTATION CONSTRAINTS

7.2.1 Introduction

From the initiation of the microbial monitoring programme indications were that the programme would have to deal with a number of implementation constraints. A situational analysis indicated that the following major constraints could be expected:

- limited funding;
- limited infrastructure in many areas; and
- limited skills base for monitoring activities.

7.2.2 Funding

Due to other commitments such as the provision of water and sanitation services to previously undersupplied areas, housing, education and employment only limited funds are available from governmental sources for monitoring activities. A lack of concern for the problem of microbial water quality among some of the water quality managers exacerbates the situation. In addition, compared with chemical water quality programmes, microbial monitoring programmes are usually more expensive to operate due to the nature of the variables measured.

Because funding was considered to be a limiting factor care was taken to ensure that the conceptual design allowed for the adjustment and optimization of the monitoring network. Adjustment of the design when the same programme also has to meet other unrelated objectives such as those set out for chemical and biological monitoring would be difficult to achieve. The difficulty in meeting unrelated objectives was one of the main reasons why a separate programme for microbial water quality monitoring of surface water was established.

When funds are limited, one of the possible actions to be taken could be to reduce the number of samples. Reducing the number of samples can be done by either decreasing the proposed sampling frequency or by reducing the number of the sampling sites. The objectives of the programme, as based on the information requirements of end users, clearly indicated that there was a need for information covering both the spatial and temporal variance of microbial water quality. The main aim in terms of temporal variation was to provide information on the status of and trends in the microbial quality of surface water. Detecting such trends and variations at a specific sampling point within an acceptable level of confidence require regular sampling. This restricts the degree to which compromises can be made in terms of sampling frequency. Optimization of the programme should therefore be focused on the spatial distribution of sampling stations.

Methods to deal with the optimization of sampling points have been addressed previously and Ward *et al.* (1990) described a specific case study. For the acid lakes monitoring case study a comprehensive data set on which the necessary grouping and statistical analyses could be performed was available. In South Africa, reliable data at a national level, on which to base such an analysis, are not available. The initial compilation of a national data base would be unrealistic as compiling such base would require effort, time and resources that could be applied more effectively elsewhere. A selection approach that allowed for the identification of high risk areas was developed as discussed in Chapters 4 and 6. With the prioritization approach, a limited number of high risk areas could be selected for initial implementation followed by the expansion of the programme to other areas whenever more funds become available.

7.2.3 Human capacity and infrastructure

A lack of suitably trained human resource capacity and appropriate infrastructure in the regions was also identified as constraints which could restrict the full scale implementation of the programme. A phased approach towards implementation was seen as one of the best ways to deal with these issues. The initial implementation phase of the programme will only focus on a selected number of areas of high priority and will allow for the development of the necessary capacity to operate the programme. Once the monitoring programme is operational in one area, some of the individuals involved could be seconded to another area to help establish the monitoring programme. With a phased approach, regions which lack the necessary infrastructure would also be able to initiate the programme in one priority area while developing the infrastructure required for larger scale operations.

7.3 EMERGING ISSUES AND TRENDS

7.3.1 Introduction

The broader global and national environmental and social-political issues are often outside the control of organizations and individuals involved in water quality monitoring. National and international issues are usually driven by global environmental, economic, technological, social and political developments and the precise impact of such issues on water quality monitoring is often difficult to predict. Note was taken of some of these issues in order to create a flexible monitoring design that would be able to accommodate changes should they occur. Some of these issues and trends are discussed below.

7.3.2 Political and social environment

The political and social environment in South Africa is very dynamic and has been characterized by a number of far reaching changes in governmental policies and laws after the 1994 election when the African National Congress alliance come into power. The primary drive of the new government is to ensure sustainable economic growth and upliftment of all people. To steer development the Reconstruction and Development Programme (African National Congress, 1994) was initiated to serve as a framework for the development of new policies and legislation. A key principle of the new policies was to ensure equitable use of resources, including water. These policies finally lead to the promulgation of the required legislation, among others also in the water arena.

7.3.3 Legislation

7.3.3.1 Introduction

Since the conceptual design of the national microbial monitoring programme was completed, the Water Services Act of 1997 (Republic of South Africa, 1997) and the National Water Act of 1998 (Republic of South Africa, 1998) have been promulgated. The main purpose of these to acts was to provide an integrated institutional framework for the implementation of the new government's policy of improved access to water and the use of water resources for all people. Although the aim of the new policies is to ensure the use of water for the benefit of all people, water utilization should be done in a sustainable manner. Both acts therefore strongly focus on the management of these processes and provide detailed information on the responsibilities of and control over various existing and new institutions. The greatest changes and impact of the new laws are therefore at the institutional level. Although, provision for possible changes in the law has been made in the conceptual design, the impact of these new laws on the programme's objectives and design had to be investigated to ensure that the programme still address the information required for water quality management in the new environment. The assessment of the impact was described in Section 7.3.3.4. Before the assessment could, however, be performed a brief description of the new stipulations of the two acts has been provided in Section 7.3.3.2 and 7.3.3.3.

7.3.3.2 Water Services Act of 1997

The aim of the Water Services Act, Act 108 of 1997 (Republic of South Africa, 1997) is to provide the necessary framework for the provision, regulation and management of water supply and sanitation services to communities. The Water Services Act deals with issues such as the right of access to basic water supply and sanitation and the responsibility of authorities to realise these rights. Little changed since the adoption of the new constitution which identified the provision of sanitation services as the responsibility of local government. Under the Water Services Act, central government has the ultimate responsibility to monitor water services provision, using data mainly provided by the service providers themselves. The act also makes provision for the intervention by the relevant province or the Minister to ensure compliance with national standards, development plans and policies.

The management of surface water quality is not the main focus of the Water Services Act but it does make provision for the setting of national standards relating to the quality of water taken from or discharged into any water resource system. According to the act, the standards could differentiate between different geographical areas based on the socio-economic and physical attributes of an area. The concept of receiving water quality objectives were subsequently expanded in more detail in the National Water Act (Republic of South Africa, 1998).

7.3.3.3 National Water Act of 1998

The National Water Act, Act 36 of 1998 (Republic of South Africa, 1998) provides the framework for a number of fundamental reforms relating to water resources and its management. Sustainability and equity of access were identified as the two guiding principles used for the development of the new law. In terms of water quality, the purpose of the law based on these two principles was described as follows: "The protection of the quality of water resources is vital to ensure the sustainability of these resources in the interest of all users and where appropriate management functions will be delegated to a regional or catchment level to enable possible participation of all users." With this participation approach a definite shift was made towards increasing local input into the management of water resources.

In terms of the overall responsibilities for water quality management there were no major changes from the situation that existed before promulgation of the new act. DWAF as representative of the National Government, is still the custodian of the water resources and will have the responsibility to manage it in a sustainable manner. The Department is also responsible for the development of a national water resources strategy and oversight of the implementation of the strategy. Catchment management agencies (CMA) as separate statuary bodies forming the second tier of the water management structure are new institutions created by the act (Department of Water Affairs and Forestry, 2000a).

According to the new policy, DWAF will delegate its water resource management functions to a regional level where appropriate. To enable regionalisation, the Act allows for the establishment of CMAs for the 19 identified water management areas in the country. Initially, the CMAs will have some planning, co-ordination and advisory functions and will have to develop catchment management strategies for the specific water management areas controlled (Department of Water Affairs and Forestry, 2000a, Department of Water Affairs and Forestry, 2000b). Over time, other management and control functions, including water resource monitoring, could be delegated or assigned to the agencies based on their proven ability and capacity. As part of the government's policy of transparency and decentralisation, CMAs should also facilitate and ensure greater public participation in water resource management (Department of Water Affairs and Forestry, 2000c)

The Act also provides for the establishment of catchment management committees to which a CMA can delegate some of its powers. Two types of committees are foreseen, those that will deal with specialist functions across the whole water management area and the geographical committees which will focus on specific catchments or zones within the water management area. Monitoring and management of water quality will typically be addressed by a specialist committee. Committee members could be drawn from various institutions and may increase the scientific and technical knowledge and skills available to the CMA (Department of Water Affairs and Forestry 2000b).

The Minister (per definition DWAF) remains ultimately accountable for water resource management and has considerable control over the functioning of the CMAs. Their operations will have to be audited regularly and the Minister can intervene if difficulties are experienced, or if CMAs do not comply with the national water resource strategy.

The ultimate aim of the act is to ensure the comprehensive protection of all water resources. More specifically, resources of significance will be classified and, based on the classification, resource quality objectives will be determined. The purpose of resource quality objectives is to establish binding water quality goals which will guide all decisions with regards to water use, development, protection and management. Once these objectives have been determined, progress in terms of achieving these goals should also be monitored.

The Act deals specifically with monitoring, assessment and information in Chapter 14 (Republic of South Africa, 1998). The Minister is required to establish national monitoring systems, to coordinate monitoring, and to collect relevant information on various aspects of water resources. The data to be collected should include among others, information necessary to assess the quality of water resources and compliance with resource quality objectives. Information and data could be obtained from a variety of sources such as government organisations, water management institutions and water users. The Minister also has the power to obligate the provision of such information by means of regulations.

The data collected by the national monitoring systems will provide input for national water quality information systems, also to be established. The objectives of such information systems are to provide information for the protection, sustainable use and management of water resources as well as for the development and implementation of a national water resource strategy. Information collected by national systems should not only be accessible to water management institutions, but also to water users and the general public wherever possible. The vision of DWAF is that the monitoring and information systems should be implemented by 2004 and the Department is at present developing an implementation strategy (Harris and Howman, 2000).

In terms of the approach towards water quality management, the National Water Act does not present a major departure from the water quality management policies already implemented during the last decade (van der Merwe and Grobler, 1990; Department of Water Affairs and Forestry, 1991). The new act has for instance strengthened, expanded and renamed the philosophy of receiving water quality objectives (Department of Water Affairs and Forestry, 1995) which is now implemented under the broader concept of resource quality objectives. The major change in terms of water quality management is that the act proposes the delegation of management functions, where appropriate, to catchment level in order to ensure greater transparency and participation of all the parties involved. Implementation of this participation policy and co-ordination between the various role players and levels of government will be the major challenge for the future.

7.3.3.4 Assessment of the present conceptual design in terms of the new legislation

Objectives

The National Water Act clearly states that monitoring, assessing and dissemination of information on water resources is critically important for the functioning of the act. Among others, the minister is required to co-ordinate a monitoring system to assess the quality of water resources. The present interpretation of these requirements is that national programmes focussing on status and trend monitoring will continue to operate under similar conditions and objectives as before. The coordination of these programmes will most likely remain at a national level within DWAF.

With the creation of CMAs at a separate management level responsible for water resource, the objectives of the national microbial programme might have to be expanded to fulfill newly arisen information needs, if necessary. As part of its national responsibility DWAF might for example now have a need to assess CMAs in terms of their ability to manage the microbial water quality of surface resources under their control. These requirements will, however, only become apparent once CMAs have been successfully established and a needs analysis has been performed. At present no changes in terms of the programme's objectives are required. In fact the reliance on external organisations to collect data for the national programme anticipated the devolution of responsibility to others.

Monitoring network

The design of the national programme does not allow for the quantification of the effect of individual land use activities on the microbial quality of surface waters. The responsibility for such short term surveys will not lie with the national department but with the CMA's. The approach for the prioritization of high risk areas provides a suitable means by which CMAs could prioritize and allocate funding for surveys to investigate the sources of microbial pollution in a catchments.

Short term surveys should not be operated as an integral part of the national programme. Logistically, however, such efforts, should whenever possible, be combined as the combination of monitoring efforts could result in major savings in terms of transport and labour costs. The conceptual design of the microbial programme has also made provision to link data of such surveys to the main monitoring programme.

Data collection and management

The National Water Act provides the Minister with the power to obtain monitoring data on a regular basis from water management institutions or water users which do not form part of DWAF. The fact that other institutions might have to provide data for national monitoring programmes will not pose a problem to the microbial programme as the programme was designed to collect information from various sources. As mentioned in the conceptual design, quality control measures and standard operating procedures are even more important under these circumstances to ensure the success of the monitoring programme. Regulations to request monitoring data from institutions might even strengthen the implementation of the programme which is often handicapped by a lack of funds available within the Department. It is, however, not foreseen that the Minister will use these powers readily without prior consultation as additional monitoring functions may have far reaching financial implications for the institutions involved.

Data assessment and reporting

Once CMAs are operational, they would also require information on the status of and trends in the microbial quality of surface waters under their specific control. It would be necessary to include a separate report for CMAs. The format of the proposed report would be similar to that of the yearly overview report described in section 4.5.5.1. but will only cover a specific water management area. Reports covering water management areas will allow for comparison between water management areas and could even be used by DWAF as a means to evaluate the way CMAs manage the microbial quality of surface water resources.

At present the management of water quality problems is often dealt with by staff from the same directorate within DWAF which ensures a high degree of uniformity in the way people react to and deal with water quality issues. According to the new National Water Act , DWAF will be responsible for the development of a national water resource strategy but will delegate its water resource management functions to CMAs where appropriate. A uniform management approach will be more difficult to ensure once these changes are implemented as the CMAs will operate as separate entities. To ensure consistency in the management of microbial water quality under the new structure, management principles to guide the actions taken by all water quality managers including those at CMAs, should be developed and linked to the yearly report on a high risk area. DWAF's Directorate for Water Quality Management is at present addressing the issue of management principles. Having management principles established will even, under the present system of more centralized control, be of use as it encourages managers to take appropriate actions on the basis of the assessment.

Implementation

The creation of CMAs could have some implications for the implementation of the national programme. Initiating monitoring in at least one high risk area within each of the 19 water management areas within the next few years could assist in the creation of the necessary capacity for dealing with microbial water quality monitoring and management within these areas.

According to the new National Water Act, CMAs will in part be funded by parliament but they may also raise funds required for operation by other mechanisms such as water use charges. Should extra funding for monitoring come available from CMAs, the microbial monitoring programme could be expanded to include more of the high risk areas within that water management area.

Recommendations

Seen in the light of the above mentioned comments the present conceptual design for the national microbial monitoring programme still adequately deals with the changes brought about by the new National Water Act and no major revision of the programme is required. The programme could also be expanded without major changes to allow the basic monitoring design to cater for the possible role of CMAs in microbial water quality management.

7.3.4 Economy

Funding for the programme has been identified as one of the major constraints and has already been discussed in section 7.2.1. In future, South Africa's ability to became more competitive in the global market will have an impact on the development of local industries and the creation of wealth. An improved economic situation in the country would release more funds for governmental spending, including the improvement of water supply and sanitation services and the management of water resources. The opposite scenario will result in further cuts in the funds available for these activities. Economic development and change is, however, a gradual process and may not have any immediate substantial impact on the design and operation of the monitoring programme.

7.3.5 Technology

Technological advances such as improved detection techniques and instrumentation, could be the impetus for a re-evaluation of the water quality parameters selected. Improved techniques should however only have a limited impact on the overall design of the programme as changes to the analysis, assessment and reporting procedures will have to be made. Constant developments in the computer and communication sector will also impact on the methods of data transfer, storage and assessment as well as the availability of the data to a wider audience. Technological developments would , however, seldom necessitate a design review, but would rather be incorporated into existing activities as, and when, needed.

7.4 CONCLUSIONS

This chapter has demonstrated that apart from its ability to meet the set information objectives, the present conceptual design for the national microbial monitoring programme also deals effectively with implementation constraints and provides the necessary flexibility to accommodate changes in the broader environment and society. The flexibility can be attributed to decisions taken during the development of the design. One of the decisions was to develop a separate programme to monitor the microbial water quality. The decision to have a separate programme assisted with the optimization of the programme under conditions of limited resources. No compromise had to be made between unrelated objectives and a design which caters for many of the constraints in terms of funding and implementation could be produced. The other important decision was to develop an objective selection approach that allowed for the identification of high risk areas. The area selection and prioritization approach assisted with both the spatial optimization of the programme as well as allowing for a phased implementation of the programme. Finally, the design is at present still flexible enough to accommodate change in the broader global and national issues as was demonstrated with the design review initiated after the promulgation of two new acts which have a direct impact on water quality monitoring.

CHAPTER 8: SUMMARY AND CONCLUSIONS

8.1 OBJECTIVES

The Department of Water Affairs and Forestry acknowledged the need for information on the microbial quality of South Africa's water resources and initiated the development of a national microbial surface water quality monitoring programme. This study described the development of the conceptual design which could serve as the basis for full scale implementation of such a programme in South Africa. The principal requirement of the programme was to provide information necessary for the management of the potential health risk posed by surface water resources of poor microbial quality.

After consultation with a number of key persons involved in water quality management the following objectives were formulated for the programme:

- To locate, assess and prioritize those areas in the country where potential health risks related to faecal pollution of water resources are highest;
- To provide information on the status of and trends in the extent of faecal pollution, in terms of the microbiological quality of surface water resources in the high risk areas;
- To provide information to help assess the potential health risk to humans associated with the possible use of faecally polluted water resources;
- To help assess the effectiveness of measures to protect water resources against faecal pollution in terms of trends in the microbiological water quality.

Apart from the abovementioned objectives the design also had to take local conditions and constraints that might impact on the successful implementation of the programme, into account. In order to cater for all these requirements, the approach adopted for the development of the conceptual design was expanded using a unique concept for the identification and prioritization of impacted areas.

8.2 DESIGN APPROACH

During the last twenty years, designers have realized that the main focus of water quality monitoring systems should be on the supply of appropriate information. Data without valid assessment and interpretation has little meaning to water quality managers (Ward et al., 1986, Ward 1996). Various approaches have been followed to improve the information provision of monitoring programmes (Whitfield, 1988; Ward et al., 1990) of which the research performed at Colorado State University, Fort Collins, Colorado, USA is probably the best documented. The approach proposed by Ward *et al.* (1990) served as the basis for the design of the national microbial monitoring programme.

In the light of the extent of microbial pollution of surface water in certain areas and the limited resources available, the main focus of the programme was on areas with a high possible human health impact. The design approach had to be expanded to allow for the identification and prioritization of specific areas of concern.

The basic concept of the approach to select priority areas is that one should have, or be able to develop, a clear understanding of all the factors which could influence the specific water quality variable and/or associated risk. Without a clear understanding of all the influences involved, determining the relevant contributing factors, possible sources of information, methods to quantify these factors or methods to compare risks in different areas, are difficult.

For the purpose of the microbial monitoring programme, two factors that could quantify the potential health risk were identified. They were the threat of increased microbial pollution levels of the water (the result of land use) and the exposure of consumers to the water (sensitivity of water uses). Predictions of the potential health risk were therefore based on a number of applicable land and water uses information sources and serve as the basis for determining the priority among the areas. As described in chapter 6, the initial evaluation of the prioritization procedure indicated that the approach yielded relevant information in terms of the potential health risk to water users.

The approach to focus on specific areas of concern has a number of benefits which could be exploited when designing water quality monitoring programmes. Areas of high risk can be identified which will assist in focusing the monitoring efforts on the problems areas with the highest priority. Many developing countries experience severe health problems related to the microbial quality of water resources but national monitoring programmes are not implemented due to a lack of available resources for operation of an extensive programme. The most evident application for the above described approach would be the design of similar microbial water quality monitoring programmes for these countries. This approach does not require extensive historical microbial water quality data sets but could use a variety of relevant information sources. The area prioritization approach is, however not restricted to developing countries, but could also be used for the optimization of microbial monitoring programmes in developed countries where cuts in funding may necessitate the down scaling of a programme. The area prioritization approach could also be used to assist with the selection of area to be monitored within specific regions.

The area prioritization approach for site selection is of great benefit for the optimization of monitoring programmes which have to supply information on both the spatial and temporal variance of microbial water quality. The main aim in terms of temporal variation is to provide information on the status of and trends in the microbial quality. Detecting trends and variations at a specific sampling point often require enough data to ensure acceptable levels of confidence which restricts the degree to which compromises can be made in terms of sampling frequency. Optimization of a programme is therefore often focused on the spatial distribution of sampling stations. In such cases the approach to select areas of high priority would be ideal to optimize the number of sampling stations and to assist in determining their national distribution without jeopardizing the statistical basis of the design.

The ability to select areas of high priority also allows for a phased approach towards the implementation of a monitoring programme. In a developing country, phased implementation allows for the development of the necessary skills and capacity, as well as the required infrastructure needed for the large scale operation of a programme. When funds to support the implementation of a monitoring programme are limited, a phased approach could also be used to demonstrate the benefits of the specific programme. Once water quality managers have experienced the value of such a programme it might be easier to motivate for and secure the extra funding required for expansion.

The approach to focus on impacted areas is generic enough not to be restricted to the design of microbial water quality monitoring programmes alone. Other monitoring objectives could also be dealt with in the same manner. Applications could, among others, include the design of programmes to monitor eutrophication, pesticides levels or even oestrogen mimicking substances. An additional benefit of the area prioritization approach is that a better understanding of the factors influencing a specific issue could also be of use when formulating management strategies to deal with the problem.

8.3 CONCEPTUAL DESIGN

The adopted approach lead to the development of a design which could effectively cater for the information requirements and objectives formulated at the initiation of the project. The main features of the monitoring programme include among others the use of the faecal coliform group as the only microbial variable to be monitored on a weekly basis in predetermined high risk areas. To ensure uniform sampling and analysis the preparation of standard operating procedures was proposed as part of the data collection specifications. A health risk index based on the assessment of the actual monitoring data was developed to indicate the potential health risk associated with water use in an area. The preparation of both technical reports and reports aimed at the general public was proposed.

During evaluation of the design on a pilot scale the ability of the design to meet the set information objectives was demonstrated. The present conceptual design for the programme also deals effectively with constraints and changes in the external environment in which it has to operate. The decision to design a separate programme to monitor the microbial water quality is one of the factors that contributed to the flexibility of the design. The design could be optimized for microbial water quality monitoring without having to make compromises to unrelated objectives such as those specific to chemical or biological monitoring. Another factor that contributed to the successful development of the conceptual design, suitable for local conditions, was that the design approach was expanded to cater for some of the constraints experienced in the South African context.

Since completion of the design phase, implementation of the national programme started and monitoring was initiated in four of the identified high risk areas. Plans to increase the number of high risk areas monitored are progressing well. The programme appears to address a significant information need on an important aspect of water resources management and to do so in an efficient and effective manner

8.4 SUMMARY

In conclusion, the concept of high risk areas and the procedure to identify and prioritize them as developed during this study is a critical component of the overall design and could ensure the success of the national microbial water quality monitoring programme for the following reasons:

- The programme addresses immediate water quality management needs as it focuses on areas most likely to experience microbial water quality problems.
- The programme can be implemented using a phased approach which successfully deals with possible financial and resource constraints.
- Spatial optimization of the programme could be achieved without jeopardizing the detection of temporal trends and variations.
- Once implemented the programme can easily be expanded or down scaled on the basis of the list of priority areas.
- The design is flexible enough to address changes in the external environment e.g. new legislation.

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