Water Quality Monitoring in the SADC region

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DECLARATION

I declare that this thesis is my own unaided work and the sources for the information used have been acknowledged. It is being submitted for the degree of Masters of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted for any degree or examination in any other University.

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ABSTRACT

Water plays a global role in an enormous variety of ways. More importantely it also plays a fundamental role on a regional and local scales where it has a profound effect on the environment and socio economic development. It is a prerequisite for many of the mans activities and as such it must be managed and protected accordingly. In this water quality plays a fundamental role and water quality monitoring is a foundation stone of any serious efforts to manage water resources on any scale.

The research conducted focused on water quality monitoring in the SADC region. It looked at the current practice and the gaps present with respect to the real needs and international best practice.

SADC region is characterized by trans-boundary water systems where pollution of water resources is often not understood properly nor has been seriously studied. A regional Water Quality Monitoring Program is advocated to address these issues and is seen as one of the prerequisites for effective water resources management in the SADC region.

Existing Water Quality Monitoring in individual countries of the SADC region has been studied on the basis of existing (limited) information and gaps with respect to international best practice have been identified. Recommendations have been made regarding the establishment of the SADC Water Quality Monitoring program. A set of principles on which this should be based have been formulated.

It has been concluded that SADC countries do not have an appropriate water quality monitoring in place and that what does exist is not in line with the best practice recommendations. It is suggested that without an appropriate regional water quality monitoring program water quality could become one of the limiting factors of the future economic development in the region.

DEDICATION

To my parents late Mr. A.S. Macatsha and Mrs. I. N. Macatsha

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

1.0   Introduction

Water plays a global role in an enormous variety of ways. In its liquid and solid forms, for example water is a powerful agent of topographical change. Water is also a solvent in many of the chemical reactions that weather rocks and it acts as a chemical agent in weathering through freeze-thaw temperature cycles (Marjanovic and Miloradov, 1998). It is an essential element for life on earth, playing a major role in climate regulation and in biochemical cycles. The movement of such key elements as carbon, nitrogen, phosphorus and oxygen through the earth system are mediated by water in both liquid and gaseous forms producing a basic unity of the fluid and biological earth (Marjanovic and Miloradov, 1998).

Water is the most important and most abundant substance on earth and yet it is also the most lacking resource needed for the survival of the human society as we know it today. Man takes away from nature approximately $100x10^9$ tonnes of different raw materials annually, but uses almost $4000x10^9$ tonnes of fresh water per year. Water is also a key element in socio-economic development. While the total amount of available water resources remains more or less constant, the demand for water tends to increase with the growth of population and the development of industry and agriculture. It is not surprising that water is becoming a scarce resource in many regions of the world where once it is used to be plentiful. Social and economic developments now require people to start making major efforts to protect water and control its use and pollution (UNESCO-IHE, 1998).

In order for water scarcity not to hamper socio-economic development, it is essential for many countries to improve their water resources planning and management. A water resource plan consistent with the overall economic, social and environmental policies of a country is an important element which ensures that water resources contribute to the sustainable development of that country. In 1997 the Mar del Plata Action Plan adopted by the United Nations Water Conference in Argentina recommended the formulation of Water Resources

Master Plans (WRMP) for countries and river basins. The objective was to provide a long-term perspective for the planning and management of available water resources. The conference suggested that planning should be considered as a continuous activity recommending that long-term plans be revised and completed periodically, preferably once every five years(Marjanovic and Miloradov, 1998). Water quality monitoring is a constituent part of a broader Water Resources Management Plan and should also have characteristics of it.

1.1 Problem Definition

Water resources in the SADC region are highly variable, both over space and time. The northern portion of the region receives between 1000mm to 4000mm in an average year, while the southern area typically receives between 250mm and 1000mm (USAID, 1995), with some receiving less than 50mm per year. The problem of low precipitation in many areas is compounded by exceedingly high rates of potential evaporation, resulting in the majority of SADC member countries being dominated by an arid or semi-arid climate thus having limited water resources and estimates suggest that six countries will suffer from water scarcity by the year 2025. Precipitation patterns are typically very seasonal, with a six month summer wet season and a winter season with little or no rainfall. In addition, wide meteorological variations occur naturally from one year to the next – often creating water shortages or severe drought, and occasionally excess rainfall and floods. For example, areas receiving average rainfall of 400-600 mm per year can expect a drought of two years or more approximately every eight years (Rukuni, 1995). In some areas of South Africa, rivers have experienced periods of 10 consecutive years of less than average flows (Vander Merwe, 1995).

SADC's renewable freshwater resources are estimated to be 650 billion m^3 per year (excluding the Democratic Republic of Congo) (Chenge and Johnson, 1996), which is equivalent to approximately 15,000 litres per person per day (GWP-Southern Africa Technical Advisory Committee, 1999). The variable and uneven distribution of water resources in Southern Africa combined with the region's

current state and pace of development together pose significant challenges to meeting water needs. More than 170 million people live in Southern Africa and with a growth of roughly three percent per year; it is one of the fastest growing regions in the world. Today more than half of the region's population has no access to safe water and sanitation services (Chenge and Johnson, 1996). The majority of those without access live in rural areas some distance from existing water supply systems, making supplying services to them difficult and expensive. Urban populations, which make up 32 percent of the total, are growing approximately five percent each year, meaning a doubling every 15 years, further straining many overburdened water systems(Johansson, 1999) **(See Figure 1.1)**

Figure 1.1: Expected Population Growth in SADC
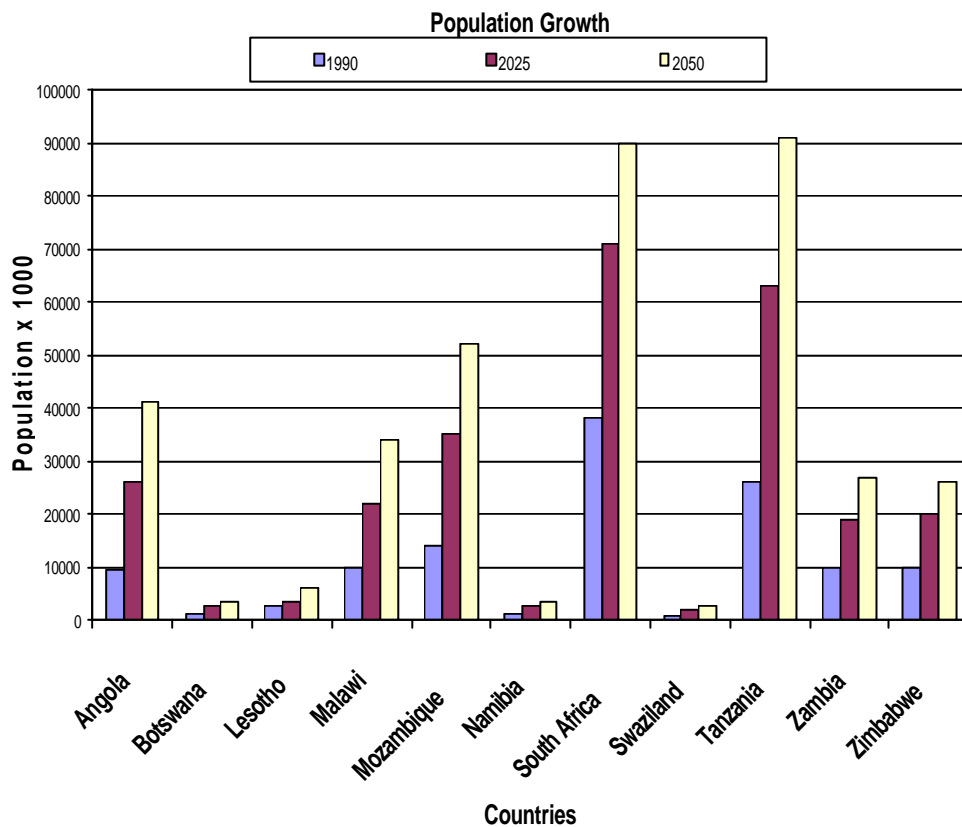
(Source: Ohlsson, 1995)

Water supply in many countries is falling behind the population curve, raising the water stress and scarcity. A country is considered "water stressed" when the

number of people per million cubic meters of water supply exceeds 600, and "water scarcity" arises when the population surpasses 1000 per million cubic meters of water availability. According to a study by Leif Ohlsson, South Africa was already water stressed by 1990, and six other countries had water quality and/or dry season water supply problems (Ohlsson, 1995). **(See figure 1.2 and 1.3)** By 2025, five countries are expected to have water quality and/or dry season supply problems; four are expected to face water stress, and two are expected to face water scarcity. Not one is expected to have adequate water resources

Figure 1.2: Water Scarcity Indices for SADC Countries
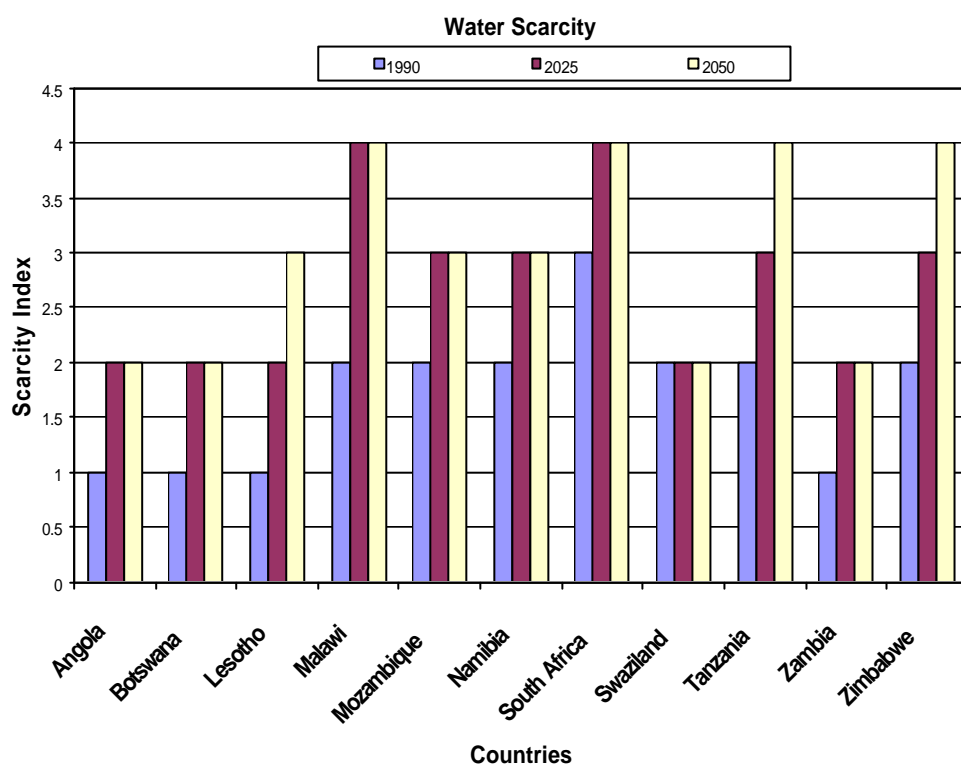
1= adequate; 2 = quality & dry season problems; 3 = water stress; 4 = absolute scarcity;

5 = water barrier

(Source: Ohlsson, 1995)

Figure 1.3 Water Scarcity
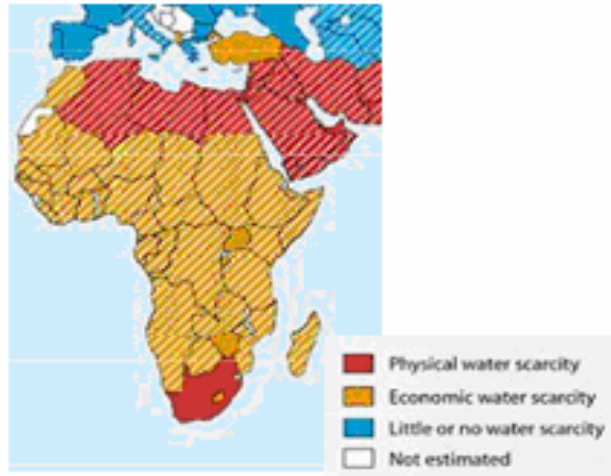
Source : www.iaea.org/.../ water_supply_demand.html (International Water Management Institute, 2000)

Figure 1.4 Water Stress
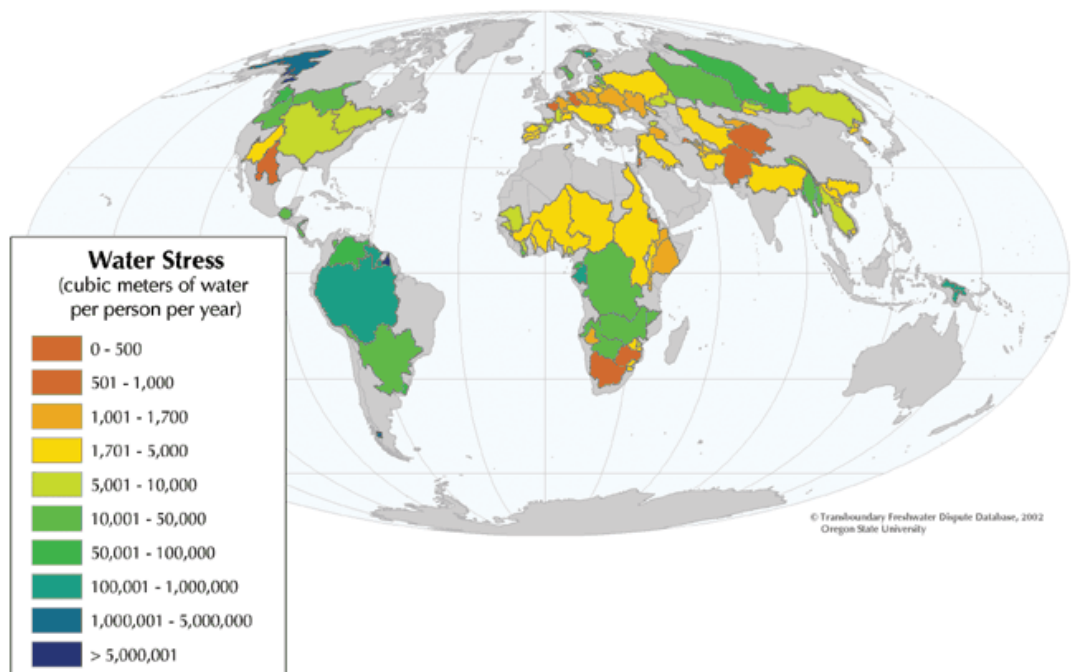
Source : www.transboundarywaters.orst.edu/.../

The causes of water stress are many **(See figure 1.5)**

Figure 1.5 Causes of water stress
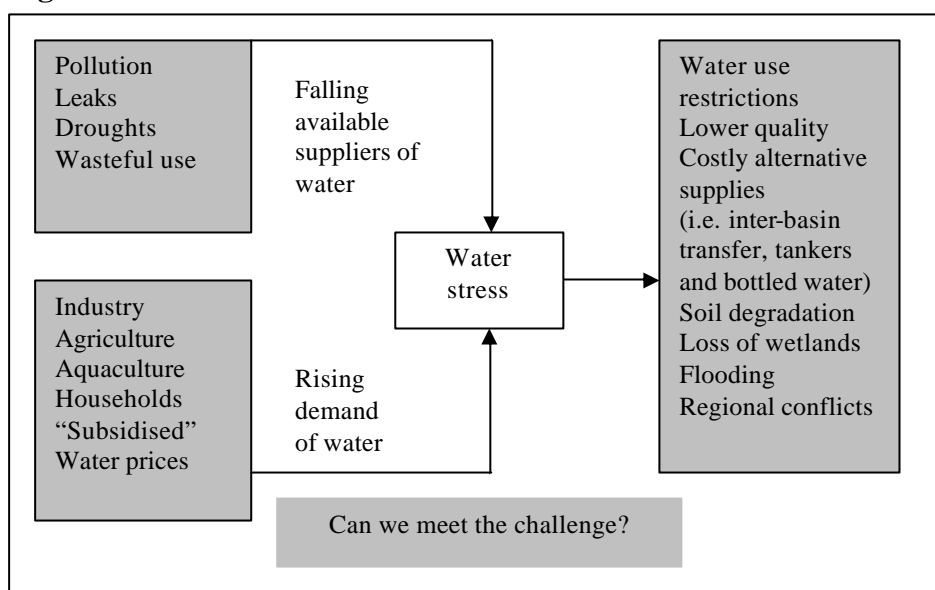
Source: http://org.eea.eu.int/documents/ar1997/ar97_monitoring.html

The persistent supply side mentality of many Southern African water planners and managers exacerbates the region's already difficult water situation in many ways. Ecosystems and communities dependent on rivers that are sustained by scant and erratic rainfall are further stressed by water extractions that are larger than would be with Water Conservation and Demand Management (Rothert, 2000). Governments (often poor) incur debt for infrastructure that could be delayed with Water Conservation Demand Management. Water suppliers must commit scarce revenues to high cost bulk water supplies at the expense of improving water service to needy customers. Water consumers are forced to pay higher water tariffs to pay for infrastructure that is not yet needed. And those with poor service or no service must continue to suffer the inconveniences and health problems associated with inadequate water and sanitation services. The supply side approach has resulted in higher costs to the regional economy, society and environment.

In parallel to the water quantity problems indicated, water quality problems are often as severe as those of water availability but less attention has been paid to them, particularly in developing regions. Sources of water quality problems

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include discharges of untreated sewage, chemical discharges, petroleum leaks and spills, dumping in old mines and pits and agricultural chemicals that are washed off or seep downward from farm fields etc. More than half of the World's major rivers are seriously depleted and polluted, degrading and poisoning the surrounding ecosystems, threatening the health and livelihood of people who depend on them (World commission on Water, 1999). For example in Zimbabwe the Mukuvisi river, which runs into Harare's drinking water supply contains high amounts of nutrients, such as phosphorus, nitrogen, sulphate, calcium, magnesium, fluoride, aluminium and iron largely from industrial dumps along the river banks (SADC/IUCN/SARDC, 1999).

Poor water quality leads not only to water related diseases but also reduces agricultural production, which means that more foodstuff and agricultural products must be imported. Poor water quality also limits economic development options, such as water-intensive industries and tourism, a situation that is potentially disastrous to developing countries (UNEP, 2002). In Southern Africa the widespread invasion of the water hyacinth (Eichornia crassipes) is a further cause of deteriorating water quality. The hyacinth forms dense mats that block water channels, disrupting flow patterns. Decaying mats of the weed generate bad odours and lead to eutrophication of the water body. Areas afflicted by the water hyacinth include lakes Victoria and Kariba and in some rivers in the SADC region. In summary water quality management is one of critical aspects of the overall water resource management in general and in Southern Africa in particular.

1.2 Research questions, objectives and outcomes

The objectives of the research carried out are to come with answers to the following questions within the context of water quality monitoring as a component of water resources management.

- Is water quality monitoring effective with respect to the needs of water resources management in the SADC region?

- Does SADC region have an effective monitoring program? And if not what are the deficiencies?

- Are the SADC countries using aligned monitoring programs with respect to best practice requirements regarding scope, extent and dynamics of monitoring?

- How do existing monitoring results relate to established water quality standards in SADC region?

- What resources are necessary to ensure adequate water quality monitoring for the future?

- What resources are necessary to ensure that SADC water quality monitoring systems are aligned?

The following will be the main outcome of the research project

- Framework for water quality monitoring programme for the SADC region
- Suggestions for monitoring programme in SADC countries.

1.3 DESCRIPTION OF THE STUDY AREA AND RESEARCH METHODOLOGY

The Southern African Development Community is a grouping of 13 countries (Angola, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Mauritius, Tanzania,

Zambia, Democratic Republic of Congo and Zimbabwe), with the main objective of advancing co-operation, co-ordination and integration of the socio-economics of member countries. The continental part of SADC region occupies an area of about 7 million Km^2 with geographical and climatic conditions varying from sub-equatorial rain-fed vegetation to the oldest desert in the world, in Namibia (Chenje, 1996). Economic conditions between the countries vary also.

Figure 1.6 GDP density
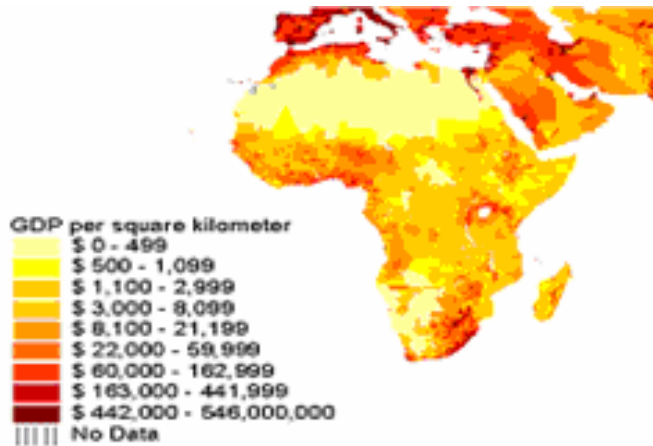
1.3.1   Population

The SADC Region represents about 130 million people or about 20 percent of the
population of Africa.

Figure 1.7 Population density
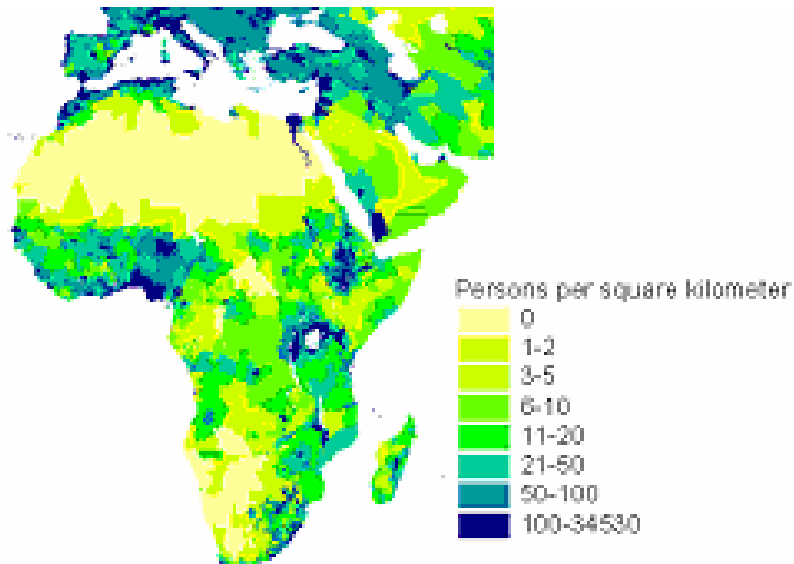
1.3.2 Climatic Factors

Water falls from clouds in many forms, in its liquid or solid state it may be rain, drizzle, sleet (freezing rain) hail or snow. In Southern Africa, hail is uncommon but snow sheet occur only in certain areas such as Lesotho and Drankensburg mountains in South Africa (Chenje, 1996)

- **Weather Patterns:** The Inter-Tropical Convergence Zone (ITCZ) brings most of the rain that falls in the Southern Africa region. This Zone occurs between a dry, warm air mass and moist, cool air mass. The ITCZ is a zone of intense rain-cloud development created when the South East Trade Winds (from the Southern part of the region) collide with the Northeast Monsoon. (Chenje, 1996).

- **Rainfall Patterns:** Rainfall in Southern Africa comes almost entirely from evaporation over Indian Ocean, although several weather systems combine to produce the rainfall pattern. Evaporation is essentially the opposite of rainfall because the heat of the sun draws moisture from earth, plants and water bodies back to the atmosphere.

- **Temperature:** Life earth depends on the sun, which changes temperature, thus facilitating water transfers from the oceans to the land and back to the oceans. Atmosphere and surface temperatures set in motion the air vapour over land that precipitates as hail, snow, sleet rain and drizzle (SADC/IUCN/SARDC, 1994).

  Seasonal and regional extremes of temperature occur throughout the interior plateau. Daytime temperatures exceed 40°C in the low altitude areas summer, while by contrast; frosts are common in winter in the South. Two lowest temperatures recorded in the region were -18°C at the top of the Drankensburg escarpment in Lesotho and -19°C on the old planalto in Angola. Below freezing temperatures are experienced in areas in areas of over 1.600 m above sea level. Widespread frosts are common in the southern and central interior of southern Africa (Wits, 1986).

- **Winds:** Surface winds in southern Africa often reach high speeds. Over much of the region, the average wind speed is between 1-4 metres/second with very little seasonal variation. The winds are usually lighter in the afternoon and at night. The strongest gusts are usually associated with well-developed thunderstorms or outbreaks of showery rain, although, in general winds are much lighter and more variable in direction during the wet season. Winds tend to be strong during winter, blowing from the east-south east over much of southern Africa (SADC/IUCN/SARDC, 1994).

1.3.3 Economic Development

Water, be it fresh or marine has always been central to human life as a result of that, in some of Southern African large cities like Dar es Salaam, Beira, Maputo, Durban, Cape Town, Walvis Bay and Luanda grew as the major ports of the region (Chenje, 1996). Fisheries, agriculture, transport and industry all depend on water for production distribution and consumption. It is therefore not surprising that water has been described as the single most important resource for our future and the pivot on which all future development depends(Williams, 1995).

The unreliability of rainfall in Southern Africa has therefore a major bearing upon various economic sectors, particularly agriculture which accounts for 90 percent of the water demand in the region (USAID, 1995).

1.3.4 Availability of Water

The socio-economic future of people in southern Africa depends on agriculture, fisheries, mining, industry, manufacturing, tourism and industrial development to generate employment and economic growth. This can only be achieved if water of acceptable quality and quantity can be supplied in time at the right locations at the low cost to support the planned, expected socio-economic development in a country or region. Human activities and natural conditions that affect the

environment also determine the availability of water in many ways, either by overuse or pollution of water resources or even the dry conditions (Heyns, 1995).

In this region there is pollution of rivers, lakes, aquifers from domestic and industrial wastewater discharges, mining runoff, agro-chemicals and other sources are growing threats to the water resources in the region. Solid, liquid and particulate waste by-products of urbanization and economic activities are contaminating air, soil and water quality. The quality of water supplies in the SADC region once taken for granted is becoming the focus of increasing concern. The quality of a particular water body determines the use that is suited for or the level of treatment that would be required before it can be of a particular use. The map below shows the major rivers in the SADC region.

Figure 1.8: SADC Map

1.4 Research Methods

The choice to take on the present research has been based on the availability of data in ongoing monitoring process in SADC region. The research has been done

since May 2004. The core of the research deals with evaluating the monitoring program of water quality in SADC region. The methodology of this research consists of 5 stages namely: (1) Inventory and preparation stage, (2) Data collection, (3) Data analysis, (4) Gap analysis stage and (5) Evaluation and Reporting stage.

1.4.1   Inventory and Preparation Stage

This stage is composed of activities such as literature review, proposal finalization and collection of data, **figure 1.9** presents flow chart of the methodology implemented to achieve objectives of the research.

Literature review: A literature review is an evaluative report of information found in the literature related to the research topic. It includes the bibliographic studies from journals and books concerning the research topic. Literature review is going to be carried out in order to develop the researcher's knowledge on scientific and technical aspects methodology development for assessment and monitoring of water quality.

Data collection: Data collection is by means of sending questionnaires to all the SADC countries in addition to questionnaires by visiting, discussion and electronic mail communication with people from the institutions responsible for water quality monitoring in each and every country in the SADC region. The data to be collected includes the following:
- The institution responsible for the water quality monitoring in each country.
- Number of monitoring station they have
- The parameters they are looking at
- Frequency of monitoring
- The map showing monitoring stations

Figure 1.9: Flowchart of the research methodology
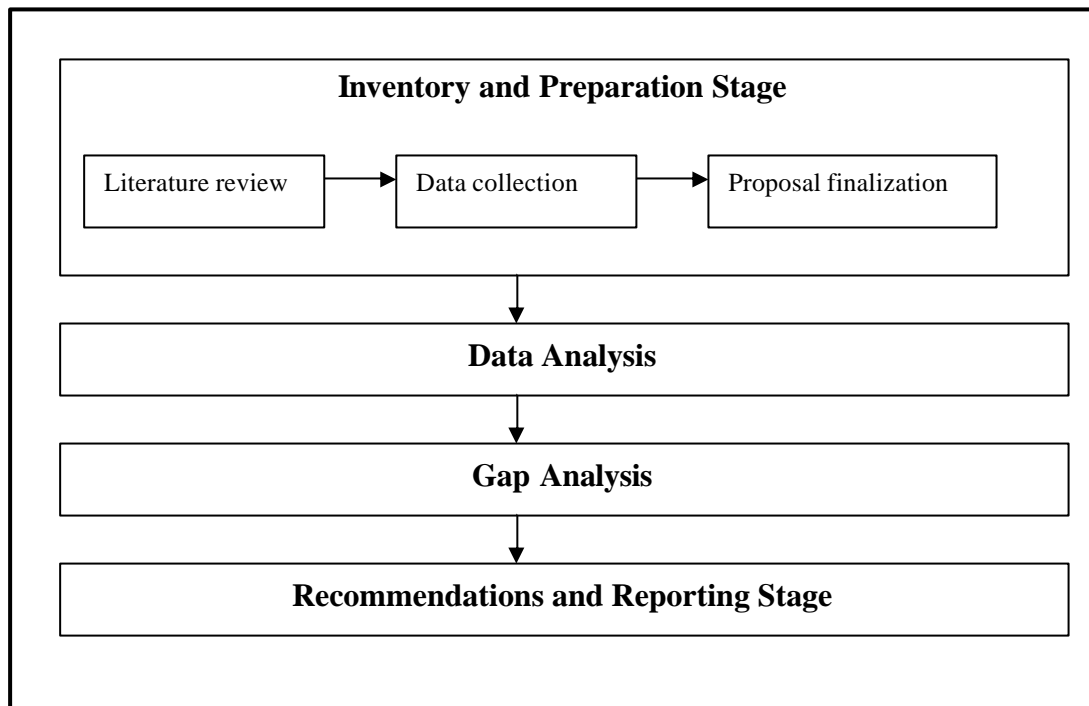
1.4.2   Data analysis

In analysing the data the researcher was responding to the research questions. The researcher compared the existing water quality monitoring programmes of SADC region with those of the best practice.

1.4.3   Gap analysis

The researcher undertook analysis and priority setting exercise that identified weakness or omissions in current monitoring program.

1.4.4   Recommendation and Reporting Stage

This is the last stage of the research. This stage includes recommendations of the monitoring programme to be used in future to meet the required standards of water quality monitoring. The present report is the final result of this thesis work.

1.5 Structure of Thesis

According to the adopted methodology, the research chronology and in view of the clarity of the present document, this thesis has been structured in six chapters. In Chapter 1 as an introduction, water resource problems in SADC region are identified and the research questions and objectives are explained it also introduces the study area covered by the research and available data is described.

Chapter 2 is the literature review where current knowledge based on Water Quality Monitoring is discussed through available literature publications. The major facts that have been addressed here are Water Quality problems, Water Quality Monitoring definition and purpose of Water Quality Monitoring.

Chapter 3 gives the best practice/ required practice in water quality monitoring. The major facts that have been discussed are the objectives of Water Quality Monitoring, Selecting sampling stations, Frequency of Monitoring, Water Quality Monitoring Parameters, Resources that are needed for Monitoring and how to report Monitoring information.

Chapter 4 gives the results and discussion, existing water quality monitoring programs in each SADC country are discussed and SADC monitoring deficiencies are also discussed.

Chapter 5 gives a summary of recommendations and conclusions.

CHAPTER 2: LITERATURE REVIEW

2.0   Introduction

This chapter summarises the finding of the literature review. Its purpose is to provide an introduction to the basics of surface water quality and monitoring.

2.1 Water Quality

Water quality is a term used to express the suitability of water to sustain various uses or processes. Any particular use will have certain requirements for the physical, chemical or biological characteristics of water, for example limits on the concentrations of toxic substances for drinking water use, or restrictions on temperature and pH ranges for water supporting invertebrate communities. Consequently, water quality can be defined by a range of variables which limit water use. Although many uses have some common requirements for certain variables, each use will have its own demands and influences on water quality (Bartram & Ballance, 1996). Quantity and quality demands of different users will not always be compatible and the activities of one user may restrict the activities of another either by demanding water of a quality outside the range required by the other user or by lowering quality during use of water (Meybeck and Chapman, 1996).

The quality of surface and underground waters is dependent on natural factors (geological, topographical, meteorological, hydrological and biological) in the drainage basin and varies with seasonal differences in run-off volumes, weather conditions and water levels. Large natural variations in water quality may therefore be observed even where only a single watercourse is involved and in the absence of any influence of human activities. Human intervention also has significant effects on water quality (Bartram and Balance, 1996). Some of these effects are the result of hydrological changes such as the building of dams, draining of wetlands and diversion of flow. More obvious are the polluting activities, such as the discharge of domestic, industrial, urban and other wastewaters into the watercourse (whether international or accidental) and the

spreading of chemicals on agricultural land in the drainage basin (Bartram and Balance, 1996).

The effects of human activities on water quality are both widespread and varied in the degree to which they disrupt the ecosystem and or restrict water use. Pollution of water by human faeces for example is attributable to only one source, but the reasons for this type of pollution, its impacts on water quality and the necessary remedial or preventive measures are varied. Faecal pollution may occur because there are no community facilities for waste disposal, because collection and treatment facilities are inadequate or improperly operated, or because on-site sanitation facilities (such as latrines) drain directly into aquifers (Bartram and Balance, 1996).

The effects of faecal pollution vary. In developing countries intestinal disease is the main problem, while organic load and eutrophication may be of greater concern in developed countries (in the rivers into which the sewage or effluent is discharged and in the sea into which the rivers flow or sewage sludge is dumped)(Meybeck, 1989). A single influence may, therefore give rise to a number of water quality problems, just as a problem may have a number of contributing influences. Eutrophication results not only from point sources, such as wastewater discharges with high nutrient loads (principally nitrogen and phosphorus), but also from diffuse sources such as run-off from livestock feedlots or agricultural land fertilised with organic and inorganic fertilisers. Pollution from diffuse sources, such as agricultural run-off or from numerous small inputs over a wide area, such as faecal pollution from unsewered settlements, is particularly difficult to control (Bartram and Balance, 1996).

The quality of water may be described in terms of the concentration and state (dissolved or particulate) of some or all of the organic and inorganic material present in the quality in the water, together with certain physical characteristics of the water (Meybeck, 1989). It is determined by *in situ* measurements and by

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examination of water samples on site or in the laboratory. The main elements of determining water quality are therefore on-site measurements, collection and analysis of water samples, the study and evaluation of the analytical results and the reporting of the findings. The results of analyses performed on a single water sample are only valid for the particular location and time at which that sample was taken. One purpose of a monitoring programme is therefore to gather sufficient data (by means of regular or intensive sampling and analysis) to assess spatial and temporal variations in water quality (Bartram and Ballance, 1996).

The quality of the aquatic environments is a broader issue that can be described in terms of:

- Water quality
- The composition and state of the biological life present in the water body,
- The nature of the particulate matter present
- The physical description of the water body (hydrology, dimensions, nature of lake bottom or river bed etc)

Complete assessment of the quality of the aquatic environment, therefore requires that water quality, biological life, particulate matter and the physical characteristics of the water body be investigated and evaluated (Bartram and Ballance, 1996). This can be achieved through:

- Chemical analyses of water, particulate matter and aquatic organisms (such as plank tonic algae and selected parts of organisms such as fish muscle), etc.
- Biological tests, such as toxicity tests and measurements of enzyme activities, etc.
- Descriptions of aquatic organisms, including their occurrence, density, biomass, physiology and diversity (from which, for example, a biotic index may be developed or microbiological characteristics determined), etc.
- Physical measurements of water temperature, pH, conductivity, light penetration, particle size of suspended and deposited material, dimensions of the water body, flow velocity, hydrological balance, etc.

The importance attached to quality will depend on the actual and planned use or uses of the water (water that is to be used for drinking should not contain any chemicals or micro-organisms that could be hazardous to health). Since there is a wide range of natural water qualities, there is no universal standard against which a set of analyses can be compared. If the natural, pre-polluted quality of a water body is unknown it may be possible to establish some references values by survey and monitoring of polluted water in which natural conditions are similar to those of the water body being studied.

All this constitutes Water Quality Monitoring which is defined below

2.2 Water Quality Monitoring

Monitoring is defined as the programmed process of sampling, measurement and subsequent recording or signalling or both of various water characteristics, often with the aim of assessing conformity to specified objectives one can also define monitoring as the effort to obtain quantitative information on the physical, chemical and biological characteristics of water via statistical sampling (Sanders et al, 1987). Water quality monitoring is defined as a systematic, regular and continuous (long term) observation and measurement with the purpose to describe and qualify variability in space and time of water quality. It can also be viewed as both the beginning point of water quality management efforts. Data are collected to compare with those in the past and in the future (Nader and Tate, 1998). The type of information sought depends on upon the objectives of the network. Objectives range from detecting stream standard violations to determining temporal water quality trends (Sanders et al, 1987)

The word monitoring in the strictest sense, implies watching the ongoing of water in order to ensure no laws or rules are broken. This connotation, while relevant to some objectives, has in general been lost since water quality monitoring refers to most types of water quality sampling or measurement (Sanders et al, 1987).

Monitoring provides the information that permits rational decisions to be made on the following:

- Describing water resources and identifying actual and emerging problems of water pollution.
- Formulating plans and setting priorities of water quality management
- Developing and implementing water quality management programmes
- Evaluating the effectiveness of management actions

Once sufficient data have been gathered, it is possible to describe the average conditions, the variations from average and the extremes of water quality, expressed in terms of measurable physical, chemical and biological variables (Nader and Tate, 1998).

Monitoring in the broader sense can be placed in the information cycle (figure2.1). The guiding principle is that monitoring (and assessment) should be seen as a sequence of related activities that starts with the definition of information needs and ends with the use of the information products (Maasdam, 2000).

Figure 2.1: The Monitoring Cycle

Water management

Information needs

Monitoring strategy

Network design

Sample collection

Laboratory analysis

Data handling

Data analysis

Reporting

Information utilization
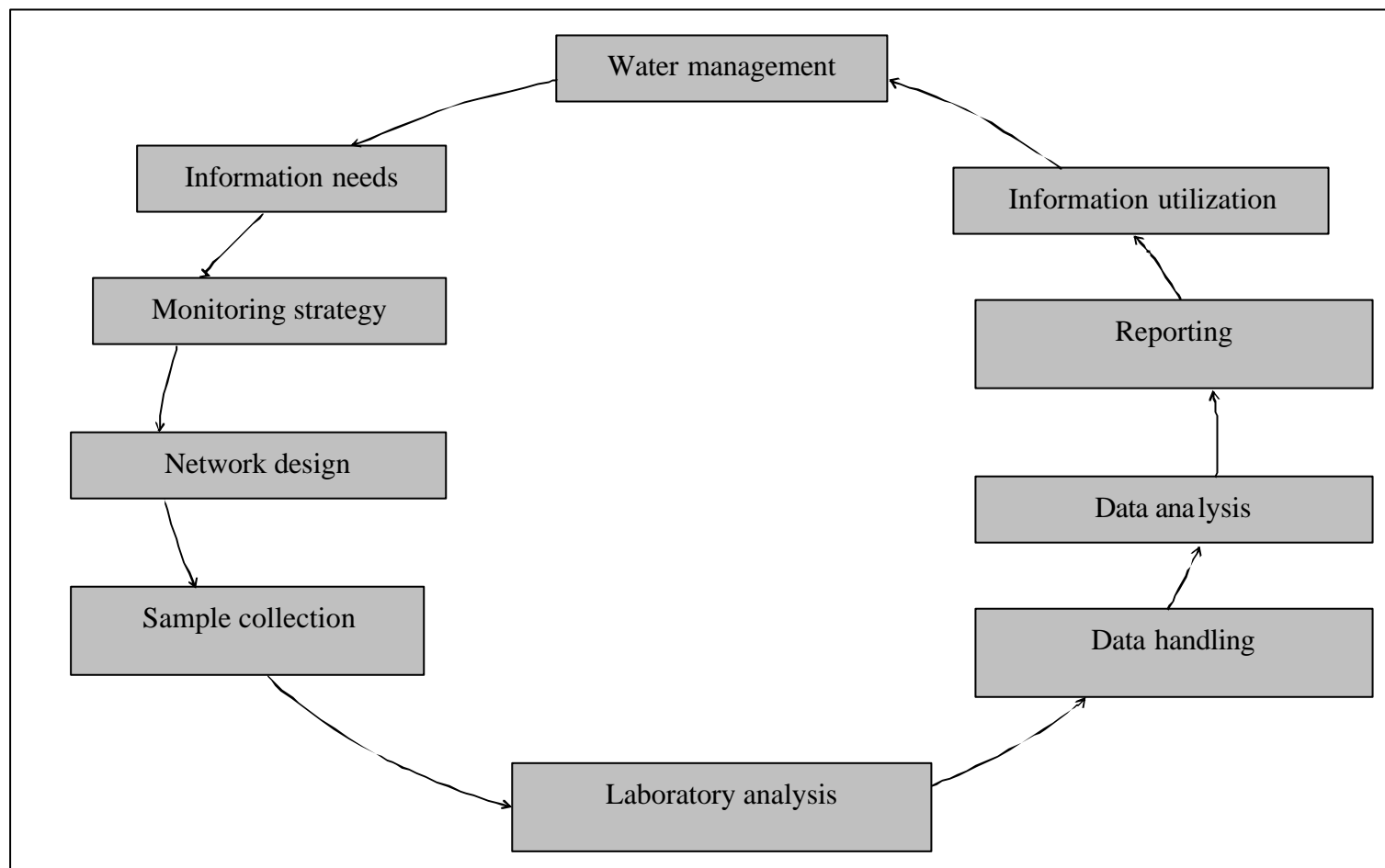
(Source: Maasdam, 2000)

This cycle emphasises that the ultimate goal of monitoring is to provide information, not only data. As in the past many monitoring programmes have been characterised by the data rich but information poor syndrome (Ward etal., 1986). Attention should be directed towards the end-product of monitoring, i.e. information.

Any attempt to evaluate water quality monitoring programmes should begin with the question "Why do we monitor?" It is very important to be able to describe the purposes and objectives of monitoring as they create the background for the direct monitoring activities, that is, the set-up of sampling networks, variables to be measured, sampling frequency, data storage and information utilization including data analysis and reporting(Kriestensen and Bogestrand , 1996)

The purpose of monitoring is generally laid down by laws or other regulatory actions (directives, water quality standards, action plans) and aim at assessing the environmental state and detecting trends. The regulatory actions set up water quality goals or standards (e.g. a 50 percent reduction of nitrogen loading to surface waters, no pesticides in drinking water, etc), and the purpose of monitoring is to supply data and information on the water quality in relation to these regulatory actions(Kriestensen and Bogestrand , 1996)

2.3 Purpose of Monitoring

The principal reason for monitoring water quality has been, traditionally the need to verify whether the observed water quality is suitable for intended uses. However monitoring has also evolved to determining trends in the quality of the aquatic environment and how the environment is affected by the release of the contaminants by other human activities and or by waste treatment operations. This type of monitoring is often known as impact monitoring (Bartram and Ballance, 1996). More recently monitoring has been carried out to estimate nutrient or pollutant fluxes discharged by rivers or groundwater to lakes and oceans, or across international boundaries. Monitoring for background quality of

aquatic environment is also widely carried out as it provides a means of comparing and assessing the results of impact monitoring (Meybeck, 1996).

No monitoring programme should be started without critically scrutinizing the real needs for water quality information. Since water resources are usually put to several competing beneficial uses, monitoring should reflect the data needs of the various water users involved. The implementation of a monitoring and assessment programme may focus on the spatial distribution of quality, on trends or on aquatic life. Full coverage of all three elements is virtually impossible or very costly. Consequently, preliminary surveys are necessary in order to determine the focus of the operational programme (Bartram and Ballance, 1996).

The monitoring and assessment of water quality is based ultimately upon the fundamental physical, chemical and biological properties of water. However, water quality monitoring and assessment is a process of analysis, interpretation and communication of those properties within the wider context of human activity and use and the conservation of the natural environment. It is not a fixed process, but is adapted in the light of local, national or international needs. Styles and strategies of management vary greatly, depending on institutions, resources and priorities (Meybeck and Makela, 1996). Water quality monitoring and assessment can be conducted from a number of different perspectives that may combine the following goals in different ways:

- Uses of water: Does water meet user requirements for quantity and quality? (For example, with respect to meeting use-defined standards. In this context conservation of biodiversity may be considered a water use.)
- Influences on water quality from direct use or from other human activities or natural processes. What are these influences?
- Impacts on water quality (e.g. water as a medium for pollutant transport and exposure).
- Control and regulation of water quality. What is the capacity of water to assimilate pollutants? Are standards met? Are control strategies and management action appropriate and effective?

- How does water quality differ geographically in relation to uses and quality influences?
- How have past trends in water quality, influences and policies led to the present status?
- What factors in present water quality and in the past, present and planned activities, give an insight into future trends? What will these be?
- How does water quality influence other parts of the environment, such as marine coastal waters, soil, biota, wetlands?

These are examples of the types of goals, answers or information that are sought in undertaking water quality monitoring. They approach water quality monitoring from different perspectives in terms of basic variables and present status, time trends and spatial differences, uses, pollution impacts and management needs for information for decisions and action (Bartram and Balance, 1996). These differences will result in different approaches to the design and implementation of monitoring programmes, to the selection of variables to be measured, to the frequency and location of measurements, to the additional information needed for interpretation and the way in which information is generated and presented to meet particular information requirements(Meybeck and Makela, 1996).

South Africa, for example has identified the scope for Water quality monitoring. Generally, the scope of water quality monitoring has been divided into three categories:
- Hydrological monitoring
- Resource quality monitoring
- Water resources monitoring

Hydrological monitoring involves monitoring of the quantity and quality of surface and ground water.

Resource quality monitoring involves monitoring the quality and quantity of surface water and groundwater as well as monitoring of ecosystem linked to water resources.

Water resources monitoring involves both the natural and the impacted resource, including resource use and rehabilitation.

In general the scope of water quality monitoring in the SADC region was focused on hydrological monitoring with very little attention given to water quality proper. To have meaningful and successful monitoring programmes the scope should include all aspects of water quality monitoring such as resource quality monitoring and water resources monitoring.

CHAPTER 3: WATER QUALITY MONITORING

3.0 The Best Practice

When a water quality monitoring programme is being planned, water-use managers or similar authorities can reasonably expect that the programme will yield data and information that will be of value for management decision-making (Meybeck and Makela, 1996). The following are examples of the types of information that may be generated by a monitoring programme:

- How the quality and quantity of water in a water body relate to the requirements of users.

- How the quality and quantity of water in a water body relate to established water quality standards

- How the quality of water in a water body is affected by natural processes in the catchment

- The capacity of the water body to assimilate an increase in waste discharges without causing unacceptable levels of pollution

- Whether or not existing waste discharges conform to existing standards and regulations

- The appropriateness and effectiveness of control strategies and management actions for pollution control

- The trends of changes in water quality with respect to times as a result of changing human activities in the catchment area. Quality could be declining as a result of waste discharges or improving as a result of pollution control measures.

- Control measures that should be implemented to improve or prevent further deterioration of water quality

- The chemical or biological variables in the water that render it unsuitable for beneficial uses.

- The hazards to human health result, or may result from poor water quality in the water body

- How developments in the catchment area have affected or will affect water quality

- The effects that deteriorating water quality have on plant and animal life in, or near the water body.

The information required for monitoring programme does, however provide an indication of the type of programme that should be implemented. Some monitoring programmes will be long-term and intended to provide a cumulative body of information; others will have a single objective and will usually be of short duration (Bartram, 1996).

3.1   Designing a Monitoring Programme

The design of a monitoring programme should be based on clear and well thought out aims and objectives and should ensure, as far as possible that the planned monitoring activities are practicable and that the objectives of the programme will be met(Bartram and Ballance, 1996). The design of a water quality monitoring programme, the selection of a sampling stations, the frequency of sampling, the parameters to be analysed, etc all depend greatly on the objectives of the programme. No monitoring programme should therefore be started without defining the objectives also should be evaluated regularly (Kelderman, 2002). When a new programme is being started, it is very useful to begin with a survey of the region. The duration of such surveys will be between a few months up to a year and should preferably include the different seasons. Of course much information can be derived form previous historical data (Kelderman, 2002).

It is useful to prepare a programme document or study plan, which should begin with a clear statement of the objectives of the programme and a complete description of the area in which the monitoring is to take place. The geographical limits of the area, the present and planned water uses and the present and expected pollution sources should be identified. Background information of this type is of great help in preparing a precise description of the programme objectives and in deciding on some of the elements of the study plan. Subsequent sections of the study plan should cover the locations and frequency of sampling and the variables for analysis. The plan should also specify whether the analyses would be done in the field or in the laboratory. This decision must take into consideration the

resources available for all the necessary field and laboratory work, data handling, analysis and interpretation and the preparation and distribution of reports (Bartram and Ballance, 1996). The principal elements of a study plan are:

- A clear statement of aims and objectives

- Information expectations and intended uses

- A description of the study area concerned

- A description of the sampling sites

- A listing of the water quality variables that will be measured

- Proposed frequency and timing of sampling

- A estimate of the resources required to implement the design

- A plan for quality control and quality assurance

3.2 Objectives of Water Quality Monitoring

It is particular important that the objectives of a water quality monitoring programme be clearly stated and recorded. The objectives may be very general, such as when monitoring is for several purposes or when it would be premature to prepare highly detailed objectives, whereas statistical descriptions of objectives are usually reserved for the more advanced types of monitoring programme (Meybeck and Makela, 1989). To help with the establishment of objectives, the following questions should be addressed:

- Why is monitoring going to be conducted? Is it for basic information, planning and policy information, management and operational information, regulation and compliance, resource assessment or other purpose?

- What information is required on water quality for various uses? Which variables should be measured art what frequency and in response to which natural or man-made events?

- What is practical in terms of the human and human and financial resources available for monitoring? There is little point in setting unrealistic objectives.

- Who is responsible for the different elements of monitoring?
- Who is going to use the monitoring data and what are they intending to do with the information? Will it support management decisions, ensure compliance with standards, identify priorities for action, provide early warming of future problems or detect gaps in current knowledge?

The following is a list of typical monitoring objectives that might be used as the basis for design of sampling networks. The list is not intended to be exhaustive, merely to provide some examples.

- Identification of baseline conditions in the water-course system
- Detection of any signs of deterioration in water quality
- Identification of any water bodies in the watercourse system that do not meet the desired water quality standards.
- Identification of any contaminated areas.
- Determination of the extent and effects of specific waste discharges
- Estimation of the pollution load carried by a water course system or subsystem
- Evaluation of the effectiveness of a water quality management intervention.
- Development of water quality guidelines and/or standards for specific water uses.
- Development of regulations covering the quantity and quality of waste discharges.
- Development of a water pollution control programme.

There are two different types of monitoring programmes: those with a single objective which are set u to address one problem only and multi-objective programmes which may cover various water uses, such as drinking water supply, industrial manufacturing, fisheries, irrigation or aquatic life. It is rare that a monitoring programme has a single objective. In practice, programmes and projects generally combine multiple objectives and data are used for multiple purposes. Monitoring with several objectives is commonly the first major,

national programme to be established in a country (Bartram and Ballance, 1996). The design of such programmes requires preliminary survey work; so that the selection of sampling sites takes into account such considerations as actual and potential water uses, actual and potential sources of pollution, pollution control operations, local geochemical conditions and type(s) of water body.

3.3 Preliminary Surveys

When a new programme is being started, or a lapsed programme is being reinstated, it is useful to begin with a small-scale pilot project. This provides an opportunity for newly trained staff to gain hands-on experience and to confirm whether components of the programme can be implemented as planned. It may also provide an opportunity to assess the sampling network and provide indications of whether more (or possibly fewer) samples are needed in order to gain knowledge of the water quality at various points throughout a water body (Bartram and Ballance, 1996).

During the pilot project or preliminary survey it is important to test assumptions about the mixing of lakes, reservoirs and rivers at the selected sampling sites and times. It might be appropriate to consider variations in water quality through the width and depth of a river at selected sampling sites throughout an annual cycle in order to confirm the number of samples required to produce representative data. In a lake or reservoir, it may be necessary to sample at different points to determine whether water quality can be estimated at a single point or whether the lake or reservoir behaves as a number of separate water bodies with different water quality characteristics. It is also essential to investigate variations in water quality with depth and especially during stratification. Lakes and reservoirs are generally well mixed at overturn (i.e. when stratification breaks down) and sampling from a single depth or the preparation of a composite sample from two depths may adequately represent the overall water quality (Bartram and Ballance, 1996).

For groundwaters, it is important during preliminary surveys to confirm whether or not the well casing is perforated, allowing access to more than one aquifer. If this is the case then an alternative site should be sought or measures taken to sample from a single aquifer only. The latter is generally problematic. Preliminary surveys also help to refine the logistical aspects of monitoring. For example, access to sampling stations is tested and can indicate whether refinements are necessary to the site selection. Sampling sites could also be found to be impractical for a variety of reasons, such as transport difficulties (Bartram and Ballance, 1996). Similarly, operational approaches may be tested during the pilot project and aspects such as the means of transport, on site testing techniques or sample preservation and transport methods, can be evaluated. Sample volume requirements and preservation methods can then also be refined. Preliminary survey also provides opportunities for training staff and for ensuring that staff is involved in the planning process. Such involvement, together with the undertaking of preliminary surveys, may often avoid major problems and inefficiencies that might otherwise arise.

3.4 Description of the Monitoring Area

The description of a monitoring area should consider as a minimum:

- A summary of the environmental conditions and process (including human activities) that may affect water quality
- Meteorological and hydrological information
- A description of the water bodies and
- A summary of actual and potential uses of water

A monitoring programme commonly covers the watercourse system of a catchment area (i.e. a main river and all its tributaries, streams, brooks, ditches, canals, etc as well as any lakes or ponds that discharge into the river or tributaries). The catchment area is defined as the area from which all water flows to the watercourse (Makela and Meybeck, 1996). The land surface that in such a way that precipitation falling on it flows towards the watercourse is called the topographic catchment area. In some cases groundwater enters the watercourse

system from a groundwater catchment area, all or part of which may lie outside the topographic catchment. Topographic and groundwater catchment areas are rarely coincident (Makela and Meybeck, 1996)

Since a watercourse system may be very large, it is often convenient to divide the catchment into several small sub-catchments. A catchment area and its associated watercourse are hydrologically and ecologically discrete and therefore constitute a logical unit for the planning and management of water use and for the monitoring of water quality (Bartram and Ballance, 1996). The dynamics of upstream water quality and sources of pollution can be related to downstream effects. A description of the catchment area includes its size (in Km^2), its geographical location and the identification of each water body in the watercourse system.

3.5 Selecting Sampling Sites

Processes affected water quality and their influences should be taken into account when sampling sites are selected. A sampling site is the general area of a water body from which samples are to be taken and is sometimes called a macrolocation (Bartram and Balance, 1996). The exact place at which the sample is taken is commonly referred to as a sampling station or sometimes a microlocation. Selection of sampling sites requires consideration of the monitoring objectives and some knowledge of the geography of the watercourse system as well as of the uses of the water and any discharges of wastes into it. Sampling sites can be marked on a map or an aerial photograph, but a final decision on the precise location of a sampling station can be made only after a field investigation (Bartram and Balance, 1996).

3.6 Selecting Sampling Stations

For each Water Management Unit Area at least two Reference Data Collecting Stations (RDCS) should be established (an inflow and an outflow station). There should also be at least one hydrometeorological station within the boundary of

each Water Management Unit Area. It is not unusual to establish more than the recommended number of stations. If the area is characterized with major changes in topography, more than one hydrometeorological station should be established, the reason being Water Resources Assessment requires qualitative and quantitative balancing of water resources, the basic and criteria for the selection of RDCS and their positioning are very important. The same holds for the extent of data collection at each RDCS and is particularly so for water withdrawal and discharge points between two consecutive RDCS, within the same Water Management Unit Area.

Two other types of data collection stations should also be established, these are:

- Reference Withdrawal Monitoring Station (RWMS), which is used to monitor quality and quantity of water withdrawn from the surface and ground water
- Reference Discharge Monitoring Station (RDMS), used to monitor quantity and quality of water discharged into the surface water from point sources of pollution.

The selection of and location of all three types of stations primarily depends on the water regime and the quantity and quality of the water withdrawn and discharged within the Water Management Unit Area. The criteria for selecting the locations of RDCS should be based on the following:

- An RDCS should be located at each confluence of a tributary, if the flow of the main river is increased by more than 5 % immediately below the confluence.
- An RWMS should also be located at each individual or group water withdrawal point if the amount of withdrawn water is greater than 50 L/sec. (or greater than 10% of the 95 % probable low flow).
- An RDMS should also be located at each discharge point if the amount of water discharged is greater than 10 L/sec (or 10% of the 95% probable low flow), if a number of discharge points are located close to one another (in cities, for example) then each discharge point should be monitored

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separately or an RDCS should be established immediately downstream of the last discharge point (and water quality and quantity should be monitored accordingly), it is important to adjust the sampling programme to account for the mixing of the discharged effluents with the stream water (multiple sampling point, composite samples etc).

- An RDCS should be located at the discharge point of all reservoirs and lakes (existing and planned)
- An RDCS should be established wherever a stream crosses an international or regional border.

Depending upon hydrographical network and the previously established criteria within a Water Management Unit Area it is also possible to have not only two RDCS (inflow and outflow), but also a number of other second order RDCS, RWMS or RDMS. These second order RDCS and monitoring stations should be located at each point within the WMUA where there are significant changes in the water resources quantity and quality. Within a given WMUA these stations should be considered as control stations to collect data for analyzing water demand in the area and assessing the impact of waste water discharge on the water resources.

The data collected at the control stations are not used for WRA at the higher levels of territorial division, since the data collected at the first order RDCS are sufficient for this purpose. Occasionally when one analyses the impact of a discharge, within the lower levels of territorial division on the overall water quality at higher level of territorial division, the data from the second order RDCS can be used.

3.6.1 Rivers

Sampling stations on rivers should as a general rule must be established at places where the water is sufficiently well mixed for only a single sample to be required. The lateral and vertical mixing of a wastewater effluent or a tributary stream with the main river can be rather slow, particularly if the flow in the river is laminar

and the waters are at different temperatures (Bartram and Ballance, 1996). Complete mixing of tributary and mainstream waters may not take place for a considerable distance, sometimes many kilometres, downstream of the confluence.

Sampling for determination of dissolved oxygen, however should take place upstream of the rapids or waterfall because the turbulence will cause the water to be saturated with oxygen. In such a case, several samples should be taken across the width of the river to allow for the possibility of incomplete mixing. A bridge is an excellent place at which to establish a sampling station (provided that is located at a sampling site on the river). It is easily accessible and clearly identifiable and the station can be precisely described (Makela and Meybeck, 1996). Furthermore a bridge is often a hydrological gauging station and if so one of the bridge piers will have a depth gauge marked on it, thus allowing the collection of stream flow information at the time of sampling. Usually a sample is taken from a bridge at mid-stream or in mid-channel, in a well mixed river will adequately represent all water in the river (Bartram and Ballance, 1996).

To verify that there is complete mixing at a sampling station it is necessary to take several samples at points across the width and depth of the river and to analyse them. If the results do not vary significantly one from the other, a station can be established at mid-stream or some other convenient point. If the results are significantly different it will be necessary to obtain a composite sample by combining samples taken at several points in the cross-section of the stream (Bartram and Ballance, 1996). Generally the more points that are sampled the more representative the composite sample will be. Sampling at three to five points is usually sufficient and fewer points are needed for narrow and shallow streams (Desilets, 1988)).

3.6.2 Lakes and Reservoirs

Lakes and reservoirs can be subject to several influences that cause water quality to vary from place to place and from time to time. It is therefore prudent to

conduct preliminary investigations to ensure that sampling stations are truly representative of the water body. Where feeder streams or effluents enter lakes or reservoirs there may be local areas where the incoming water is concentrated because it has not yet mixed with the main water body (Desilets, 1988). Isolated bays and narrow inlets of lakes are frequently poorly mixed and may contain water of a different quality from that of the rest of the lake. Wind action and the shape of a lake may lead to a lack of homogeneity, for example when wind along narrow lake causes a concentration of algae at one end. If there is good horizontal mixing, a single station near the centre or at the deepest part of the lake will normally be sufficient for the monitoring of long-term trends. However if the lake is large has many narrow bays or contains several deep basins, more than one station will be needed.

To allow for the size of a lake, it is suggested that the number of sampling stations should be the nearest whole number $\log_{10}$ of the area of the lake in Km^2. Thus a lake of 10 Km^2 requires two stations and so on. For lakes with regular boundaries it is advisable to conduct pre-liminary investigations to determine whether and where differences in water quality occur before deciding on the number of stations to establish. Access to lake and reservoir sampling stations is usually by boat and returning to precisely the same locations for subsequent samples can be extremely difficult (Makela and Meybeck, 1996). The task is made simpler when the locations can be described in relation to local, easily identified landmarks. This as well as the representativeness of samples taken at those locations should be borne in mind when sampling stations are chosen.

The most important feature of water in lakes and reservoirs, especially in temperature zones, is vertical stratification, which results in differences in water quality at different depths. Stratification at a sampling station can be detected by taking a temperature reading at 1m below the surface and another at 1m above the bottom. If there is a significant difference (for example, more than 3°C) between the surface and the bottom readings there is a thermocline (a layer where the temperature changes rapidly with depth) and the lake or reservoir is stratified and it is likely that there will be important differences in some water quality variables

above and below the thermocline (Bartram and Ballance, 1996). Consequently in stratified lakes more than one sample is necessary to describe water quality.

For lakes or reservoirs of 10 m depth or more it is essential, therefore that the position of the thermocline is first investigated by means of regularly spaced temperature readings through the water column (e.g. metre intervals). Samples for water quality analysis should then be taken according to the position and extent (in depth) of the thermocline. As a general guide, the minimum samples should consist of:

- 1 m below the water surface
- Just above the determined depth of the thermocline
- Just below the determined depth of the thermocline and
- 1 m above the bottom sediment (or closer if this can be achieved without disturbing the sediment)

If the thermocline extends through several metres depth, additional samples are necessary from within the thermocline in order to characterise fully the water quality variations with depth. Whilst the position of the thermocline is stable, the water quality for a given station may be monitored by fewer samples but in practice the position of a thermocline can vary in the short- (hours) or long term (days) due to internal seiches (periodic oscillations of water mass) and mixing effects.

Even in warm climates and in relatively shallow lakes and reservoirs, the possibility of a thermocline should be investigated by taking temperature profiles from the surface to the bottom (Chapman, 1996).

3.6.3 Ground Water

Sampling points for groundwater monitoring are confined to places where there is access to an aquifer and in most cases this means that samples will be obtained from existing wells. To describe such a sampling station adequately it is essential to have certain information about the well, including depth to the well screen, length of the screen and the amount by which the static water level is lowered

when the well is pumped (Bartram and Ballance, 1996). One sample is usually sufficient to describe the water quality of the aquifer. If the water in the well is corrosive and is in contact with steel pipe or casing the water samples may contain dissolved iron. Wells with broken or damaged casings should be avoided because surface water leak into them and affect the water quality. Springs can also be useful groundwater sampling points, provided that they are adequately protected against the ingress of contamination with surface water. Springs are often fed from shallow aquifers and may be subject to quality changes after heavy rainfall. Other possible sampling stations are boreholes drilled especially to investigate the features of an aquifer, although these are expensive and would be justified only in particular circumstances (WHO, 1992).

3.7 Frequency and Timing

Sampling frequency at stations where water quality varies considerably should be higher than at the stations where quality remains relatively constant. The required monitoring frequency will also be dependent on the objectives of the monitoring programme. A new programme, however with no advance information on quality variation, should be preceded by a preliminary survey and then begin with a fixed sampling schedule that can be revised when the need becomes apparent (WHO, 1992).

The time interval between the collections of samples depends on the water body and its specific characteristics. An interval of one month between the collection of individual samples at a station is generally acceptable for characterising water quality over a long time period (e.g. over a year in a river), whereas for control purposes weekly sampling may be necessary. If significant differences are suspected or detected, samples may have to be collected daily or on a continuous basis. In extreme cases, time-intergraded, composite samples may have to be made up mixing equal portions of samples taken at regular intervals over a 24-hr period, but this should be done only if they conform to the requirements of the

objectives and are not to be used for the determination of unstable variables, such as dissolved oxygen.

Individual samples taken at a given station should be obtained at approximately the same time of day if possible, because water quality often varies over the course of the day (WHO, 1992). However, if detection of daily quality variation or of the peak concentration of a contaminant in an effluent is of interest, sampling at regular intervals (e.g. every two or three hours throughout the day) will be necessary. Exceptional conditions of stream flow are frequently of interest because it is at maximum and minimum flow rates that extreme values of water quality are reached. For example when flowing at its peak rate, a river usually carries its greatest load of suspended material, while pollutants will be the least diluted when a river is at minimum flow (WHO, 1992). The violation of a waste discharge regulation and the seriousness of its environmental effects will be easier to detect during periods of minimum flow.

Sampling regimes may need to take such factors into consideration. It is usual to take samples of groundwater at only one depth. Frequency of sampling is low for large, deep, confined aquifers, which typically have long residence times, but higher (perhaps) for shallow, unconfined aquifers with short residence times. Sampling should be supplemented by occasional mapping to describe the aquifer fully. Sample collection should be frequent enough to enable an accurate calculation of the mean concentrations of the variables included in the monitoring programme. The frequency of sampling required to obtain a desired level of confidence in the mean values depends on statistical measures, i.e. standard deviation and confidence interval (Makela and Meybeck, 1996).

Table 3.1 below shows how monitoring frequency for the stations could vary.

Table 3.1 Monitoring frequency

Water body	Sampling frequency
Baseline stations Streams	Minimum: 4 per year, including high and low-water stages Optimum: 24 per year(every second week),weekly for suspended solids
Headwater lakes	Minimum: 1 per year at turnover, sampling at lake outlet Optimum: 1 per year turnover, plus 1 vertical profile at end of stratification season
Trend stations Rivers	Minimum:12 per year for large drainage areas, approximately 100,000 km^2 Maximum: 24 per year for small drainage areas, approximately 10,000 km^2
Lakes/reservoirs	For issues other than eutrophication: Minimum: 1 per year at turnover, 1 at maximum thermal stratification For eutrophication: 12 per year, including twice monthly during summer
Groundwaters	Minimum: 1 per year for large, stable aquifers Maximum: 4 per year for small, alluvial aquifers Karst aquifers: same as rivers

3.8 Water Quality Parameters

For all other terms it is necessary to determine the qualitative parameters according to a uniform methodology. This raises the issue of which parameters are relevant for defining the quality of certain components of the balance, especially of those pertaining to the surface water resources. After looking into the existing practices in considerable detail and analysing the quality of the water

resources in many countries WHO guidelines are recommended (Barabas, 1986). These guidelines are observed by 113 countries which have signed an agreement concerning the monitoring of surface water quality in an attempt to overcome the current water quality and environmental pollution problems.

Water quality parameters are designed as either basic or specific. The basic parameters are important regardless of the proposed use of water.

Table 3.2: Basic water quality parameters

PARAMETER	RIVERS	LAKES &RIVERS
Alkalinity	+	+
Bicarbonates	+	+
Biological O_2 demand (BOD)	+	+
Calcium	+	+
Chlorides	+	+
Chlorophyll		+
Colour	+	+
Dissolved oxygen	+	+
Electro conductivity	+	+
Flow	+	
Free ammonia	+	
Free CO_2	+	+
Magnesium	+	+
Nitrates	+	+
Nitrites		
Odour	+	+
Orthophosphates	+	+
pH value	+	+
Transparency		+
Potassium	+	+
Sodium	+	+
Sulphates	+	+
Temperature	+	+
Total phosphorus	+	+

(Source: UNESCO-HE, 1997)

The division into specific parameters or parameters which are a function of the use of water can be done in a different way; however care must be taken to include those parameters which are of importance in a given situation.

Table 3.3: Specific water quality parameters

PARAMETER	RIVERS	LAKE AND RESERVOIRS
Water supply settlements		
Total coliform bacteria	+	+
Faecal coliform bacteria	+	+
Arsenic	+	+
Cadmium	+	+
Chromium	+	+
Lead	+	+
Mercury	+	+
Selenium	+	+
Cyanide	+	+
Fluorides	+	+
Total OC compounds	+	+
Dieldrin	+	+
Aldrin	+	+
DDT	+	+
Copper	+	+
Iron	+	+
Manganese	+	+
Zinc	+	+
Phenols	+	+
Oil and grease	+	+
Detergents	+	+
Humid substances	+	+
Radio-activity	+	+
irrigation		
Boron	+	+

(Source: UNESCO- IHE, 1997)

3.9 Resources for Monitoring Programme

Implementing a monitoring programme requires access to resources, including an equipped laboratory, office, space, and equipment for fieldwork, transport and trained personnel (Bartram, 1996). Two important points should be considered when starting a new monitoring programme:

- It is better to have a complete record of reliable data concerning water quality at a few sampling stations than to have a lot of data of questionable quality from many sampling stations.
- If reported data are not creditable, the programme and its staff will lose credibility.

In the initial stages of a new monitoring programme, therefore it is generally advisable to proceed as follows:

- Start slowly with analyses for a few variables
- Train staff to ensure that proper procedures are followed
- Impose quality assurance on all procedures from the beginning
- Take samples at stations where the water quality is of major relevance to the monitoring programme
- Prepare reports that are factual and are written so that they can be understood by persons other than scientists
- Increase the number of variable, the number of sampling stations and the frequency of sampling as the capacities of the sampling and analysis teams increase.

3.9.1   Laboratory facilities

A number of options may be available for conducting analyses of water samples. The agency responsible for the monitoring programme may have its own laboratory or laboratories, the facilities of another agency or of a government ministry may be available, or some or all of the analytical work may be done under contract by a private laboratory. Some analytical work will inevitably be done in the field, using either field kits or a mobile laboratory (WHO, 1984). Regardless of the options chosen, the analytical services must be adequate for the volume of work expected. Some of the relevant considerations in this context are:

- **Variables to be analysed:** If only a few simple tests are required, analyses can be undertaken in the field using field kits. Most complex testing programmes may require the services of specialised laboratories
- **Sampling frequency and number of sampling stations:** The frequency with which samples must be taken and the number of sampling stations

involved will obviously influence the volume of work necessary and, hence the staff and facilities required

- **Existing laboratory facilities:** Laboratory facilities may be under the direct control of the monitoring agency or be associated with another agency (e.g. the health ministry, a regional hospital, or a college or university). The major concern is that the laboratory is sufficient close to the sampling stations to permit samples to be delivered without undue delay.

- **On-site testing:** Some analyses must be performed in the field. Modern field kits are available that permit analyses of a wide range of variables. This makes it possible to run a monitoring programme without the need for a fixed laboratory, but raises certain problems of analytical quality control.

- **Temporary laboratories:** If a monitoring programme is expected to be of short duration, it may be expedient to set up temporary laboratory. Sufficient space, water and electricity supplies are essential, but equipment and supplies can be brought in and then removed after the monitoring programme is completed.

- **Mobile laboratories:** It is possible to set up laboratory in a suitable motor vehicle, e.g. truck or van. In effect, this is a variant of on-site testing, but may provide better facilities than field kits.

In practice, the usual arrangement is for the agency responsible for water quality monitoring to establish its own central laboratory, which can be organised to provide training and supervision of staff, repair of equipment and various other services. However, if the monitoring area is large or transportation is difficult, regional laboratories may be set up or field kits used for certain analyses. Analyses that require expensive and sophisticated equipment, or that can be undertaken only by highly trained personnel, are performed only at the central laboratory, for example analysis for heavy metals using atomic absorption spectrophotometry and analysis for pesticides and herbicides using gas chromatography.

Whatever arrangements are finally chosen, it is essential that procedures be established for quality control of analytical work. This is of particular importance in relation to all aspects of fieldwork, including sampling, sample handling and transport, as well as on-site testing (WHO, 1984)

3.9.2 Transport

The types of vehicle needed for sampling expeditions depend, to large extent on the ease of access to the various sampling stations. If access is difficult, an off road vehicle with four-wheel drive may be necessary and in some remote or rural areas a light motorcycle can be useful for transporting one person (with a minimum of equipment e.g. portable kit), although it is important to consider the safety aspects of the latter arrangement. For some sampling programmes in large lakes and rivers, sampling stations may have to be reached by boat. It may be possible to rent a boat in the vicinity of a sampling station (WHO, 1986). Renting is generally preferable to the purchase of a boat unless there are numerous sampling stations that have to be reached regularly. If a boat must be transported by the expedition, the work of the sampling team will be slowed by the need to launch and recover it at each sampling station.

In countries or regions where reliable public transport is available, it may be possible to arrange for samples to be transported to the laboratory by bus or train. Local agents, appropriately trained and supplied with the necessary sampling equipment, can take samples at prescribed times and send them to the laboratory. The system requires careful supervision and particular attention to sample quality control (Bartram, 1996).

3.9.3 Staffing

Staff on a water quality monitoring programme fall into four broad categories: programme management, filed staff, laboratory staff and data processors. The

numbers required in each category will depend on the size and scope of the monitoring programme (WHO, 1986).

Programme manager

The programme manager will probably require the assistance of several technical and administrative staff members during the design and planning phases of the programme. After the programme has reached the implementation stage, some of these staff members can be transferred to operations, possibly as supervisors of field and laboratory of field and laboratory work (Bartram, 1996). Others, together with the programme managers will assume responsibility for data manipulation, preparation of reports, staff training and programme co-ordination (if other agencies are involved in the programme).

The co-ordination tasks may become quite complex if programme implementation depends on other agencies, part-time staff, temporary or rented facilities and public transport. The following description of the responsibilities of a programme manager may not be complete for any specific situation but is presented as an example of what may be expected of the manager. The responsibilities of the programme manager will include some of the following:

- Planning of water quality monitoring activities.
- Co-ordination with regional centres, collaborating agencies, participating laboratories and others not under his or her direct control.
- Procurement of necessary equipment and consumable supplies.
- Arranging suitable transport.
- Recruitment of staff.
- Training of staff.
- Preparation of training manuals.
- Safety in the field and in the laboratory.
- Preparation of standard operating procedures

- Organising and managing central office facilities for the storage, handling interpretation and distribution of data.

- Supervising and evaluating the performance of all staff.

- Reviewing and evaluating procedures.

- Preparation of reports and dissemination of the findings of the monitoring programme.

Field staff

Staff recruitment for fieldwork and sampling may not have had previous experience in water quality monitoring and new methods or procedures may be introduced from time to time. A short period of training is, therefore appropriate. Assuming that candidates have a good general education, a well-organised training session that includes practical fieldwork will require 1-2 weeks (WHO, 1986). If field-testing is also to be carried out, the training period will have to be somewhat longer. Staff should be evaluated after training and, if satisfactory should work under fairly close supervision until they are sufficiently experienced to require only occasional supervision. Periodic short term training sessions should be arranged for reviewing, reinforcing or extending knowledge. Preliminary training for field staff may include, for example:

- Objectives of the water quality-monitoring programme.

- The local, national and international importance of the programme.

- The importance of samples being of good quality and representative of the water body from which they are taken.

- How to ensure that samples are of good quality.

- Planning of sampling expeditions.

- Map-reading.

- Making field notes.

- Maintaining up to date descriptions of sampling sites and stations.

- Health and safety in the field.

Training sessions for the continuing education of field staff might include the following topics:

- Sampling for sediment.
- Sampling for biological analysis.
- Stream gauging.
- Microbiological field-testing of samples (membrane filter method).
- Chemical tests in the field.

The responsibilities of field staff should include all or some of the following:

- Undertaking sampling expeditions in accordance with a planned programme.
- Obtaining samples according to standard operating procedures.
- Labelling sample bottles, making notes and recording unusual conditions at the sampling station.
- Preparing samples for transport and delivering them to the local laboratory in accordance with standard operating procedures.
- Routine maintenance of equipment used in the field.
- Preparing sample bottles (cleaning and addition of appropriate preservatives).
- Performing field tests for selected variables

Laboratory staff

Two or possibly three types of laboratory staff may be required to undertake the required chemical, microbiological and biological analyses.

Laboratory chief: The chiefs of each type of laboratory, in liaison with the programme manager would typically be responsible for:

- Laboratory management
- Determining and procuring the equipment and supplies that will be needed.

- Ensuring that standard operating procedures are being followed, this includes supervising laboratory staff and training them in the use of new equipment and procedures.
- Quality control of analytical procedures
- Enforcing safety precautions and procedures, especially for fire, explosions and noxious fumes.

Laboratory technician (analyst): Laboratory technicians will usually have had formal training and possibly practical experience in analytical work. Working under the direction of the laboratory chief, a technician will be responsible for the preparation and carrying out of analytical work in the laboratory. Their duties would typically include the following:

- Care, regular maintenance and ensuring cleanliness of laboratory and equipment, especially refrigerators, freezers, incubators, water-baths, stills, ovens and work areas.
- Ensuring the cleanliness of laboratory glassware and other reusables.
- Safe storage of all equipment and glassware
- Preparation of reagent and media, standardising as necessary
- Storage under proper conditions of reagents and media.
- Checking accuracy of electronic equipment used in field analyses.
- Preparation (or supervising the preparation) of sample bottles (including the addition of preservatives when appropriate) and application of correct identification labels.
- Laboratory safety
- Training of field staff in the use of field testing equipment.
- Training of junior laboratory staff
- Recording the results of analyses
- Performing the tests and analyses, including those necessary for internal quality control.

Laboratory assistant: Laboratory assistants may have had some formal training but are usually untrained and often learn whilst in post. Their duties are

performed under the direct supervision of the laboratory technician(s). These duties typically include:

- Cleaning of the laboratory, glassware and equipment.
- Preparing sample bottles, including washing, addition of preservatives and correct labelling.
- Storage of laboratory and sample glassware.
- Storage and stock of control of chemicals and media.

In time and with appropriate training and experience an assistant can be promoted to a higher level of laboratory work. The technicians will teach the assistants how to use various items of laboratory equipment, prepare reagent solutions and carry out certain analyses (Bartram, 1996)

3.10   Human Resources Development and Training

The quality of the data produced by a water quality monitoring programme depends on the quality of the work done by field and laboratory staff. It is, therefore important that staff is adequately trained for the work they are expected to do. As a result, monitoring agencies often develop training programmes that are specific to their needs (Bartram, 1996). The content and extent of training programmes depend on the various training and experience of staff, the range of activities involved in the monitoring programme and whether analytical work will be done at a central laboratory or regional laboratories and the extent to which analyses will be performed in the field. For large, permanent monitoring programmes a comprehensive strategy for personnel development is advisable. This should include:

- Clear lines of responsibility and accountability
- Job descriptions
- Recruitment guidelines (qualification, experience, skills requirements)
- Career structures
- Mechanisms for enhancing the motivation of staff at all levels.
- Systems staff appraisal and feedback and often

- Standardised training packages, procedures manuals and training manuals as appropriate to the work of field and laboratory staff, regional and national managers.

Training is not a once-only activity but should be a continuing process. Ideally, there should be a basic framework of courses for staff at all levels, followed by short courses, seminars and workshops. Supervision of work, in both the laboratory and the field is essential and contributes to in-service training. It is particular valuable in water quality monitoring programmes because it permits staff to gain hands-on experience, thus reinforcing what was learnt in formal training sessions, while taking an active part in programme operations. Laboratory staff, especially those in larger laboratories are progressively trained and authorised to use certain items of equipment or undertake certain analyses.

Training should be flexible, responding to experience and feedback and taking account of the specific needs of individual staff members. In-house training can provide this flexibility and can be readily tailored to local requirements but needs staff that is familiar with the necessary training techniques, usually senior laboratory and field staff (it also makes heavy demands on them). It may also make significant demands on financial resources and requires access to classrooms, fieldwork sites and training laboratories with appropriate equipment (WHO, 1986). For much of their staff training, therefore many agencies will make use of courses already available at local educational establishments, supplementing these with short courses, work shops and refresher training in specific topics.

In its broadest sense, training should also be understood to include encouraging staff to join appropriate professional organisations, attend conferences and symposia and communicate with peers in technical schools, colleges, universities and similar establishments.

3.11 Communication

Good communication is important, not only for achieving programme outputs (such as data production), but also to ensure that wider aims (such as increasing awareness of environmental issues and ensuring that staff of all types see their role positively) are met. It is also indirectly important as a means of ensuring continued outside interest in and support for the work being undertaken (Bartram, 1996).

It is a good practice to ensure that responsibilities for communication are identified in every individual's job description. Communication may be aimed at a wide audience, such as writing reports or speaking at a seminar, or more specific such as communicating results from analyst to laboratory chief or discussion of fieldwork plans between co-ordinator and field staff. In practice, much general communication should take the form of consultation and by generating goodwill. This helps to ensure that problems are overcome through mutual interest and not become insurmountable blocks. Communication with external agencies is especially important if they play a role in international assessments and if they provide other types of support (Chapman, 1996).

For consistency, liaison with such agencies, where it occurs should be the specific responsibility of an identified member of staff. Internal communication in the form of short discussions, such as lunch time seminars or workshops are good means of ensuring that all staff are kept informed about general issues and are in contact with programme progress and findings. Representatives of monitoring programmes may attend committees at both local and national levels. This representation is important as a means communication and to maintain the profile of the programme and as such should also be the specific responsibility of an identified member of staff (Bartram, 1996). Communication functions such as those noted above may demand a significant proportion of time and this should be borne in mind when preparing job descriptions.

3.12   Quality Assurance

Quality control is necessary in all stages of the monitoring cycle. This holds especially for the quality assurance and control (QA/QC) in the laboratory. In certified, top-quality laboratories in the world the allocated resources for QA/QC may easily amount to 20% of the total annual budget for operational cost (Kelderman, 2002).

QA/QC in laboratory involves:

- Well-trained, critical personnel, working in adequate facilities (instrumentation, cooling, space, storage facilities, etc) and under optimum working conditions the management structure of the laboratory should clearly be defined.

- The daily running of Standard Operating Procedures (SOP) for the whole routine of sample handling (receipt, storage, analysis, disposal) and the use of well-validated, robust standard procedures of analysis.

- Accurate and controlled reporting of data.

- A frequent control of methods, instruments (calibration) and personnel.

The laboratory staff should always be involved in the preparatory steps before the analysis: sampling, storage and transport (Garfield, 1991). They must also be familiar with the objectives and the general set-up of the monitoring programme. Day-to-day practices for assuring high quality data involve: using clean glassware and chemicals, careful, scrupulous adherence to the prescribed methods and tidiness on the work floor. This can be summarised with the term: Good Laboratory Practices (GLP) (ISO, 1994).

Specialised Quality Control and Assurance in the laboratory may be carried out via a number of techniques, which generally involve some statistical tests for the reliability of the laboratory results:

Internal control, usually carried out on a daily basis by

- Use of blanks, duplicates or of "spiked" samples, these should be unrecognisable for the analyst to avoid extra-careful working

- Checking the cation/anion balance and use of other tricks (e.g. PO_4-P<$P_{tot.}$, dissolved heavy metals<total heavy metals)

External control, which may be carried out 1-2 times per year:

- Reference samples of known composition can be used to critically check the whole analysis cycle in the laboratory

- Inter-laboratory checks (Ring analyses), such as carried out in the GEMS-WATER monitoring programme. Ring analyses give insight in the general errors made in the group of laboratories as well as in the performance of the individual laboratories.

The laboratory supervisor should always be aware of the tendency of analysts to simplify procedures; this may lead to completely erroneous results. Also the supervisor should create an open atmosphere where it is possible to make mistakes and discuss them. Finally it must be realised that 100% perfect results can never be reached. The quality goals will always be a compromise between **quality needed** and **the variable resources** (Kelderman, 2002).

3.13   Reporting

The whole system of water quality monitoring is aimed at the generation of reliable data, which must then be processed and presented in a way that is understandable also for the non specialist. Much too often, water quality data are buried in annual reports with data presented in a tabular form only without any statistical assessment, interpretation or graphical presentation. The actual water quality data can be compared with the objectives set and appropriate measures if necessary can be taken

For data handling and management, computer software can be used for the processing of numerical data and performing statistical tests as well as for carrying out graphical presentations. Statistical tests compromise calculations of means, medians, standard deviation, the exclusion of outliers, carrying out regression analysis, etc. In the statistical processing, great care should be taken that the integrity of the original data base is always secured. A recent

development known as GIS (geographical information system) is specifically designed to relate monitoring data to geographical locations in the form of maps. Data on surface and ground water quality can thus be overlaid on population, land use or geology (Kelderman, 2002).

3.13.1 Trend plots

A common way to show trends are time-series plots, examples of which are shown in Figure 3.1. If a significant long-term trend exists, it may be apparent upon visual examination of a plot of the raw data. Many parameters exhibit strong seasonality and therefore a "typical" range of values can also be shown. In Figure 3.1, the typical range was defined to encompass approximately 70% of the values for each month. In this case fifteen percent of the values should exceed the high value and fifteen percent should be lower than low value (EUROWATERNET, 1998). The shaded areas in Figure 3.1 represent the typical range across the middle of each plot. Comparing the data points to that shaded area makes any trend more apparent should it exist. If seasonal variability is too great to use the time series plots to identify long-term trends, a twelve-month moving mean can be calculated for each site. The moving mean smoothes out seasonality in many cases and makes long-term trends easier to see. If the moving mean plot suggests that a trend might exist, the raw data can then be analyzed further for trend analysis (Gilbert, 1987).

Figure 3.1: Example of trend plots
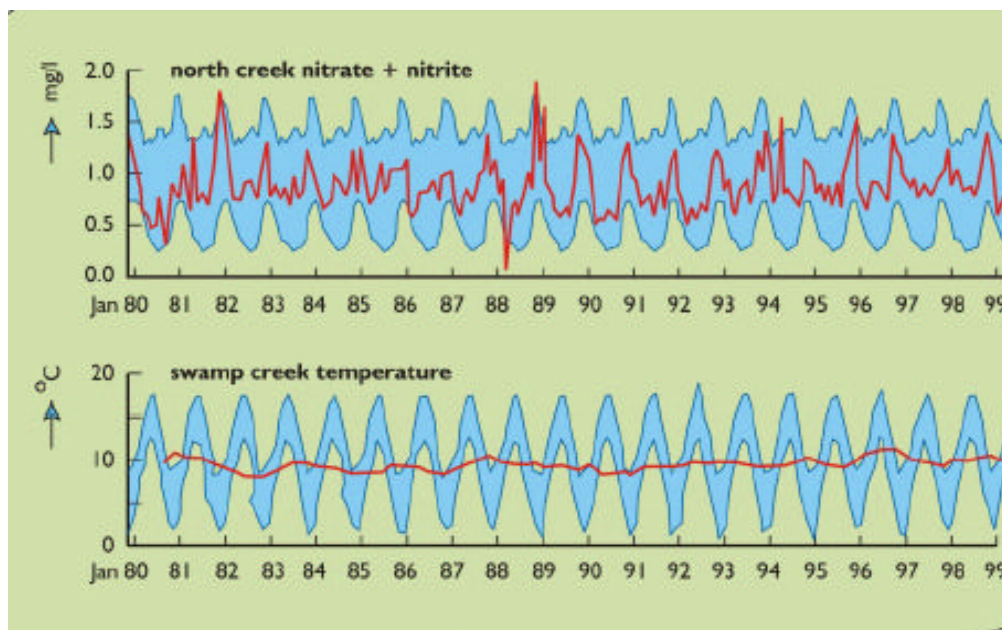
(Source: Gilbert, 1987)

3.13.2 Comparison plots

One way of comparing data is through the use of amoeba plots. An amoeba plot is a schematic representation of a given condition compared to the natural average or baseline condition. For the water body under study, a set of parameters considered to be representative of the water body's condition is chosen. The reference system is represented by plotting the value of the parameters under "natural" conditions on a circle. The present values of the selected parameters are plotted relative to the circle (Gilbert, 1987). This provides an amoeba-like figure, representing deviations from the reference or normal state, as illustrated in Figure 3.2.

In Figure 3.2, stream health is shown as indicated by eight measures of stream bugs (benthic macroinvertebrates). Stream bugs are excellent indicators of stream health. They are relatively easy and inexpensive to collect. They play a crucial role in the stream nutrient cycle and their populations affect the whole ecosystem (Groot, 1995). The presence or absence of pollution tolerant and intolerant bug types can indicate the condition of the stream. Population fluctuations might

indicate that a change (positive or negative) may have occurred in the stream. One can detect population fluctuations in a short period of time.

The circle in Figure 3.2 represents the normal (healthy) value of each parameter. Deviations from that circle are expressed in percent of these normal values. Sometimes log scales are convenient (Groot, 1995).

Figure 3.2: Amoeba diagram showing status of system with respect to the target or normal state
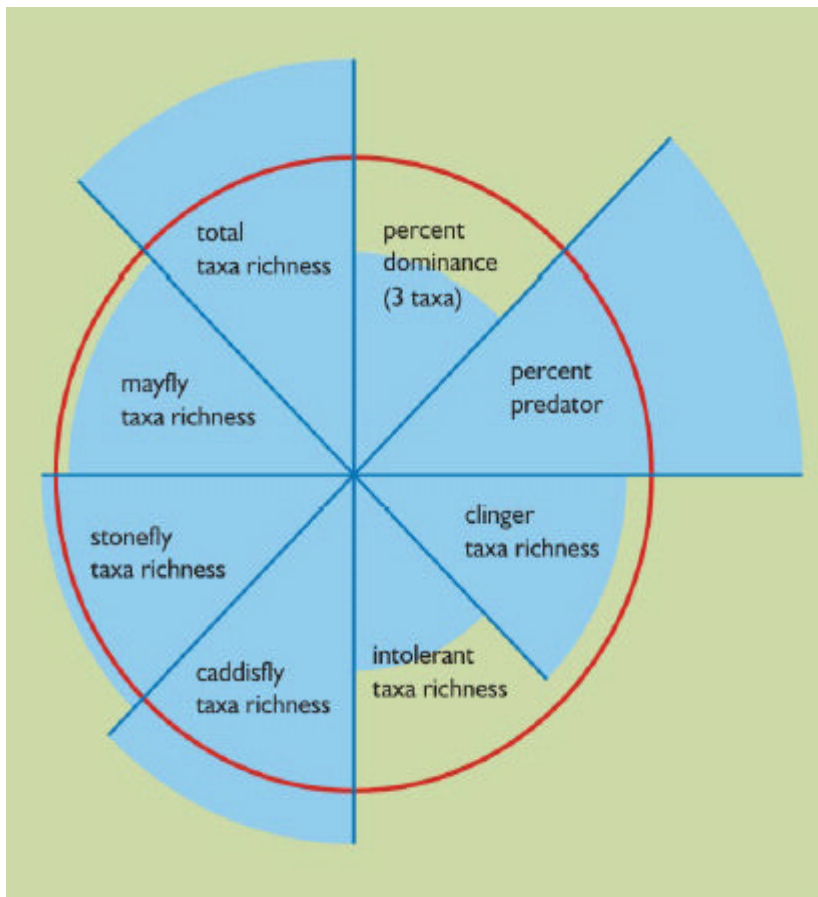
(Source: Groot, 1995)

Amoeba plots can be used to compare data at a given site or compare the data at one site with that of other sites in a specified region.

Figure 3.3 illustrates another way to compare the baseline averages measured in one stream to the median levels for all tributaries measured in the region. The shaded area represents the range in which the middle 50 percent of all site averages fell (i.e., 25 percent were higher and 25 percent were lower than the shaded area). Along with these charts can be tables, not shown here, that list the average, minimum, and maximum values for each parameter for each stream (Harmancioglu, 1998).

Figure 3.3 Comparison plots showing how selected parameter values at one site compare with the values at the other sites in the area
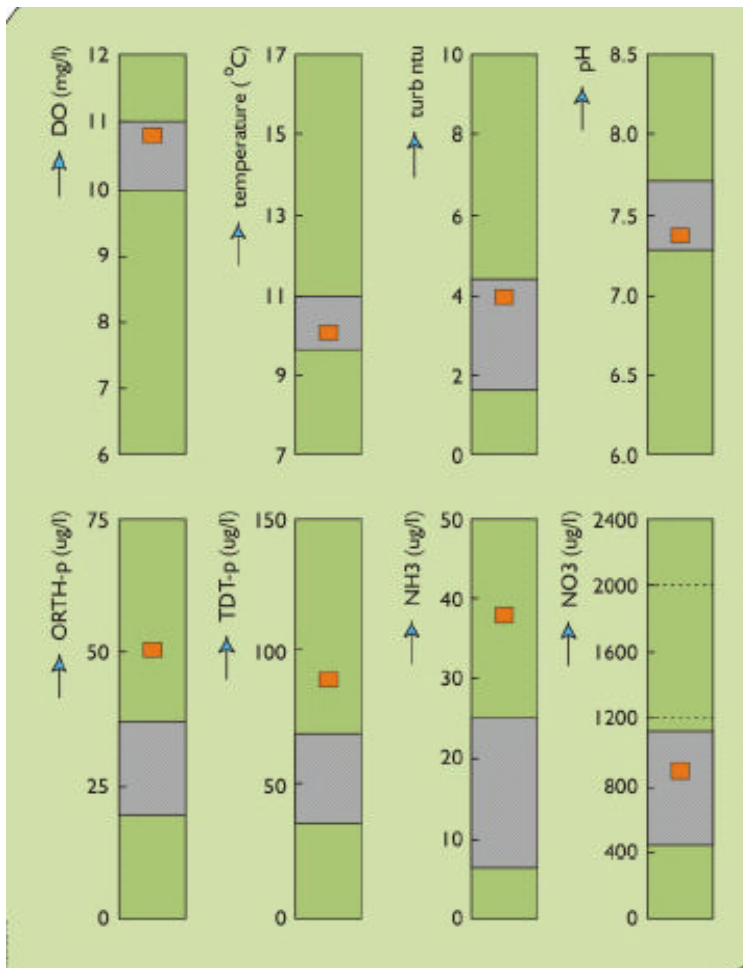
(Source: Harmancioglu, 1998)

Other ways of displaying data are shown in Table 3.3. In this case the data are being summarized with respect to the percentage of values that met specified standards.

Table 3.4: Ways of displaying information pertaining to whether or not sample data met the standards for these selected parameters

Parameter collected	# of samples	# of samples not meeting criteria	% of samples not meeting criteria
D.O.	231	16	7.1
Temperature	245	17	6.9
Turbidity	234	15	6.4
pH	231	1	0.4
Enterrococcus	127	64	50.4
Fecal Coliforms	235	172	73.2

Data can be interpreted by risk assessments as well. This refers to the comparison of measured or modeled or predicted values with target values. Target (desired) values of various parameters will be based on specific functions of waters, e.g. use for drinking water or recreational use. The measured or predicted data are referred to as Predicted Values (PV), the target or desired values are referred to as Target Values (TV). For the former, terms like Predicted Environmental Concentrations (PEC) of pollutants are sometimes used. For the latter, terms like Predicted No Effect Concentrations (PNEC) or Maximum Permissible Concentration (MPC) or function-related directives are also used. The risk quotient is the ratio of predicted (PV) over target (TV) value. This ratio will indicate the relative priority of that parameter (Gilbert, 1987).

The outcome of a sediment quality assessment could be expressed as a PEC/PNEC ratio. If this ratio is < 1, little priority is given to the potential risk derived. If this ratio is >1, a certain risk is indicated. Classifying the responses might help to visualize the estimated risks in time trends or spatial gradients. The more function-related the quality criteria used, the more specific the conclusions that can be drawn on which function might be impeded due to the pollution present (Gilbert, 1987).

3.13.3 Map plots

Two examples of map plot are shown in figures 3.4 and 3.5

Figure 3.4: Map showing lake shore areas, in red that are at risk of bank failure.

(Source: Gilbert, 1987)

Figure 3.5: Map displays showing distribution of habitat suitability index (SI) values for ecosystem indicators applicable to southern Florida in the US.
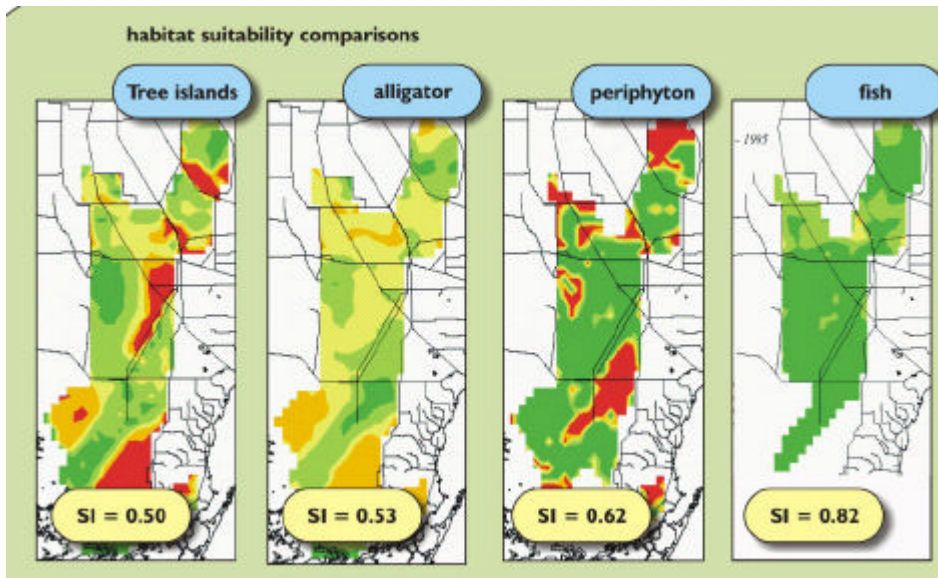
(Source: Gilbert, 1987)

Separate colors represent ranges of SI values. The average index is shown for each indicator. Finally the water quality monitoring report must show a clear structure and be understandable also for non-specialists. It must at least contain:

- A short summary
- An introduction on the objectives of the programme
- A description of the region
- The different methods used, both in the field and the laboratory, including QA/QC protocols
- A clear presentation of the results followed by an analysis of these results
- Conclusion and recommendation for the decision makers.

CHAPTER 4: RESULTS AND DISCUSSIONS
4.0 Existing Monitoring Program in SADC Region

The following chapter aims at giving an overview of monitoring activities in the 13 countries from SADC region that have information. The monitoring activities of each country are briefly summarised, an overview of the involved institutions and the organisations of surface water monitoring activities is presented. The main monitoring activities in relation to rivers, lakes, etc are described including a table listing:

- Name of the monitoring institution
- Involved institutions
- Measured variables
- Period of operation and sampling frequency
- Geographical coverage
- Data storage and Reporting

4.1 Swaziland

Water resource agency is responsible for water quality monitoring in the country, it is a government agency under Department of Natural Resources and Energy. Swaziland Environmental Authority is the collaborating agency.

They have five monitoring officers and have several spread countrywide monitoring stations.

The parameters they monitor are listed below:
Temperature, pH, Conductivity, Turbidity, COD, Total dissolved solids, Chlorides, Alkalinity and Total solids

Water is being monitored for domestic use, they monitor only local rivers. The information on water quality and quantity is used by consultants and NGO's and when there is a project which requires information about water quality/quantity, they consult the department of natural resources and energy and they get it.

The applicable legislation is Water Act of 2003. Legal actions are taken against offenders e.g. the major companies are polluting rivers they are discharging to and actions have been taken against them. They are currently implementing the Water Act of 2003 and very soon they will be having the Department of Water Affairs.

Table 4.1 summarises the water quality monitoring programme of Swaziland compared to the best practice monitoring.

Table 4.1: Comparison of water quality monitoring programme of Swaziland and required best practice

	Swaziland	Best practice
Monitoring Institution	Government Institution	Government Institution
Parameters	Temperature, pH, Conductivity, Turbidity, COD, Total dissolved salts, Chlorides, Alkalinity and Total salts	Alkalinity, Bicarbonates, BOD, Calcium, Chlorides, Chlorophyll, Colour, DO, Conductivity, Flow, Free Ammonia, Free CO_2, Magnesium, Nitrates, Nitrites, Odour, Orthophosphates, pH, Transparency, Potassium, Sodium, Sulphates, Temperature, Total phosphorus
Frequency	-	24 times per year
Stations	1 station at each WMUA	3 stations at eat WMUA
Data Storage	Paper files	Computerised data files

As it can be seen, existing water quality monitoring programme in Swaziland is not in line with the best practice recommendations.

4.2 Zambia

The Department of Water Affairs in collaboration with the Zambezi River Authority are responsible for water quality monitoring in the country. The Zambezi River Authority has embarked on a water quality monitoring for Zambezi River and Kariba Lake. With technical assistance from Stockholm Environment Institute under Sida funding, the Authority reviewed its original programme in order to fully meet its needs of understanding the source, quality of effluent and pollution loads of the Zambezi system.

4.2.1   Water quality monitoring network

The water quality monitoring network follows the Zambezi River from Chavuma to Kanyemba/ Luangwa where the river form a common border between Zambia and Zimbabwe. Sampling stations have been established on the Upper Catchment, above the Victoria Falls to Chavuma and Lower Catchment, Victoria Falls to Kanyamba/ Luangwa on the Zambezi River at ZRA's hydrometric stations and selected sites on the lake Kariba.

The Zambezi River sampling network comprises Chavuma, Lukulu, Matongo Platform, Senaga, Sesheke, Nana's farm, Kanzinze Road Bridge (Maamba) and Watopa Pontoon on the Kabompo River on the Upper Catchment. The Lower catchment network comprises, Deka, Gwaii and Sanyati. The lake network sampling stations have been established according to the lake basins. Other stations beyond the dam wall are Dam Wall Down Stream, Chiawa Kafue River Pontoon on the Kafue River and Kanyemba/ Luangwa on the Zambezi River (figure 4.2)

FIGURE 4.1: ZAMBEZI RIVER: Upper and Lower Catchments showing sampling sites for Zambezi River Authority
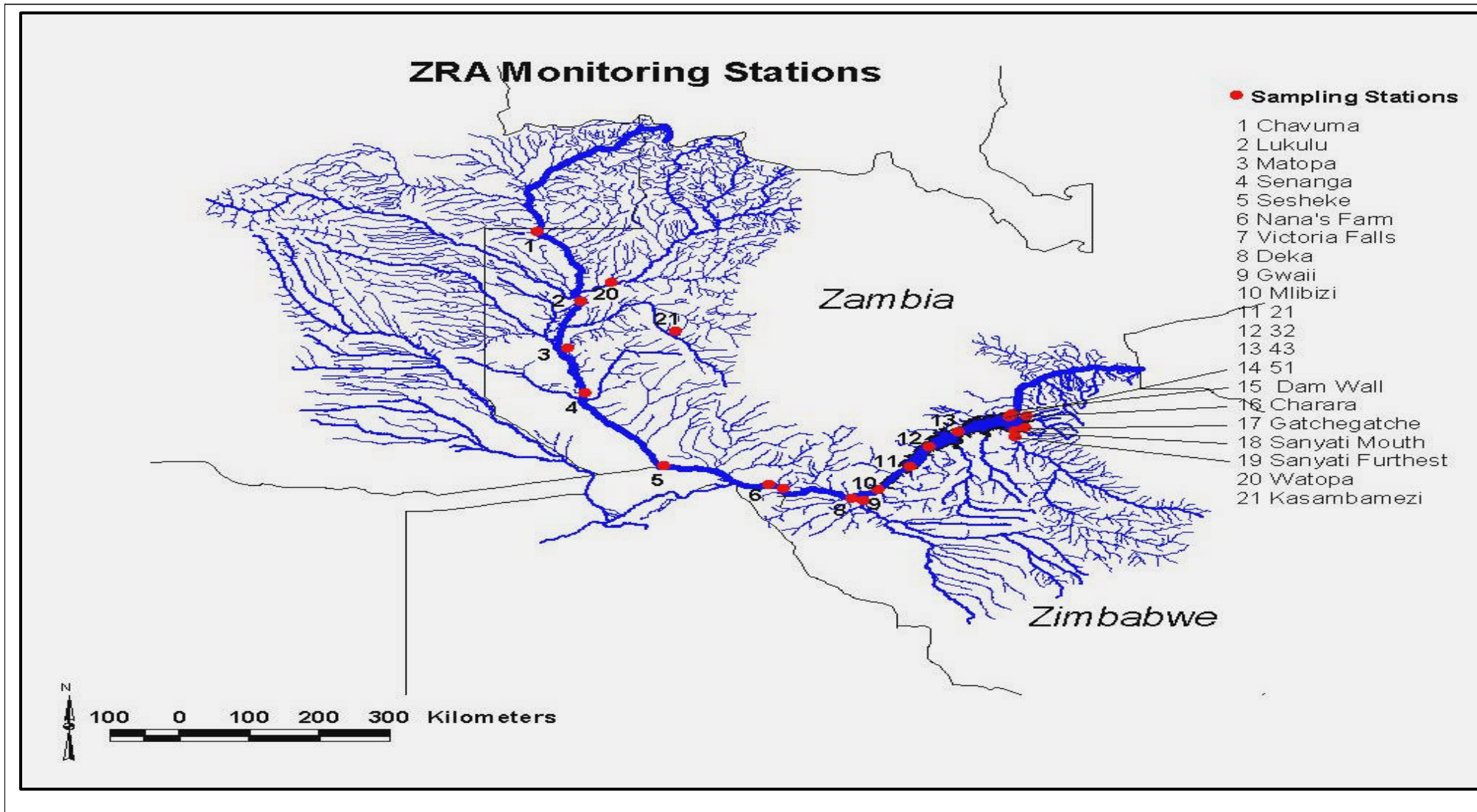
Table 4.2: The sampling sites and their respective geographic positions

No	Sampling Site	Co-ordinates	
1	Zambezi River at Chavuma	S 13° 05' 01.0"	E 22° 40' 36.9"
2	Kabompo River at Watopa	S 14° 02' 21.8"	E 23° 37' 42.6"
3	Zambezi River at Lukulu	S 14° 23' 01.0"	E 23° 14' 0.9"*
4	Little Zambezi at Matongo platform	S 15° 16' 24.6"	E 23° 03' 58.8"
5	Zambezi River at Senanga	S 16° 06' 36.7"	E 23° 17' 24.2"
6	Zambezi River at Sesheke	S 16° 30' 48.0"	E 28° 46' 12.0"
7	Zambezi River at Nana's Farm	S 17° 49' 41.8"	E 25° 39' 03.1"
8	Kanzinze River (Maamba)	S 16° 35' 02.9"	E 30° 25' 00.0"
9	Decca River at Road Bridge (Deka/Hwange)	S 18° 05' 57.6"	E 26° 43' 14.5"
10	Gwaii River at Road Bridge	S 18° 07' 28.4"	E 26° 51' 37.9"
11	Sanyati River (furthest - Gorge)	S 16° 30' 48.0"	E 28° 46' 12.0"
12	B 11 Lake Kariba Basin 1 – Mlibizi	S 17° 55' 42.0"	E 27° 03' 48.0"
13	B 21 Lake Kariba Basin 2	S 17° 29' 00.0"	E 27° 27' 28.0"
14	B 32 Lake Kariba Basin 3	S 17° 07' 28.0"	E 27° 42' 36.0"
15	B 43 Lake Kariba Basin 4	S 16° 50' 46.0"	E 28° 05' 00.0"
16	B 51 Lake Kariba Basin 5 – Dam Wall Upstream	S 16° 33' 12.0"	E 28° 44' 30.0"
17	B 51 Lake Kariba Basin 5 – Dam Wall Downstream	S 16° 30' 48.0"	E 28° 46' 12.0"
18	Kafue River at Chiawa Pontoon	S 15° 56' 39.0"	E 28° 52' 35.9"
19	Kanyemba / Luangwa	S 17° 22' 01.0"	E 27° 05' 30.0"

Figure 4.2: Map showing Sub-basin of Lake Kariba

Sub-Basins of Lake Kariba.

Basin 4.

Basin 5.

Basin 3.

Basin 2.

Basin 1.

20   0   20   40 Kilometers
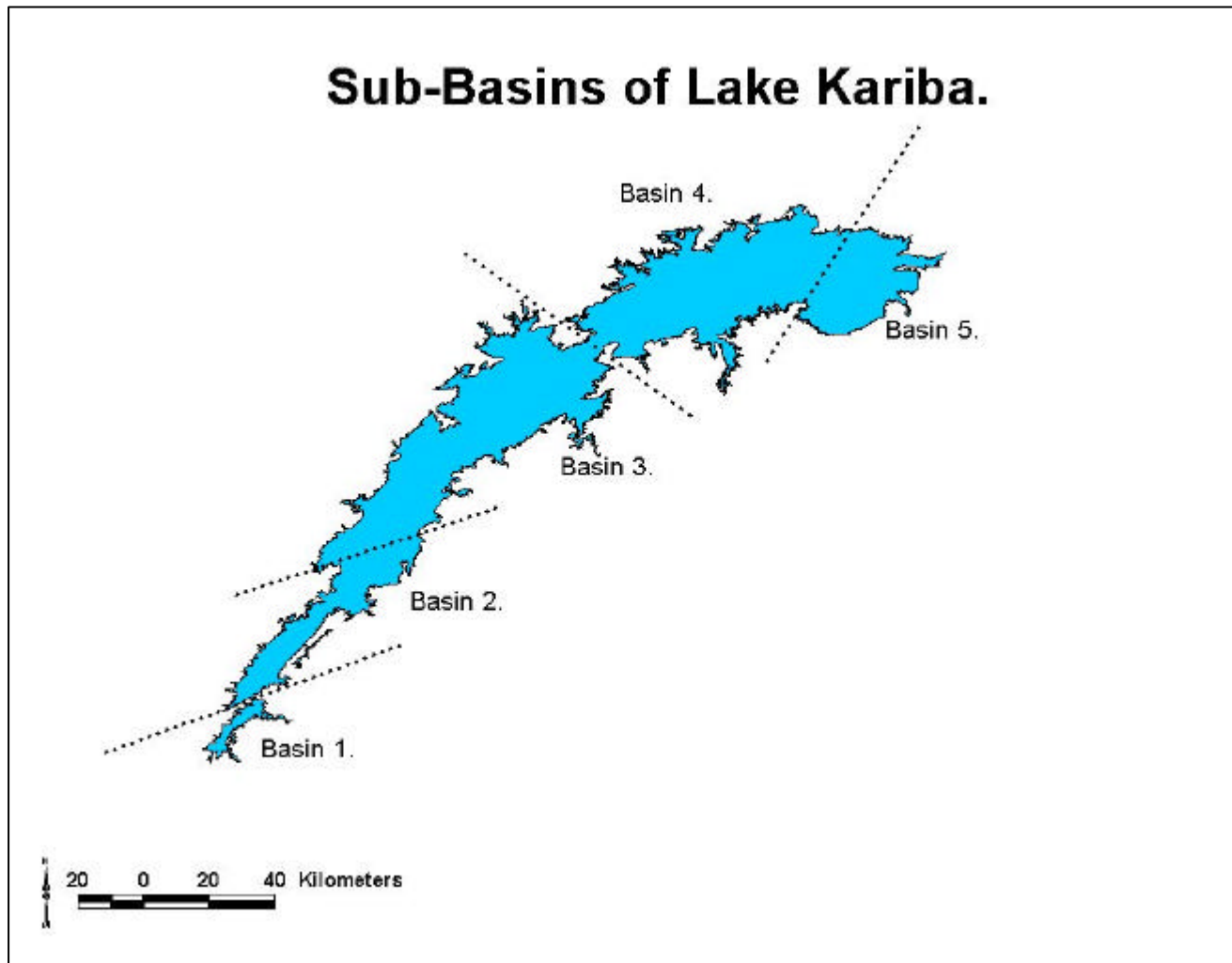
4.2.2 Parameters of immediate concern

The Zambezi River Authority has recently been more concerned with the nutrient loading of the lake. This came as an immediate concern due to proliferation of the water hyacinth, which is believed to be enhanced by nutrients.

Among the parameters being analyzed at the laboratory are:
pH, Temperature, Total Suspended Solids, Conductivity, Dissolved Oxygen, Ammonia, Ortho Phosphate, Total Phosphate, Nitrate – Nitrogen, Nitrite, Total Nitrogen, Silica, Alkalinity, Turbidity, Chloride and Sulphates

Other parameters that will be determined in due course are:
COD, Mn, Chlorophyll, Colour, Secchi depth, Calcium, Magnesium, Sodium, Potassium, Pesticides, Faecal coli form and Oil

In order to effectively expedite the Water Quality Monitoring Programme, ZRA with the assistance from Sida, have come up with a sampling protocol and is currently working on a   production of its own Laboratory Manual as well as Standard Operation Procedures (SOP), based on ISO standards, to suite its laboratory as per equipment and apparatus available.

In the same vain, a Quality Control Protocol is also being put in place. Institutions that deal with water quality will be approached for assistance in water analyses quality control matter. Inter laboratory analyses will be conducted so as to compare the results.

4.2.3 Frequency of sampling

At the moment, ZRA has embarked on a minimum sampling programme, from sampling stations which include, Sanyati, B 51 (Basin 5), and Dam wall down stream. Victoria Falls is also part of this programme, but unfortunately due to logistics, the site has been left out for now. The above programme is carried out

once every month. Sampling sites, Chavuma, Watopa, Lukulu, Senanga, Sesheke, Nana's Farm, Deka, Kanzinze, Gwaii, Chiawa Kafue River Pontoon and Kanyemba / Luangwa are sampled twice per year. However, the sampling frequency will depend on logistics.

Within the programme ZRA/ Sida, have managed to train other technicians in hands on water sampling techniques. This is in order to complement to the workload the Field Technician (P&E), who has been undertaking both the sampling and analyses.

Table 4.3 summarises the water quality monitoring programme of Zambia compared to the best practice monitoring.

Table 4.3: Comparison of water quality monitoring programme of Zambia and required best practice

	Zambia	**Best practice**
Monitoring Institution	Government Institution	Government Institution
Parameters	pH, Temperature, TSS, Conductivity, DO, Ammonia, Ortho Phosphate, Nitrate-Nitrogen, Nitrite, Total Nitrogen, Silica, Alkalinity, Turbidity, Chloride, Sulphate	Alkalinity, Bicarbonates, BOD, Calcium, Chlorides, Chlorophyll, Colour, DO, Conductivity, Flow, Free Ammonia, Free CO_2, Magnesium, Nitrates, Nitrites, Odour, Orthophosphates, pH, Transparency, Potassium, Sodium, Sulphates, Temperature, Total phosphorus
Frequency	once every month	24 times per year
Stations	1 stations at each WMUA	3 stations at eat WMUA
Data Storage	Paper files	Computerised data files

As it can be seen the existing water quality monitoring programme in Zambia is not I line with best practice recommendations.

4.3 Namibia

Department of Water Affairs in collaboration with some municipalities is responsible for water quality monitoring in the country.

4.3.1   Sampling stations

The country has ten monitoring stations:
Okavango 71, Waterberg 67, Omaheke 94, Kunene 36, Cuvelai 31, Brandberg 130, Namib 149, Khomas 62, Hardap 67, Karas 109

4.3.2   Chemical parameters

Among the parameters being analyzed at the laboratory are:
Alkalinity in mg/l $CaCO_3$, Cadmium in mg/l Cd, Calcium in mg/l Ca, Chloride in mg/l Cl, Colour in mg/l Pt, Conductivity in mS/m, Copper in mg/l Cu, Fluoride in mg/l F, Hardness total in mg/l $CaCO_3$, Iron in mg/l Fe, Lead in mg/l Pb, Magnesium in mg/l Mg, Manganese in mg/l Mn, Nitrate in mg/l N, Nitrite in mg/l N, pH, Potassium in mg/l K, Silica in mg/l SiO_2, Sodium in mg/l Na, Sulphate in mg/l SO_4, Turbidity in NTU and Zinc in mg/l Zn
 Microbiology parameters:
Heterotrophic plate count (CFU/1ml), Total coliform (TC/100 ml) and E.coli (EC/100ml)

4.3.3 Frequency

Sampling sites for chemical analysis are sampled twice per year (purification plants on a daily basis). Sampling sites for microbiological analysis, its sampling

frequency depends on the population (varies from twice per week to four times a year). Minimum analysis is done once in every three months.

Table 4.4 summarises the water quality monitoring programme of Namibia compared to the best practice monitoring.

Table 4.4: Comparison of water quality monitoring programme of Namibia and required best practice

	Namibia	**Best practice**
Monitoring Institution	Government Institution	Government Institution
Parameters	Alkalinity, Cadmium, Calcium, Chloride, Colour, Conductivity, Copper, Fluoride, Hardness, Iron, Lead, Magnesium, Manganese, Nitrate, Nitrite, pH, Potassium, Silica, Sodium, Sulphate, Turbidity, Zinc	Alkalinity, Bicarbonates, BOD, Calcium, Chlorides, Chlorophyll, Colour, DO, Conductivity, Flow, Free Ammonia, Free CO_2, Magnesium, Nitrates, Nitrites, Odour, Orthophosphates, pH, Transparency, Potassium, Sodium, Sulphates, Temperature, Total phosphorus
Frequency	Two time per year	24 times per year
Stations	1 station at each WMUA	3 stations at each WMUA
Data Storage	Paper files	Computerised data files

As it can be seen, existing water quality monitoring programme in Namibia is not in line with the best practice recommendations.

4.4 Zimbabwe

In determining what geographical entity is most suitable for regional water resource management, it is important to recognise that Water Quality problems are inseparable from water quantity and land management problems. It is therefore necessary to define a geographic unit which can be viewed as a system so that all factors including water utilisation, water quality and land resources can be integrated properly. This establishes the river catchment as the most appropriate such unit. All water related activities in a region are linked by the movement of water through the catchment and interdependence between the various activities can only be defined by examining the catchment as a complete system.

Under Zimbabwe's new Water Act, water is managed at catchment level and the country has been divided into seven catchments, each run by a Catchment Council and covering the main river systems of Gwai, Sanyati, Manyame, Mazoe, Save, Runde and Mzingwane.

The functioning of the Catchment Councils is based on the policy of involving the water users in the planning, implementation and management of the water resources.

The Catchment Councils' main functions include:
- The administration of water abstraction permits
- Planning for catchment development and accountability to present and future water users
- Management of river systems and underground water aquifers
- Provision of water from Government dams(allocation and sales)
- Enforcement of laws and regulations on the local level
- Collection of local data on river systems and underground water
- Maintenance of dams and dam safety.

The Catchment Councils consist of three tiers, the Water User Boards, Sub-catchment and Catchment Boards. The area covered by individual Water User Boards corresponds to hydro sub-zones and all users within the zone are members of the Board. The Sub –catchment Boards are composed of two members from each Water User Board. The Catchment Board is composed of two members from each sub-catchment.

In all cases, if some sectors are not represented, there is a facility to co-opt them into the Boards. Communal area stakeholders hardly have a stake in the water cake at present and special attention will have to be paid to their mobilization, awareness and input in the catchment outline process.

4.4.1 Participation in water quality monitoring

Stakeholders have started getting involved in water quality control, a field which had previously been left to academics and government. An interactive and experimental approach to involve and mobilize rural communities in water quality management programmes is being investigated. The approach is designed to bring awareness to the rural farmers of the amounts of nutrients they contribute to a river system and the benefit of adhering to good farming practices both in terms of production and environmental protection. A high degree of stakeholder involvement and use of computer simulations is being employed and the kind and level of participation is quite encouraging and the stakeholders are really proving that they can be the custodians of their own resources given the chance.

A pilot project dealing with an agro-rural sub watershed in a semi-arid developing country situation has been initiated and is in its third year. In the first year water quality monitoring was done without influencing the behavior of the communal farmers. In second the farmers were influenced by convening meetings and working together in minimizing potentially polluting activities whilst the water quality continued to be monitored.

Water quality monitoring activities are done at provincial and district level. Regular checks are done on domestic water as well as effluent discharges. Samples collected are analyzed by the public health laboratories and the government analyst laboratory. Water quality management has been up to now part of the water resources management process and found in Water Act. In March 2003 the new Environmental Management Act was put in place and repealed all the sections of Water Act that were dealing with Quality Management and included them in the new Act.

4.4.2 Parameters

Temperature deg.C, pH units, BOD, COD, TSS, TDS, Conductivity μS/cm, DO% saturation, Ammonia, Chloride, Chlorine residual, Sulphate, Sulphide, CN, Detergents, Grease and oil, Arsenic, Iron, Bar, Boron, Copper, Iron, Manganese, Nickel, Tot Nitrates, Tot Phosphates, Cadmium, Cromium(VI), Mercury, Lead, Zinc, Total heavy metals, Feacal coliforms (No /100 ml), Helminth eggs (No/100 ml), Phenolic compounds (as phenol), Sodium, Potassium, Ca +Mg(Hardness), Cobalt, Alkalinity, Colour and Turbidity

Table 4.5 summarises the water quality monitoring programme of Zimbabwe compared to the best practice monitoring.

Table 4.5: Comparison of water quality monitoring programme of Zimbabwe and required best practice

	Zimbabwe	Best practice
Monitoring Institution	Government Institution	Government Institution
Parameters	Temperature, pH, BOD, COD, TSS, TDS, Conductivity, DO, Ammonia, Chloride, Chloride residual, Sulphate, Sulphide, CN, Detergents, Grease and oil, Iron, Ba, B, Cu, F, Mn, Ni, Total Nitrogen, Total Phosphorus, Cd, Cr, Hg, Pb, Zn, Total heavy metals, Faecal coliforms, Phenols, Se, Na, K, Hardness, Co, Alkalinity, Colour, Turbidity	Alkalinity, Bicarbonates, BOD, Calcium, Chlorides, Chlorophyll, Colour, DO, Conductivity, Flow, Free Ammonia, Free CO_2, Magnesium, Nitrates, Nitrites, Odour, Orthophosphates, pH, Transparency, Potassium, Sodium, Sulphates, Temperature, Total phosphorus
Frequency	12 times per year	24 times per year(twice a month)
Stations	1 station at each Cathment(WMUA)	Minimum of 3 stations at each WMUA
Data Storage	Paper files	Computerised data files

From the above information one can conclude that the water quality monitoring programme in Zimbabwe is not in line with the best practice recommendations.

4.5 Tanzania

The National Environmental Management Council, (NEMC) is the governmental parastatal organization affiliated with the office of Vice President. It coordinates the activities of all bodies concerned with environmental matters and serves as a channel between these bodies and the government. In additional several NGOs and CBOs including International Organizations such as DANIDA, SIDA and IFAD had conducted various environmental programs such as CBEM, HESAWA and KAEMP. These have added some substantial contribution to the protection of water in the lake. In Tanzania there are several Acts, Ordinates and subsidiary legislation that in one way or other deal with quality protection. However, the existing legislation is still lacking proper inter-sectoral and multilevel coordination for effective action.

The study area comprises the catchment of Lake Victoria; it includes Mara, Mwanza and Kagera regions, collectively referred to as the lake zones, lying between 1-4° S Lat and 30-35° E Long. The foremost task of water quality end ecosystem management component (WQ and EM) is to develop a system for water quality monitoring after ecosystematic collection of baseline data. Highest priority is given to acquisition of data on pollution from nutrients (Carbonaceous matter, Phosphorus, Nitrogen and Silica) that cause eutrophication of the lake. The scope of monitoring is designed to cover various aspects of surface water quality and eventually acquisition of data to utilize as the basis for an integrated water quality management.

An effective water management program requires information on water quality to be collected analyzed and interpreted to all stakeholders including policy makers. Due to lack of funds, systematic data collection and monitoring activities in the lake zone have not been carried out; this implies that data on water quality is both scarce and scattered. As a consequence it has been difficult to rank the degree of pollution in the lake and its catchment as well as to establish an environmental

policy of which further environmental pollution will be abated, including management of water quality.

Reliable data is a prerequisite of any monitoring system, therefore LVEMP started by establishing water quality monitoring stations in the lake catchment. Strengthening laboratory capability and formalizing analytical procedures. Therefore zonal laboratories in Mwanza, Musoma, and Bukoba were renovated and equipped with necessary instrument, furniture, chemicals, reagents and training of manpower. However some of the advanced instruments like the Atomic Absorption Spectrophotometer (AAS) have not yet been procured.

As discussed above water quality monitoring programme in Tanzania is in place, but there is not enough information to indicate to what extent is their monitoring programme meets the recommendations of the best practice

4.6 South Africa

The Department of Water Affairs and Forestry as a custodian of the water resources of South Africa manages and ensure efficient, equitable and sustainable use of our limited water resources. It is therefore the responsibility of the Department to support sustainable operations of potable water and sanitation systems, to monitor water quality and evaluate access to services and to provide the national resource management function with resource quality and technical information.

Status reporting is an obligation of the Department of Water Affairs and Forestry in terms of the National Water Act (Act 36 of 1998). A comprehensive status report would cover a range of water quality problems, including:
- Inorganic chemical water quality (major ions and trace metals)
- Trophic status of water resources
- Microbiological water quality
- Organic chemical water quality

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- Aquatic ecosystem health and

- Radioactivity levels in water resources

4.6.1 National Water Quality Monitoring Programmes

DWAF has had a national monitoring programme (the so-called Chemical or Salinity monitoring programme) in place since the early 1970's as well as established assessment procedures for assessing the inorganic chemical water quality of surface waters. For this programme, samples are regularly collected at approximately 1 600 monitoring stations on rivers, at a frequency that varies from weekly to monthly sampling. A trophic status monitoring programme is conducted on a much smaller scale for selected South African impoundments that are managed by the Department of Water Affairs. The design of a more extensive Eutrophication monitoring programme has been completed and the trophic status programme has been integrated with this programme.

A national microbiological water quality monitoring programme has been designed and is currently being implemented. At present only a limited sampling network exists and work is underway to extend this network, however it will be several years before it can provide a national indication of the microbiological water quality. Organic surface water resource quality sampling occurs for a very small number of sampling sites and no national network is feasible at present because of the costs of sampling and analysis. Initiatives are underway to develop a National Toxicants Monitoring Programme that will include monitoring of organic and heavy metals pollutants. Radioactivity monitoring is done at a regional level only where such problems exist.

4.6.2 Existing Water quality monitoring programmes

A summary of all existing South African water quality monitoring programmes are tabulated in Table 4.6. A total of 11 water resource quality monitoring programmes are currently run by the Department of Water Affairs and Forestry. Monitoring is mainly to consider status and trends.

Table 4.6: Current monitoring programmes in South Africa

	Purpose	Parameters	Frequency
Microbial Monitoring	Status and trend	Microbes(E coli Faecal coloform)	Bi-monthly
River Health	Status and trend	Biological indicator(fish, vegetation, invertebrates)	Annually
Chemical Monitoring	Status and trend	Water quality samples	Variable depending the need
Eutrophication Monitoring	Status and trend	Phosphates. Nitrogenous compounds, chlorophyll, algae, cyanobacteria	annually
Radioactivity Monitoring	Status and trend	Concentration of radionuclides	Regularly
Toxicity Monitoring	Status and trend	Toxicants and Toxicity	regularly
Hydrological Monitoring	Status and trend	Water samples for RQS	
Geohydrological Monitoring	Status and trend	Rainfall depth and chemical character Conductivity and Temperature	Bi-annually
Ecological Reserve Determination and Monitoring	Ecological reserve monitoring: compliance, conformance	- ----	Once in 5 year cycle from start of monitoring

4.6.3   New Programmes

A general observation is that existing national programmes have largely focussed on resource status and trends monitoring, whereas the most growth in monitoring will be:

- Towards assessing water and land-based impacts on the resource
- Towards managing impact (compliance monitoring).

As it was mentioned in previous chapters water quality monitoring programme in South Africa was restricted only to Hydrological monitoring which involves monitoring the quality and quantity of surface water and groundwater. South Africa is planning to increase its scope of monitoring from Hydrological to Resource Quality and Water Resource Monitoring.

Figure 4.3 DWAF New Scope of Monitoring
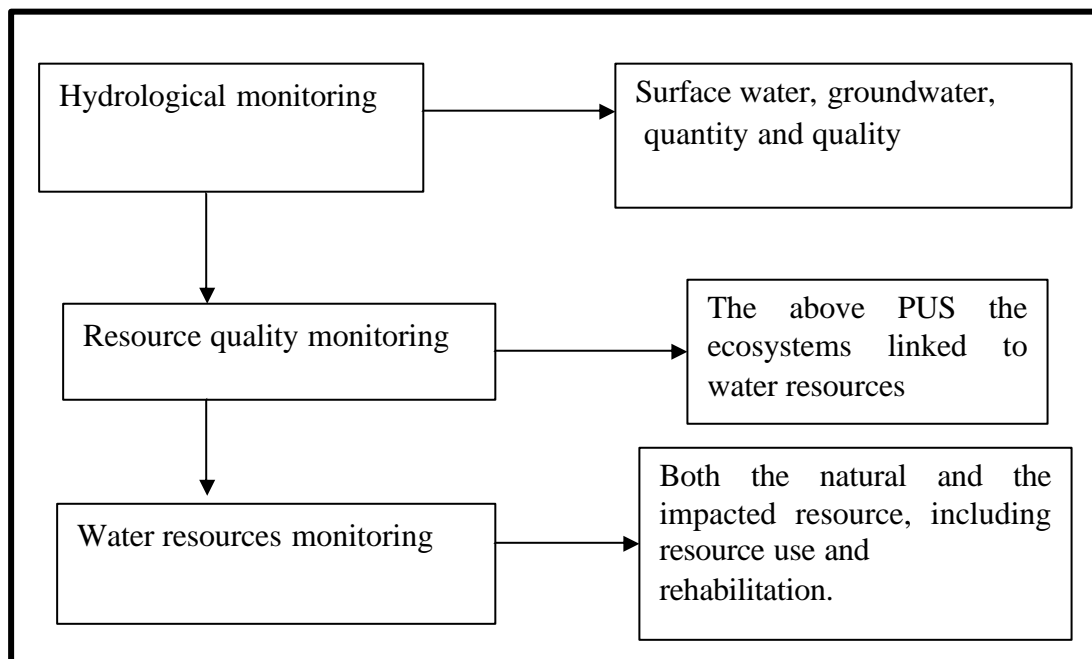
4.6.4   Water quality monitoring sites-catchments

South African catchments comprises of Limpopo, Crocodile, Olifants, Inkomati, Sutu to Mhlatuze, Thukela, Upper Vaal, Middle Vaal, Lower Vaal, Mvoti to

Mzimkulu, Mzimvubu to Keiskamma, Upper Orange, Lower Orange, Fish to Tsitsikama, Gouritz, Doorn, Breede and Berg Water Management Areas. Each catchment has its own sampling sites. The table .3 below shows the catchments and their sampling sites.

Table 4.7: List of land cover in the vicinity of national assessment sample sites selected, grouped per WMA

No	Sample Site Number	Location of site	Land Cover in the Vicinity of the Site
9	A4H013Q01	Mokolo River at Moorddrfit/Vught	Bush and Forest
10	A5H006Q01	Limpopo River at Botswana/Sterkloop	Bush and Degraded land
11	A5H008Q01	Palala River at Ga -Seleka/Bosche	Bush
12	A7H001Q01	Sand River at Waterpoort	Bush and Forest
Luvhuvhu and Letaba WMA			
13	A9H011Q01	Luvhuvhu River at Pafuri/Kruger Park	Forest
14	A9H012Q01	Luvhuvhu River at Mhinga	Cultivated land Forest
15	B8H008Q01	Great Letaba River at Letaba Ranch	Forest, cultivated land and Bush
16	B9H003Q01	Shingwidzi River at Kanniedood Dam	Bush
Crocodile (West) and Marico WMA			
1	A2H019Q01	Roodekopjes Dam on Crocodile River	Bush and cultivated land
2	A2H021Q01	Pienaars River at Buffelspoort	Forest and cultivated land
3	A2H059Q01	Crocodile River at Vaalkop/Atlanta	Bush and Cultivated land
4	A2H094Q01	Bospoort Dam on Elands River: downstream Weir	Bush
5	A2H111Q01	Vaalkop Dam on Elands River: downstream Weir	Bush
6	A2H116Q01	Paul Hugo Dam on Crocodile River: downstream Weir	Cultivated land and Bush
7	A3R003Q01	Kromelleboog Dam on Little Marico River: Near Dam wall	Bush and Cultivated land
8	A3R004Q01	Molatedi Dam on Olifants River: Near Dam Wall	Bush and degraded land

Table 4.7contiuation: List of land cover in the vicinity of national assessment sample sites selected, grouped per WMA

Olifants WMA			
17	B1H010Q01	Witbank Dam on Olifants River: downstream Weir	Grass, Cultivated land, Urban and Mining
18	B1H015Q01	Middelburg Dam on little Olifants river	Grass, Cultivated land and Urban
19	B2H015Q01	Wilge River at Zusterstroom	Grass, cultivated land and urban
20	B3H001Q01	Olifants River at Loskop North	Degraded and Cultivated land
21	B3H021Q01	Elands River at Scherp Arabie	Cultivated land and forest
22	B4H021Q01	Steelpoort River at Alverton	Bush and cultivated land
23	B4H011Q01	Bylde River at Chester	Bush and cultivated land
24	B7H009Q01	Olifants River at Finale/Liverpool	Cultivated, degraded land and Bush
Inkomati WMA			
150	X1H003Q01	Komati River at Tonga	Forest and cultivated land
151	X1H014Q01	Mlumati River at Lomati	Forest,Plantation &cultivated land
152	X2H013Q01	Krokodil Rover at Montrose	Plantation
153	X2H016Q01	Krokodil River at Tenbosch/Kruger	Cultivated land and Forest
154	X2H022Q01	Kaap River at Dalton Bush	Cultivated land and Plantation
155	X2H032Q01	Krokodi River at Weltevrede	Bush and cultivated land
156	X3H008Q01	Sand River at Exeter Forest	Bush and degraded land
Usutu to Mhlatuze WMA			
143	W1R004Q01	Lake Msingazi at Arboretum	Cultivated land and Plantation
144	W2H005Q01	White Mfolozi River at Overloed	Bush, Grass and degraded land
145	W3H015Q01	Hluhluwe River at Valsbaai/St Lucia	Bush,Plantation and cultivated land
146	W4H004Q01	Bivane River at Welgelegen /Pivaannsbad	Grass and Plantation
147	W4H006Q01	Phongolo River at M.Hlati	Forest and cultivated land
148	W4H009Q01	Phongolo River at Ndume game reserve	Forest, bush and cultivated land
149	W5H022Q01	Assegaai River at Zandbank	Grass and Plantation

Table 4.7 continuation: List of land cover in the vicinity of national assessment sample sites selected, grouped per WMA

Thukela WMA			
135	V1H001Q01	Tugela River at Tugela Drift/Colenso	Bush and Grass
136	V1H010Q01	Little Tugela River at Winterton	Cultivated land and Grass
141	V6H002Q01	Tugela River at Ferry	Grass,degraded &cultivated land
142	V7H012Q01	Little Boesmans at Estcourt	Grass and Bush
Upper Vaal WMA			
25	C1H002Q01	Klip River at Sterkfontein /Delangesdrift	Grass and cultivated land
26	C1H017Q01	Vaal River at Villiers(Flood section)	Cultivated land and grass
27	C2H004Q01	Suikerbosrand River at Uitvlgt(RW S2)	Cultivated land, grass and urban
28	C2H005Q01	Riet Spruit at Kaal Plaats(RW RV2)	Cultivated land urban and grass
29	C2H071Q01	Klip River at Kookfontein/Vereeniging	Cultivated land, urban and grass
30	C2H085Q01	Mooi River at Hoogekraal/Kromdraai	Cultivated land and grass
31	C8H001Q01	Wilge River at Frankfort	Grass and cultivated land
32	C8H027Q01	Wilge River at Ballingtomp	Grass and cultivated land
Middle Vaal			
33	C2H007Q01	Vaal River at Pilgrims Estate/Orkney	Cultivated land and Grass
34	C2H073Q01	Skoon Spruit at Goedgenoeg/Orkney Bridge	Grass and urban
35	C4H004Q01	Vet River at Fizantkraal/Nooitgedagt	Cultivated land and grass
36	C4R001Q01	Allemanskraal Dam on Sand River:	Grass, cultivated land and Bush
37	C4R002Q01	Erfenis Dam on Great Vet River	Cultivated land and grass
38	C6H003Q01	Vals River at Mooifontein/Bothaville	Cultivated land, grass and urban
39	C7H006Q01	Renoster River at Arriesrust	Cultivated land and grass

Table 4.7 continuation: List of land cover in the vicinity of national assessment sample sites selected, grouped per WMA

Lower Vaal			
No sites met the selection criteria			
Mvoti to Umzimkulu WMA			
123	T5H007Q01	Mzimkulu River at Bezweni/Island view	Cultivated land, grass, plantation and degraded land
124	U1H006Q01	Mkomanzi River at Delos Estate	Bush and cultivated land
125	U2H001Q01	Mgeni River at Howick	Cultivated land, grass plantation and urban
126	U2H006Q01	Karkloof River at Shafton	Cultivated land, grass and plantation
127	U2H011Q01	Msunduze River at Henley Dam	Grass and cultivated land
128	U2H014Q01	Albert falls Dam on Mgeni River: downstream Weir	Cultivated land and grass
129	U2H022Q01	Msunduze River at Inanda/Nomfihlelo	Garss, Bush and cultivated land
130	U2H041Q01	Msunduze River at Hampstead Park/Moto-X (Darville)	Grass and urban
131	U2H043Q01	Mgeni River at Inanda/Mgeni Confluence	Grass, cultivated land and degraded land
132	U3H005Q01	Hazelmere Dam on Mdloti River: Down Stream Weir (Hmro)	Cultivated land and urban
133	U4H008Q01	Canal (left) from Mvoti River at Hlazane/Glendal	Cultivated land and bush
134	U8H003Q01	Mpambanyoni River at Umbeli	Cultivated land and bush

Table 4.7continuation: List of land cover in the vicinity of national assessment sample sites selected, grouped per WMA

Mzimvubu to Keiskama WMA			
107	R1H015Q01	Keiskama River at Farm 7/Howard Shaw Bridge	Bush and Grass
108	R2R003Q01	Bridle Drift Dam on Buffalo River: Near Dam Wall	Shrub and Bush
109	R3H001Q01	Gqunube River at Outspan	Bush and Grass
110	R3H003Q01	Nahoon Dam on Nahoon River: Downstream Weir	Bush, Urban and Grass
111	R3H004Q01	Nahoon Dam on Nahoon River: Pipe to Purification Works	Grass and Bush
112	S1R001Q01	Xonxa Dam on white Kei River: Near Dam Wall	Grass, Bush, Cultivated land and Degraded land
113	S3H001Q01	Klaas Smits River at Weltvreden/Queenstown	Grass, Bush and Degraded and Grass
114	S5H001Q01	Tsomo River at Wyk Maduma/Tsomo	Degraded land, Cultivated land and grass
115	S7H001Q01	Gcuwa River at Butterworth	Bush, Grass and Degraded land
116	S7H004Q01	Great Kei River at area 8 Springs B/Transkei Border	Bush and Grass
117	T1H004Q01	Bashee River at Bashee Bridge	Degraded land and cultivated land
118	T3H004Q01	Mzintlana River at Slangfontein/Kokstad	Grass and Cultivated land
119	T3H005Q01	Tina River at Mahlungulu	Degraded and Cultivated land
120	T3H006Q01	Tsitsa River at Xonkonxa/Tsitsa Bridge	Grass, Degraded and cultivated land
121	T3H008Q01	Mzimvubu River at Kromdraai/Inungi	Grass, Cultivated and Degraded land
122	T7H001Q01	Mngazi River at Mgwenyana 22/Mngazi	Grass, Cultivated and Degraded land

Table 4.7 continuation: List of land cover in the vicinity of national assessment sample sites selected, grouped per WMA

Upper Orange WMA			
40	D1H001Q01	Wonderboom/Stormboom Spruit at Diepkloof/Burgersdorp	Shrub and Bush
41	D1H003Q01	Orange River at Alliwal North	Grass, Cultivated land and Shrub
42	D1H005Q01	Orange River at White Hill(Lesotho)	Grass
43	D1H006Q01	Kornet Spruit at Maghaleen	Grass and Cultivated land
44	D1H009Q01	Orange River at Oranjedraai	Grass, Cultivated and Degraded land
45	D1H011Q01	Kraai River at Roodewal	Grass, Cultivated and Degraded land
46	D2H012Q01	Little Caledon river at the Poplars	Cultivated land and Grass
47	D2H036Q01	Caledon River at Kommissiedrift	Shrub, Grass and cultivated land
48	D2R004Q01	Welbedacht Dam on Caledon river: Near Dam Wall	Grass and Cultivated land
49	D3H013Q01	Orange River at Roodepoort	Shrub and Bush
50	D3R003Q01	Vanderkloof Dam on Orange River: Near Dam Wall	Shrub and Cultivated land
Lower Orange WMA			
51	D3H008Q01	Orange River at Marksdrift	Shrub, Bush and Cultivated land
52	D5H021Q01	Sak River at De Kruis/Williston	Shrub
53	D7H008Q01	Orange River at Boegoeberg Reserve/Zeekoebaart	Shrub, bush and cultivated land
54	D7H015Q01	South Canal from Orange River at Kakamas/Neusbeerg	Shrub, Bush and Cultivated land
55	D8H003Q01	Orange River at Viioolsdrift	Herb
56	D8H008Q01	Orange River at Pella Mission	Shrub and Grass

Table 4.7 continuation: List of land cover in the vicinity of national assessment sample sites selected, grouped per WMA

		Fish to Tsitsikama WMA	
81	K8H001Q01	Kruis River at Farm 508 Pineview	Cultivated land and Bush
82	K8H002Q01	Elands River at Kwaai Brand Forest Reserve/Witelbos	Cultivated land, Bush and Urban
83	L3R001Q01	Beervlei Dam at Windheuvel	Shrub and Degraded land
84	L6H006Q01	Heuningklip river at Campherspoort	Shrub and Bush
85	L7H006Q01	Groot River at Grootrievierspoort	Shrub, Bush and Cultivated land
86	L8H005Q01	Kouga River at Stuurmnskraal	Shrub, Bush and Cultivated land
87	N1H013Q01	Mackeiesputs Eye at Graaf-REinet/Van Reyneveldspas	Bush, Grass, Urban and Cultivated land
88	N2H007Q01	Sundays River at De Draay	Shrub
89	N3H002Q01	Voel River at Rietvlei	Shrub and Bush
90	N4H003Q01	Sundays River at Addo Drift East/Addo Bridge	Bush, Shrub and Cultivated land
91	P1H003Q01	Boesmans River at Donkerhoek/Alicedale	Bush, Grass, Shrub and Cultivated land
92	P3H001Q01	Kariega River at Smithfield/Lower Waterford	Bush, Grass and Forest
93	P4H001Q01	Kowie River at Bathurst/Wolfcrag	Bush, Grass and Cultivated land
94	Q1H012Q01	Teebus River at Jan Blaauws Kop/Beaconsfield	Shrub and Cultivated land
95	Q1H017Q01	Right Canal from Great Fis h River at Katkop/Zoutpansdrift	Shrub and Cultivated land
96	Q1H022Q01	Grassridge Dam from Great Brak River. outlet to river	Shrub and Cultivated land
97	Q2H002Q01	Great Fish River at Zoutpansdrift	Shrub and Cultivated land
98	Q4H013Q01	Tarka River at Bridge Farm/Tarka Bridge(New Weir)	Shrub, Grass and Cultivated land
99	Q4H002Q01	Kommandodrift Dam on Tarka River at Kommandodrift	Shrub
100	Q6H003Q01	Baviaans River at Botmansgat/De Klerkdal	Shrub, Bush and Cultivated land

Table 4.7 continuation: List of land cover in the vicinity of national assessment sample sites selected, grouped per WMA

|			
Fish to Tsitsikama WMA continuation			
101	Q7H003Q01	Great Fish River at Leeuwe Drift	Shrub, Cultivated land and Bush
102	Q8H011Q01	Little Fish River at Rietfontein/Junction Drift	Shrub and Bush
103	Q9H001Q01	Great Fish River at Fort Brown Peninsula	Bush and Shrub
104	Q9H002Q01	Koonap River at Adelaide	Bush and Shrub
105	Q9H018Q01	Great Fish River at Matomela's Reserve/outspan	Shrub, Bush and Cultivated land
106	Q9H029Q01	Kat River at Fort Beaufort	Bush, Degraded and Cultivated land
Gouritz WMA			
68	H8H001Q01	Duiwenhoks River at Dassjes Klip	Shrub and Cultivated land
69	H9H005Q01	Goukou River at Farm 216 (SWQ4A-11) D/S River	Cultivated land
70	J1H019Q01	Groot River at Buffelsfontein/Van Wyksdorp	Shrub
71	J2H010Q01	Gamka River at Huisrivier	Shrub, Bush and Cultivated land
72	J2H016Q01	Gamkapoort Dam on Gamka River:	Shrub and Bush
73	J2R004Q01	Gamka Dam on Gamka River: Near Dam Wall	Shrub
74	J3H011Q01	Olifants River at Warm Water	Shrub, Cultivated land, and plantation
75	K1H005Q01	Moordkuil River at Banff	Shrub, Cultivated land and plantation
76	K2H004Q01	Great Brak River at Vishoek	shrub
77	K3H001Q01	Kaaimans River at Upper Barbiers kraal	Bush and plantation
78	K3H003Q01	Maalgate River at Upper Knoetze Kama/Buffelsdrift	Cultivated land, shrub and bush
79	K4R002Q01	Swart Vlei at Ronde Valley/Hoogekraal	Bush, Plantation and cultivated land
80	K7H001Q01	Bloukrans River at Lottering Forest	Forest, Plantation and Bush

Table 4.7 continuation: List of land cover in the vicinity of national assessment sample sites selected, grouped per WMA

Olifants/Doorn WMA			
57	E1R001Q01	Bulshoek Dam on Olifants River: Near Dam Wall	Shrub and Cultivated land
58	E2H002Q01	Doring River at Elands Drift/Aspoort	Shrub
59	E2H003Q01	Doring River at Melkboom	Shrub, Cultivated land and bush
Breede WMA			
63	G4H007Q01	Plamiet River at Farm 562-Welgemoed/Kleinmond	Shrub and Herb
64	H4H024Q01	Robertson Canal from Bree River at DeGoree	Shrub and Cultivated land
65	H5H005Q01	Bree River at Wagenboomsheuvel/ Drew	Cultivated land and shrub
66	H6H009Q01	Riviersondered at Reenen	Cultivated land and Shrub
67	H7H006Q01	Bree River at Swellendam	Cultivated land and Shrub
Berg WMA			
60	G1H031Q01	Berg River at Misvertand/Die Brug	Cultivated land
61	G1H036Q01	Berg River at Vleesbank/Hermon Bridge	Cultivated land and shrub
62	G2H015Q01	Eerste River at Faure	Cultivated land and Shrub

Figure 4.4: Map showing South African WMA

Water Management Areas of South Africa
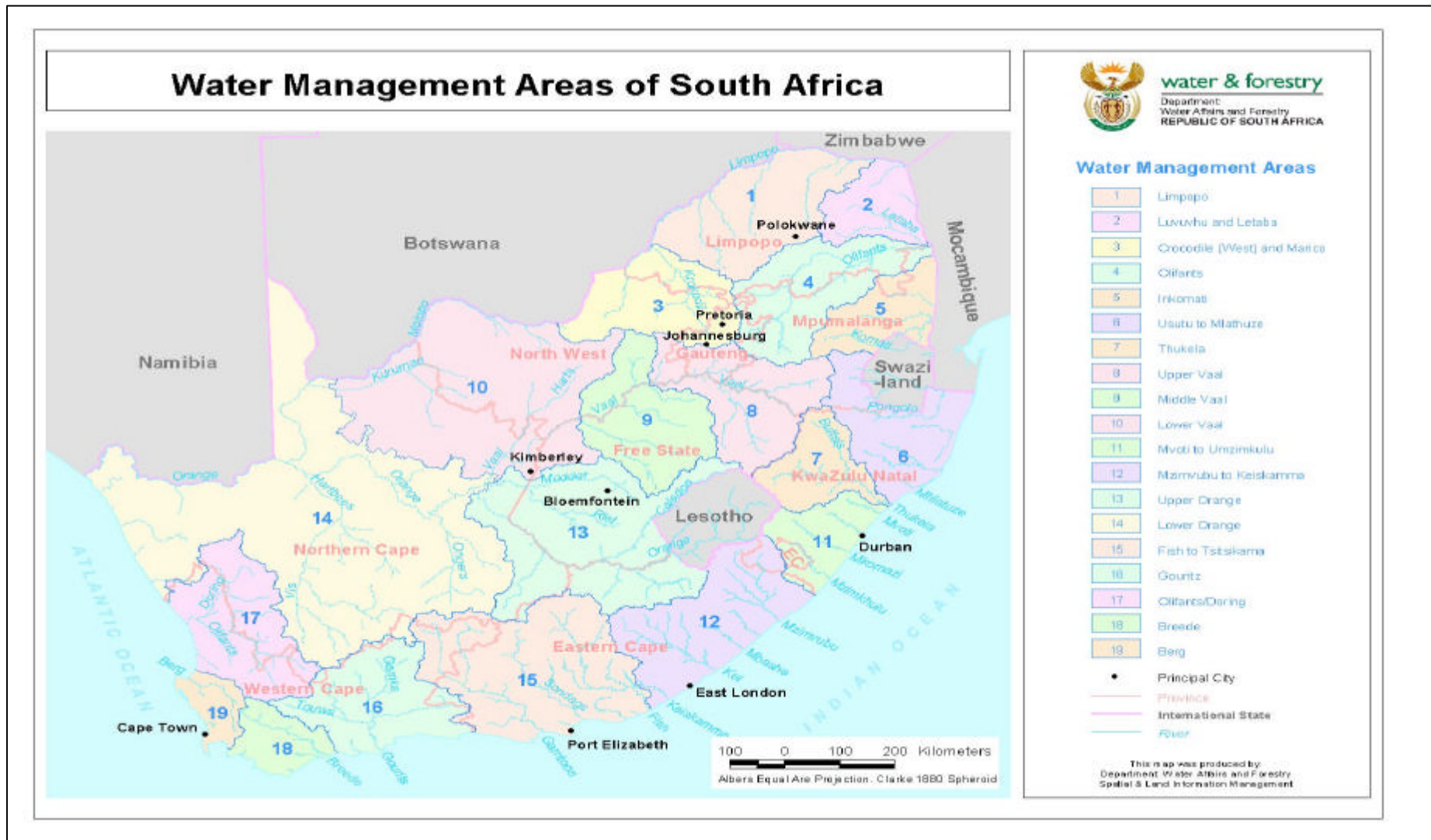
Table 4.8: Comparison of water quality monitoring programme of South Africa and required best practice

	South Africa	Best practice
Monitoring Institution	Government Institution	Government Institution
Parameters	pH, Temperature, Turbidity, calcium, Conductivity, Ammonia, Phosphate, algae, Nitrates, Cyanobacteria, chlorophyll, Microbes(E coli, Faecal coliform), Toxicity, Fluoride, TDS, Magnesium, Sulphates, Chlorides, Sodium, Potassium, Boron, Sodium Adsorption, Colour	Alkalinity, Bicarbonates, BOD, Calcium, Chlorides, Chlorophyll, Colour, DO, Conductivity, Flow, Free Ammonia, Free CO_2, Magnesium, Nitrates, Nitrites, Odour, Orthophosphates, pH, Transparency, Potassium, Sodium, Sulphates, Temperature, Total phosphorus
Frequency	24 times per year	24 times per year
Stations	More than 3 stations at each	More than 3 stations at each WMUA
Data Storage	Computerised data files	Computerised data files

Although South has many monitoring programmes in place, but they are not in line with the recommendations of the best practice, as result they have 5 year monitoring plan in place to improve their monitoring programmes.

4.7 Democratic Republic of Congo

Based on the information from (Chenge and Johnson, 1996) there is indication that the water monitoring programme is in place, but during this project no response was received from the authorities responsible fro water quality

monitoring to indicate to what extent their monitoring programme meets the best practice monitoring recommendations.

With problems like wars in this country one wouldn't expect their monitoring programme to be effective as required by the best practice monitoring.

4.8 Angola

Based on information from the (Chenge and Johnson, 1996) there is an indication that monitoring programme in Angola is in place, but during the research period there was no response received from the institution responsible for water quality monitoring to indicate to what extent their monitoring programme meets the best practice recommendations.

4.9 Botswana

Based on information from (Chenje and Johnson, 1996) there is indication that monitoring programme is in place and Department of Water Affairs is responsible for water quality monitoring, but during this research questionnaire was sent to the Department of Water Affairs of Botswana, but there was no response received to indicate to what extent is their monitoring programme meets the best practice recommendations

4.10 Malawi

According to (Kaluwa, Mtambo and Fatchi, 1997) water quality monitoring is in place, the Department of Water Development is the key government institution responsible for water management services and consists of four major sections namely the Hydrology, Hydrogeology, Rural Water Supply and Sanitation and Water Quality Section.

Water Quality Section is responsible for monitoring and assessment of the physical, chemical and biological water quality. The section also conducts inspections on pollution levels in effluent and wastes discharged in public waters. The major setback to the assessment of water quality is the inadequacy of laboratory equipment for conducting the analyses, inadequate training for the laboratory staff and acute shortage of equipment for use in water sampling procedures.

Concluding from the information above, Malawi doesn't have effective water quality monitoring programme.

4.11 Mozambique

Based on information from (Hopkins, 2003-2004) there is an indication that the water quality monitoring programme is in place, but it is decentralized, monitoring is only done by local authorities, as far as integration at National level monitoring is lacking, as a result during this research no response was received to indicate to what extent their monitoring programme meets the best practice recommendations.

4.12 Mauritius

Based on the information from(Chenge and Johnson, 1996) there is an indication that water quality monitoring is in place and The National Environmental Laboratory of the Department of Environment in collaboration with other laboratories (Ministry of Fisheries, Waste Water Management Authority, Central Water Authority) perform regular monitoring of inland and coastal water quality around the island.
 but during this research period no response was received to conclude that the water quality monitoring programme in this country meets the requirements of the best practice.

4.13 Lesotho

According to (Chenge and Johnson, 1996) water quality monitoring is in place and Ministry of Natural resources is responsible for water quality monitoring but during this research there was not enough information gathered to conclude whether Lesotho water quality monitoring programme meets the best practice recommendations

4.14 Discussion

This chapter has given an overview of surface water quality monitoring activities of the countries in the SADC region. This chapter presented summary descriptions of the monitoring activities in each country based on the supplied national descriptions. Generally the countries have several national monitoring programmer focused on assessment of the environmental state of surface waters. Some countries have a long tradition for national coordination of their monitoring programmes, however in most of the countries the monitoring of surface waters has traditionally been performed by provincial or local organizations. The growing need for national information on the environmental state of surface waters made it necessary to work out national coordinated monitoring programmes. In most cases these national programmes are based on the information collected by provincial organizations.

Water quality monitoring is carried out in some countries in Southern Africa. The existing water quality monitoring programmes concentrate on collecting data on pollution levels for various water bodies that receive wastewater discharges. There are also water quality monitoring programmes that concentrate on collecting data for the management of water supplies. However, SADC countries have not yet established optimal water quality monitoring networks. In most cases the water quality monitoring activities in each country are carried by government agencies at points of interest other than gauging stations. The

coordination necessary to ensure good quality data collection among various agencies is lacking

Although water quality monitoring is carried out in countries of SADC region, the monitoring programmes they have are not in line with the best practice monitoring programme. For example, countries like Angola, Botswana, Mozambique, Mauritius, Democratic Republic of Congo and Malawi do monitor their water quality but there is no appropriate data storage. As a result of this it was not possible to obtain any data from these countries for the purposes of this research. Apart from not obtaining data there were many other difficulties that the researcher experienced during data collection from the SADC countries, people working for the institutions responsible for water quality monitoring were not helpful at all.

South Africa, Zambia, Zimbabwe, Swaziland, Namibia and Tanzania are the only countries that supplied their data, although what they provided was not sufficient to answer all the questions the researcher was asking because they do not have enough data. Some of the research questions were not answered because the data obtained did not have much information on the researcher's interests. The data supplied showed the following deficiencies:

- Water quality monitoring is SADC region is not effective with respect to the needs of water resources management in SADC region.
- SADC region does not have effective monitoring program and the deficiencies are the following
  - Sampling methods and protocols of the agencies responsible for water quality monitoring are not necessarily the same nor in accordance with established water quality monitoring standards and best practice.
  - Data handling and storage is not in line with the established data storage guidelines and best practice
  - Lack of trained staff responsible for water quality monitoring is common

- Laboratory analysis are often not performed by trained staff and the available staff is not sufficient to carry out all the necessary responsibilities

- Lack of properly equipped laboratories is evident, e.g. in Malawi the water Department's central water laboratory has been unable to carry out full analysis in recent years because of frequent breakdowns or non-functioning equipment.

- The lack of appropriate storage facilities necessary for transporting the samples to distant places is also a constraint that has been observed

- Comprehensive water quality assessments are rarely carried out, often due to the lack of well-defined objectives, monitoring system design and resource constraints.

- So far integration at regional (SADC) level is not existent.

- SADC countries are not using aligned monitoring program.

CHAPTER 5: RECOMMENDATIONS AND CONCLUSIONS

This study has shown that major deficiencies exist with respect to water quality monitoring as practiced in the countries of the SADC region. These deficiencies are more pronounced in some countries that in others and can be linked to the overall economic status of the particular country and the importance that a particular society attaches to water resources management. In addition, the deficiencies are more often than not, related to the capacity for effective water resources management in general and water quality management in particular in each country. Human resources seem to be a main limitation but other prerequisites for effective water quality management and monitoring such as institutions, equipment, laboratory space, methodologies and procedures are also important aspects contributing too inefficient water quality monitoring.

It is evident to the researcher that there is a profound need for starting a regional (SADC) water quality monitoring initiative within a much broader water resources management framework. This is further manifested by the fact that most of the water resources of the SADC region are of international character and effective water management will need international efforts.

The process of establishing a SADC Water Quality Monitoring program will not be easy or quick. It will require significant resource investment with respect to almost all important components of the water quality management (people, labs, methods, data management etc.). South Africa, as the country with most experience to date, should play a leading role in initiating such a regional program and I have no doubt that it will have to carry the biggest burden of initiating and implementing such a program.

The section on recommendations reflects the author's view of an effective water quality monitoring program for SADC region. It is seen as a departure point for a future regional activity and should serve as such. It is noted that in this, rather limited research effort, not all important aspects could be addressed and the recommendations given should be viewed with this fact in mind.

5.1 Recommendations

A regional SADC Water Quality Monitoring Program should be initiated within a broader context of the regional water resources management.

The main components of such new initiative should be consistent with the principles discussed below:

5.1.1 Principle 1: Water Quality Monitoring in SADC should be Goal-oriented

- The design of water quality monitoring programs should be such as to allow one to measure progress in meeting clearly stated goals for water resources management and protection of resources in the region. These goals should include protection of public health, ecosystem health and economic objectives of development of the region as a minimum.

- The choice of water quality indicators should be based on international best practice and additional specific needs of the region and should be jointly decided upon by participating countries and support from international community. World Water Assessment Program of UNESCO should be engaged in the process to insure comparability with the international community and to benefit from experiences from other regions of the world.

The minimum sets of objectives for an effective SADC Water Quality Monitoring program are:

1. Identification of baseline water quality conditions

2. Detection of any signs of deterioration in water quality.

3. Identification of any waters that do not meet the desired ambient water quality standards where they exist.

4. Identification and determination of the extent and effects of specific major waste discharges.

5. Estimation of the pollution load carried by major water courses at predefined strategic location (boundary crossings, major confluences, mouths of the major rivers etc.).

6. Evaluation of the effectiveness of a water quality management interventions where possible.

7. Development of water quality guidelines and standards for specific water uses at the SADC level.

8. Contribution to the development of a water pollution control action plan for the SADC region.

5.1.2 Principle 2 - All relevant existing WQ information should be reviewed and synthesized for the SADC region

- A comprehensive regional study to characterize current water quality conditions by using all available information should be conducted to preserve historical results and provide a foundation data set for comparative purposes. Such a study would also have a purpose to, in detail, identify the deficiencies in the region which this research only flagged.. A regional base map on the water quality conditions in SADC region should be produced, if at all possible, and it should include actual locations of and reasons for impaired water quality.

- All the information captured as a part of the above mentioned study should be used to identify detailed water quality monitoring gaps and develop a priority list for action. The information captured should be managed in a matter amenable to easy data retrieval and information dissemination preferably using GIS technology.

5.1.3 Principle 3 – Water Quality Monitoring should be Flexible and comprehensive

- SADC Water Quality Monitoring should use a flexible monitoring design and should engage public and private groups to assess ambient waters nationwide comprehensively by using a watershed based rotational schedule of 5 to 10 years.

- Tailor monitoring designs based on the catchment conditions and location specific water uses should be used.

5.1.4 Principle 4 – Integrated Institutional Structures and Effective Collaboration are a pre requisite for effective WQM in SADC Countries.

- An inventory of all institutions and organizations working on Water Quality Monitoring in SADC should be established and should include the capacity assessment for each institution. This should be used to establish closer working relations among the full range of public and private organizations that monitor and use water quality information in SADC region and to identify the capacity gap on a regional scale. It may be necessary to initiate an institutional restructuring project to address the gaps identified.

5.1.5 Principle 5 – Water Quality monitoring should be based on Catchment Management Framework

- Within the SADC Region there is a huge disparity in water resources management approaches and not all countries have developed and adopted catchment management strategies. As water quality is a result of interaction of land use and human activities in the catchment and natural water cycle it is imperative that catchment based WQM strategies be adopted and implemented. Working with representatives from all levels of government and private sector, it is necessary to build support the implementation of the SADC WQM strategy (yet to be developed) by:
  - Developing SADC WQM Policy and strategy
  - Developing and distributing guidance documents
  - Sponsoring WQM technology transfer
  - Jointly planning WQM programs
  - Identifying opportunities to collaborate and share resources

5.1.6   Principle 6 – WQM should support Decision Making and Compliance Monitoring

- Develop, test and institutionalize methods to integrate WQ decision making and WQ compliance monitoring. .

- Develop minimum requirements for quality assurance (QA) and quality control (QC) for WQM.

5.1.7   Principle 7 – Align WQ Analysis Methods to Ensure Comparability

- Develop/adopt and implement and common WQ Analysis Methods for the SADC region to ensure comparability of monitoring results and integration of data from a variety of sources and across a variety of scales into a regional WQ database.

5.1.8   Principle 8 – Data and information storage and retrieval should be standardized around a set of minimum reporting requirements

- Tools to facilitate information searches and retrieval across national and subnational (catchment) data bases should be developed. Standardisation of tools across SADC would help to insure integrity and data and information dissemination and retrieval.

- Existing water-quality-information systems should be used as much as possible while new systems should be developed to facilitate data and information sharing between SADC states and the international community. This ca be done by adopting the following:
    - Common data-elements definitions and formats
    - An expanded set of recommended data elements or qualifiers to facilitate the sharing and exchange of information.
    - Common references tables, such as taxonomic and hydrologic unit codes
    - Develop and adopt common Metadata standards (metadata describes the content, quality, condition and other characteristics of data. It helps secondary users to judge whether the data would be useful for other application)

5.1.9 Principle 9 - Quality Assurance/Quality Control Programs must be integrated into the SADC WQ Monitoring Program

- For all monitoring programs, data-quality objectives to identify the precision and accuracy of data needed to achieve the monitoring goal must be established.
    - QA/QC procedures must be appropriate to the purposes of the program.
    - QA/QC Procedures must be followed correctly
    - QA/QC Procedures must be documented with the data in data management systems.

5.1.10 Principle 10: - Integrated Assessment and Reporting should be ensured

- Organizations will continue to assess and report their own data for their own purposes. However, increasingly SADC and other agencies need data from other multiple sources to understand and present their issues more completely. For this reason an Integrated Assessment and Reporting System for Water Quality should be developed and implemented at the SADC level. .

- Additional interpretive and assessment methods and tools should be developed as needed.

- Regular reporting on the Status of WQ in the SADC region should be a requirement for all SADC countries.

- It is imperative that assessment methods to be used are considered in the design of the WQ monitoring program so that the data collected effectively supports the needed analysis.

5.1.11 Principle 11 – Training is a prerequisite for effective WQM in SADC

- Training incorporating all organizations and individuals involved in WQM should be promoted to:
    - Transfer technology

- Inform others about needed changes in monitoring planning and procedures.
- Achieve the QA and QC necessary to assure scientifically sound information for decision makers.
- Facilitate comparability of methods.

5.1.12 Principle 12 – WQM Implementation Strategy for SADC countries should be established

- A SADC Water Quality Monitoring Council representing all governments and the private sector, to guide the overall implementation of the strategy should be established. Such a council is needed to:
    - Ensure that technical support and program coordination is maintained among participating organizations
    - Evaluate periodically the effectiveness of monitoring efforts in SADC and account for regional differences, such as between arid and water-rich countries.
    - Revise the strategy as needed to ensure that monitoring continues to meet changing needs.

5.2 Conclusions

The research has given an overview of surface water quality monitoring activities in the countries in the SADC region. This research presented summary descriptions of the monitoring activities in each country based on the supplied national descriptions. Generally the countries have several monitoring programmes focused on assessment of the environmental state of surface waters. Some countries have a long tradition for national coordination of their monitoring programmes, however in most of the countries the monitoring of surface waters has traditionally been performed by provincial or local organizations. The growing need for national information on the environmental state of surface waters made it necessary to work out national coordinated monitoring programmes. In most cases these national programmes are based on the information collected by provincial organizations.

The research has shown that:

- SADC region does not have an effective regional water quality monitoring programme.

- Water Quality Monitoring Programs in the SADC countries are not aligned and differ significantley.

- There are many deficiencies in the water quality monitoring in SADC countries which need to be addressed.

As has been documented many times, reliable high quality information on ambient water quality is essential for effective water management. This in itself will contribute to economic development of the region. It is therefore necessary to initiate SADC activities that will lead to a regional water quality monitoring program providing reliable and high quality information on water quality in the region.

As the competition for adequate supplies of clean water increases in the region, concerns about public health and the environment will escalate and more demands will be placed on the water quality information infrastructure. These demands cannot be met effectively and economically if the organizations responsible for water quality monitoring do not changing their approach to water quality monitoring. Each organization responsible for water quality monitoring in the SADC region will need to revise their monitoring activities and try to implement the recommended principles thus improving water quality monitoring in a series of deliberate steps over several years as staff and resources become available.

In conclusion, it is imperative that SADC water Quality Monitoring Program reflects the trans-boundary nature of almost all major rivers in the region which fully justifies a regional Water Quality Monitoring Program. The benefits of this could be felt throughout the region in terms of better resource utilization and protection, improved health situation and less limitation on the economic development of the region resulting from the water quality impairment.

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APPENDIX I

1. General information

- Agency…………………………………………………………………….
- Is it a government
- Agency…………………………………………………………….....................
- Ministry…………………………………………………………………………
  ………………………………………………………………………………..
- Other collaborating agencies …………………………………………………
- No of monitoring officers……………………………………………………….
- No of monitoring stations…………………………………………………………
- Map showing monitoring stations and gauging stations

2. Activity

- Water Quality
    - Parameters
    - Frequency of monitoring
- Water Quantity
    - Water appointment
    - Purpose for which water is appointed: Industrial, agric, municipal and
      other…………………………………………………………………………
      …………………………………………………………………………………
      …………………………………………………………………………………
- Do you monitor international rivers, local rivers or both

3. Who uses the information on water quality and quantity and for what purpose?..

....

....

4. Legislation

- Applicable
  legislations………………………………………………………………………
  ………………………………………………………………………………………
  ………………………………………………………………………………………

- Any legal actins ever taken against offenders?

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  ....

  ....

5. Any other information

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………………………………………………………………………………………