UNEP GLOBAL ENVIRONMENTAL MONITORING SYSTEM/WATER PROGRAMME

SOUTH AFRICAN MONITORING PROGRAMME DESIGN

November 2004

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Acronyms

DEWA	Division of Early Warning and Assessment
DOH	Department of Health
DWAF	Department of Water Affairs and Forestry
GEMS	Global Environmental Monitoring System
GEMS/Water	GEMS Water Quality Programme
GEO	Global Environmental Outlook
GIWA	Global International Water Assessments
GLOWDAT	Global Water Quality Database
GRDC	Global Runoff Data Centre
ISO	International Standards Organization
LIMS	Laboratory Information System
NEMP	National Eutrophication Monitoring Programme
NMMP	National Microbial Water Quality Monitoring Programme
NAEBP	National Aquatic Ecosystem Biomonitoring Programme
NTMP	National Toxicity Monitoring Programme
POP	Persistent Organic Pollutant
QA	Quality Assurance
QC	Quality Control
QMS	Quality Management System
RHP	River Health Programme
RQS	Resource Quality Services
SA-GEMS/Water	South African GEMS/Water Programme
SADC	South African Development Community
SADC-HYCOS	SADC – Hydrological Cycle Observing System
UN	United Nations
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VWG	Vital Water Graphics
WMS	Water Management System
WMA	Water Management Area
WWAP	World Water Assessment Programme

Executive Summary

Background

The United Nations Environmental Programme (UNEP) has, in conjunction with other UN agencies, been driving a global fresh water quality monitoring programme for the past 15 years. It is co-ordinated by the UNEP Global Environmental Monitoring System/Water Programme (GEMS/Water), which is hosted and managed by the Canadian Ministry for the Environment. More than one hundred countries contribute data from their existing national monitoring networks to GEMS/Water, where the data is stored in a central database called the GLOWDAT. Data from GLOWDAT are used by various UN organizations for global assessments. As part of a drive to get more African countries involved, GEMS/Water approached South Africa in 2002, with a request to join the programme. South Africa accepted the invitation and joined GEMS/Water in 2003. The Department of Water Affairs and Forestry (DWAF) went through a process of designing a monitoring network, integrated with the existing national water quality monitoring programmes, that would enable DWAF to transmit credible and globally relevant data to GEMS/Water.

The purpose of this design document is to address all design requirements and recommended design outcomes. The document contains the recommended sample sites, monitoring variables, sampling frequencies, operational requirements, data and a quality assurance strategy.

Information Requirements and Monitoring Objectives

Although each individual organization involved in global and regional freshwater assessments have their own specific reasons for doing the assessments, it has been found that the various assessments tend to produce the following types of information, namely;

- Information on the levels and trends in critical water quality indicators in freshwater resources,
- Information on natural freshwater qualities in the absence of significant direct human impact and
- Information on the fluxes (loads) of toxic substances, suspended solids, nutrients and other pollutants to the continent/ocean interfaces (WHO, 1991).

The most common global water quality issues that are being reported on by GEMS/Water, GIWA, GEO and the WWAP are as follows

- Nutrient loading,
- Salinity (Macro constituents and trace metals),
- Suspended solid transport,
- Faecal pollution (Microbiological),
- Persistent organic pollutants (POP) and
- Acidification

The SA-GEMS/Water monitoring programme will supply the raw data to GLOWDAT from where it will be used to generate a number of different information products by the various UN organizations for use in global sustainability reporting. Based on the data requirements identified, the SA-GEMS/Water programme objectives have been defined as follows:

To provide the UNEP GEMS/Water programme with credible, globally significant and comparable data (producible by existing national monitoring programmes) on:

1) the levels of variables, indicative of the global water quality issues of concern, that enters the ocean from the globally significant South African catchments, for use in global river flux calculations,

2) the levels of variables required for the detection of trends in global water quality issues in major local catchments and impacted areas and

3) the levels of water quality variables at monitoring sites representing natural conditions in un-impacted areas.

Monitoring Network Design

The purpose of this section is to design the monitoring network (sampling sites, sampling frequency and variables) required for the realization of the SA-GEMS/Water objectives. The network was designed for the three different types of data required as outlined in the programme objectives, namely;

- Global River Flux monitoring: Data will be used for calculating loads of water quality variables from globally significant catchments to the world's oceans.
- Global Trends Monitoring: Data will be used to assess global trends in water quality issues and reflect on (on a strategic level) the spatial variation in water quality globally.
- Global Baseline Monitoring: Data will be used to establish the natural water quality conditions and to determine through trend analyses the influence of long range transport of contaminants and of climatic conditions.

Global River Flux Monitoring:

The Orange River Catchment, that drains the interior of South Africa (primary catchments C and D) and mostly dry areas of Namibia and Botswana (primary catchment Z), was identified by different UN agencies as a globally significant catchment. The most appropriate monitoring site to use for flux to the ocean monitoring of this catchment was identified at Vioolsdrift in the Northern Cape. Sampling at Vioolsdrift is done for the National Chemical Monitoring on a weekly basis. The optimum sampling frequency was determined to be monthly for Macro constituents and weekly for Total Suspended Solids (TSS). Although TSS levels are not currently being measured at the site it is recommended that this variable be included in the list of variables for that sites. This is also a UN GEMS/Water recommendation.

Global Trend Monitoring:

A total of 23 trend monitoring sites were selected from more than 900 sites in the National Chemical Monitoring Programme (NCMP). This was done during a specialist workshop in which the combined years of experience in the design and operation of monitoring programmes was more than 200 years. Of the 24 trend sites,16 were on rivers and 7 on dams. Site selection was mainly based on the primary catchment hierarchy together with a number of other UN GEMS/Water requirements. The optimum sampling frequency for rivers were identified as monthly and for dams bi-weekly. The sampling variables are the same as that which are currently used in the NCMP and NEMP for dams. Additional requirements for persistent organic pollutants data have also been identified.

Global Baseline Monitoring

During the specialist workshop four areas were identified for further investigation. After area specific investigations, four sites were identified in those areas. The sites are located in the upper reaches of the Mooi River in Kwazulu/Natal, the upper reached of the Eerste River in the Western Cape, the upper reaches of the Blyde River in Mpumalanga and the Kraai River before its confluence with the Orange River. The sampling frequency and monitoring variables are the same as for trend monitoring. It is, however, recommended that temperature measurements be included for baseline sites.

Quality Assurance (QA)

The main function of any water monitoring programme is to ultimately produce data or information that will in some way be used to support water management decisions. The social, environmental and financial implications of making incorrect decisions, as a result of unreliable data or information, can be severe. Unreliable data or information is a direct result of a monitoring programme with a poorly designed or maintained quality assurance programme. In monitoring programmes, such as GEMS/Water, where more than one organization are responsible for producing data, a high level of comparability is required. This can only be achieved through a well-designed and consistently implemented quality assurance programme. The main purpose of this section is to identify QA gaps in the NCMP that is responsible for producing data that will be submitted to GEMS/Water. Recommendations are made on ways to enhance the reliability of the data submitted to GEMS/Water.

A workshop was held during which a process analyses of the NCMP was done and the associated potential errors that could negatively impact on the credibility of the data were identified. The next step was to develop a system that will reduce, avoid and mitigate the potential errors that were identified. A full quality management system (QMS) framework that is inline with the principles of ISO 9001:2000 has been designed. The QMS consists mainly of the following components, namely:

- QMS Scope,
- Quality policy,
- Quality objectives,
- QC measures,
- Training and competence,
- Queries, complaints and corrective action,
- Document control,
- Records,
- Management review and
- Systems auditing.

The proposed QMS will enhance the credibility of the data produced by the NCMP and combined with GEMS/Water and laboratory specific QA measures will enhance the credibility of the South African water quality data stored on the GEMS/Water global database.

Although this QMS has been designed for the NCMP it can be extended to other national water quality monitoring programmes at RQS. This should , however, not be attempted without a fulltime quality co-ordinator and only after it has been successfully implemented and tested in the NCMP. The total quality plan (including the proposed QMS) for SA-GEMS/Water is illustrated in Figure I below.

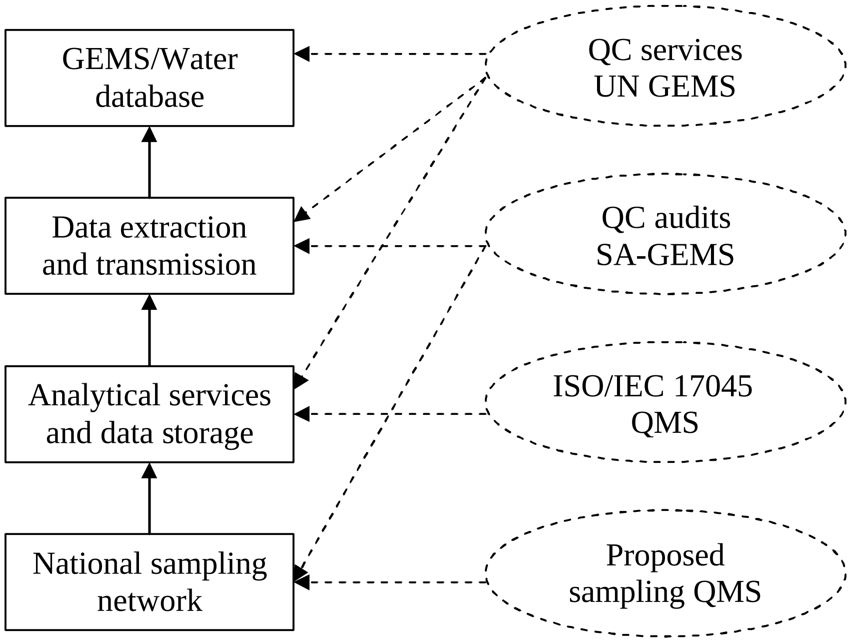

Figure I: SA-GEMS/Water total quality plan interaction.

Operational Requirements and Responsibilities

The purpose of this chapter is to identify the operational requirements and associated responsibilities to ensure that the objectives of the SA-GEMS/Water programme are met in a sustainable manner. To achieve this a monitoring process flow analyses was done as a basis to work from. From this monitoring process flow analyses the operational requirements and associated responsibilities were identified. Resources and risks involved in the operation of SA-GEMS/Water were also identified. Figure II below illustrates the SA-GEMS/Water processes and interactions involved in producing and submitting relevant and credible data to the GEMS/Water global database. The light gray arrow line indicates the main process flow from sample scheduling to data entry onto the global database. See discussion in section 5.2 for more detail regarding functions and responsibilities of the various functions.

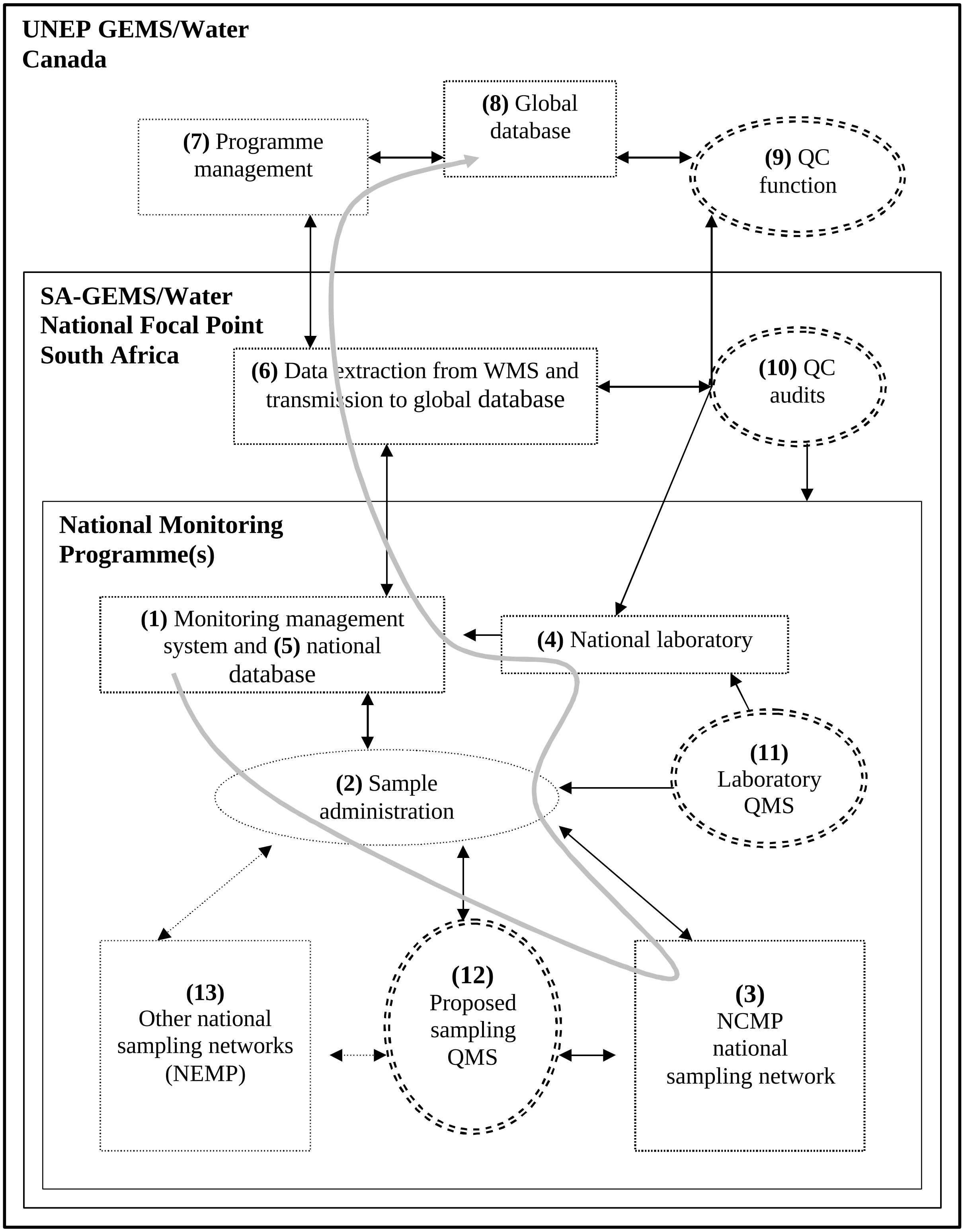

Figure II: SA-GEMS/Water Process flow

Resources

The SA-GEMS/Water programme was designed to function as an integral part of the existing national monitoring programmes. The only additional two functions that are not part of existing national programmes are that of transmitting data to the GLOWDAT on a six monthly basis and annual audits on the national programmes responsible for generating the data. It is, therefore, estimated that the SA-GEMS/Water representative will need to spend one month per year on SA-GEMS/Water issues. One week every six months for data preparation and transmission and two weeks for an annual audit.

All other resources required for issues such as sampling, analyses, etc. are already allocated to the relevant national programmes. No additional resources will be required for the operation of SA-GEMS/Water.

Risks

Two main risks linked to the sustainability of the programme have been identified, namely; 1) the SA-GEMS/Water representative can leave RQS and 2) the national monitoring programmes might not generate the required data.

The risk of loosing the programme representative is not as serious as the second risk identified above. The data transmission function can be performed by the Directorate: Resource Quality Information until a new representative has been identified.

The risk of the national programmes not performing to expectations can be avoided by implementing the quality management system discussed in chapter 4. This will not only minimize the risk for SA-GEMS/Water but also for the national monitoring programmes.

Recommendations and Conclusion

A long list of recommendations ranging from general to technical are made under the following headings, namely: general, monitoring sites, monitoring variables, sampling frequency, quality assurance and operational requirements. The recommendations are aimed at enhancing the ability of the national monitoring programmes to generate data that will help SA-GEMS/Water reach its objectives. Some of the main recommendations are summarized and listed below, namely;

- Extension of NCMP monitoring sites to the old Transkei area.
- Implementation of the proposed quality management system for the NCMP together with the appointment of a quality co-ordinator.
- Inclusion of the SA-GEMS/Water requirements in other relevant national monitoring programmes such as the toxicity monitoring programme.
- Inclusion of the two additional baseline monitoring sites in the NCMP.
- Inclusion of TSS monitoring at SA-GEMS/Water sites.
- The NCMP must follow up on selected sites where sampling performance is low.

As part of a new drive to establish national monitoring programmes, DWAF can now also contribute to the realization of Agenda 21 through the implementation of this SA-GEMS/Water design. The content of this document is proof that South Africa has the capability to supply credible and relevant data to the UNEP Global Water Quality Monitoring Programme as an integral part South Africa's national monitoring programmes.

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Chapter One: Background

1.1. Introduction

For over twenty years the Fresh Water Component of the Global Environmental Monitoring Programme (GEMS/Water) has been operating as the resource water quality monitoring and assessment arm of the United Nations Environmental Programme (UNEP). Their offices are situated at the National Water Research Institute in Burlington, Canada. The primary means by which GEMS/Water has been able to achieve its international position has been and continues to be, the direct interaction with key agencies and individuals in each participating country worldwide. By establishing a network of countries contributing data from national water quality monitoring programmes, GEMS/Water has built a global water quality database for rivers and lakes. Since 1998 the number of participating countries has increased to 101.

Monitoring programmes in participating countries contribute to approximately 700 stations worldwide. Data are stored in the GEMS/Water global database called GLOWDAT from where it is transmitted to various UN and other agencies for use in global sustainability reports. In partnership with the Global Runoff Data Centre (GRDC) in Germany, GEMS/Water has created a single port of entry for global water quality and quantity data requests from a large number of UN and other agencies.

After the World Summit in 2001 the United Nations Environmental Programme (UNEP) requested South Africa to take part in the GEMS/Water Programme. The Department of Water Affairs and Forestry (DWAF) approved the request and a representative from the Directorate: Resource Quality Services (RQS) was assigned to the project. GEMS/Water made it clear that they do not require DWAF to operationalize a new monitoring programme, but to make use of existing national monitoring programmes. It is, however, necessary to establish a programme for ensuring transmission of globally significant and credible data to GLOWDAT.

Global water assessments have in the past given extremely subjective views of the general freshwater quality in various countries, including South Africa. An example of such an assessment is the United Nations World Water Development Report (UNESCO, 2003). A Table in this report (taken from Esty and Cornelius, 2002) ranks 122 countries based on a single water quality indicator value for each country. The ranking of a number of countries (including SA ranked No. 47 and Belgium No.122) were based on data obtained through unknown means for sites that is completely unrepresentative of the general water quality of the countries. This has mainly been as a result of a lack of available good quality representative data for strategic global assessments. This is, therefore, an opportunity to make available data that will, on a global strategic level, ensure that representative water quality data from South Africa are used for producing global freshwater reports. In many instances the water quality assessments form only a small part of global sustainability reports.

One of the most important advantages for South Africa joining the GEMS/Water Programme is access to the GEMS Global Quality Assurance Programme. The national water quality laboratories now have the opportunity to take part in the international laboratory ring trials sponsored by GEMS/Water. The laboratories will be able to evaluate their accuracy against a number of international laboratories. Being part of the GEMS/Water Programme also give South African water scientists access to global water quality data and international expertise. GEMS/Water also offer a wide variety of training programmes on water quality monitoring.

1.2. Purpose of Document

In order for water quality managers and politicians on various levels to take management decisions regarding water quality and related issues, they need reliable information on which to base those decisions and actions. Much of the information needed will be generated by water quality monitoring programmes. The correctness of the decisions or actions being taken will, to a large degree, depend on the reliability of the information supplied. The reliability of the information in turn depends on the appropriateness of the design and operation of the monitoring programme (Van Niekerk, Harris and Kühn 2002).

The importance of producing a documented monitoring programme design cannot be over emphasized. This document clearly link the information needs with monitoring objectives, which in turn must be clearly linked to the design of the monitoring programme (Bartram & Balance, 1996 and Helmer, 1994). Good examples of well documented monitoring programmes are the National Microbial Monitoring Programme for Surface Water (NMMP) and the National Eutrophication Monitoring Programme (NEMP). Both these programme have well documented conceptual designs that, after implementation and testing of the designs, led to the production of operational manuals (DWAF, 2002a and DWAF, 2002b).

The purpose of this design document is, therefore, to address all design requirements and recommended design outcomes. The document contains the recommended sample sites, monitoring variables, sampling frequencies, operational requirements, data and quality assurance strategy.

1.3. Water quality monitoring and its application in South Africa

1.3.1 Water Quality Monitoring

It is not the purpose of this study to try and define the term "water quality monitoring". It is, however, important to clarify the context within which it will be used during this study. Most specialists in the field give their own definition of this term, for example:

- "Water quality monitoring is the effort to obtain quantitative information on the physical, chemical, and biological characteristics of water via statistical sampling" (Sanders et al, 2000).
- "The actual collection of information at set locations and at regular intervals in order to provide the data which may be used to define current water quality conditions" (Chapman, 1996).

- According to Chapman (1996), the International Standards Organization (ISO) defines water quality monitoring as follows: “the programmed process of sampling, measurement and subsequent recording or signalling, or both, of various water characteristics, often with the aim of assessing conformity with specific objective”.
- The South African Strategic Framework for National Water Resource Quality Monitoring (DWAF, 2004) defines water resources quality monitoring rather than water quality monitoring. The framework defines it as the acquisition of data, management & storage of data and the generation & dissemination of information on the physical, chemical, biological and ecological attributes of the water resource.

All four the above definitions are very generic and it will not be possible to use any of them as an objective for a specific monitoring programme. The specific objectives of a monitoring programme depend on the type of information required. Water quality information is generally required for one of five reasons, namely: 1) compliance auditing (including legal), (2) resource status and trend reporting, (3) assessment of fitness for use, (4) water quality objectives auditing, and (5) special studies (Van Niekerk *et al*, 2002). Each type of information required warrants a different approach to selecting sample sites, sampling frequencies, variables to be analysed and data analyses protocols.

It is also important to make the distinction between “water quality” and “water resource quality”. Water quality merely refers to chemical, physical and biological characteristics of the water component of the water resource. The water resource consists of not only the water component, but also other aspects of the aquatic ecosystem, such as riparian vegetation, water quantity, geomorphology, etc. As mentioned above, it is not the intention to try and debate the applicability of the terminology, but merely to indicate the importance of critically analysing information requirements and subsequently setting very specific monitoring objectives and design criteria (MacDonald *et al*, 1993). As a result of difficulty with global comparability only water quality as described above will be the subject of the SA GEMS/Water monitoring programme. Data on indices related monitoring such as the South African

Scoring System (SASS) are generally not considered in global sustainability assessments.

In general monitoring programmes function on three main levels, namely national level, catchment (regional) level and local level. The main objective of a national monitoring programme is to provide information on the status and trends of water quality in the country as a whole. Catchment (regional) monitoring programmes focus on the provision of information for catchment management purposes. The objective of local monitoring programmes is to fulfil the information needs of local organizations and groups. The level of detail (spatially and temporally) needed generally increases as the geographic area decreases. The three levels of monitoring are not necessarily independent as data and information from the various levels of programmes can feed into each other to help ensure more cost-effective data collection (Van Niekerk *et al.*, 2002). Data from the national monitoring programmes can in turn feed into international monitoring programmes.

Monitoring programmes generally consist of different components. Although the functions of these components in different programmes are normally similar the terminology used to describe them often differs. The terms "monitoring programme", "monitoring system" and "monitoring network" are often used in a contradictory manner.

- Sanders *et al., (2000)* define a "**monitoring network"** as the means through which data are acquired. The monitoring network (also known as data acquisition) includes sampling, measurements, sample analyses, sampling co-ordination, and the release of the data by the laboratories.
- A "**monitoring system"** or operational monitoring system is the component within the monitoring programme where the actual monitoring is done and information generated on a continual basis. The monitoring system comprises of the three main functions, namely the monitoring network, data storage & management, and information reporting. This can be seen as the complete production line.
- The term "**monitoring programme**" includes all aspects of monitoring, including the monitoring system (which includes the monitoring network),

design and revision, implementation, funding and management. This represents the overall structure responsible for the production of data or information. (Van Niekerk *et al.,* 2002). Figure 1.1 below illustrates the different components and their interaction within a monitoring programme.

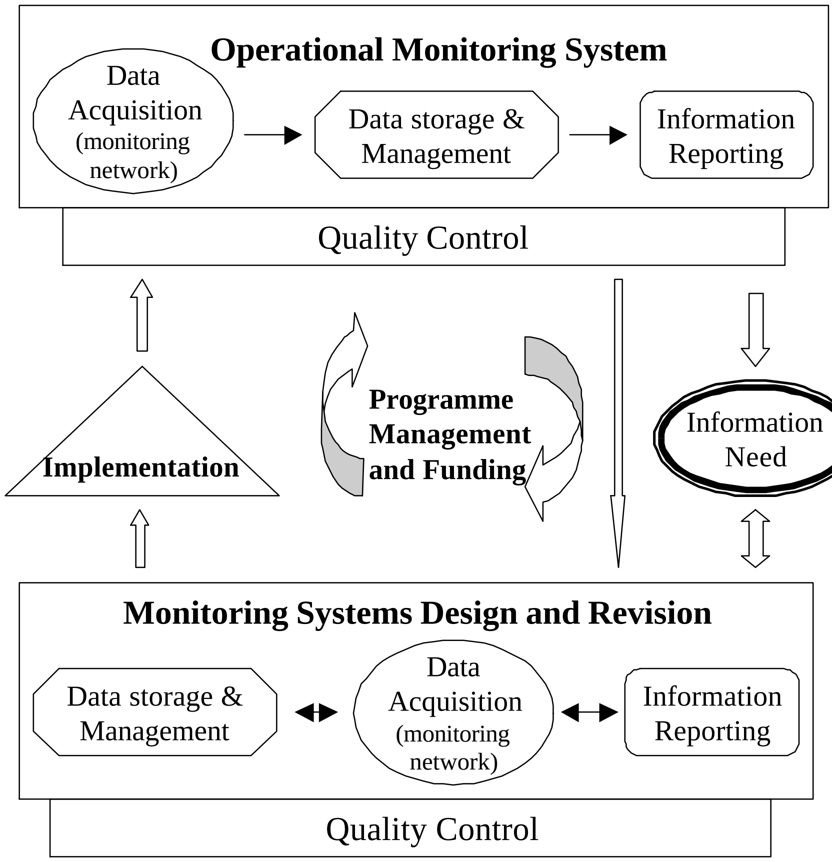


Figure 1.1.: Illustration of the various components within a monitoring programme (Van Niekerk *et al.*, 2002).

1.3.2 South African National Water Quality Monitoring Programmes

As mentioned above there are three tiers of water quality monitoring in South Africa, namely national, regional and local. In establishing the SA GEMS/Water monitoring programme a forth tier will be added, namely international. It is anticipated that this forth tier of monitoring will mostly extract the required data from the existing national monitoring programmes. It is, therefore, important to have a basic understanding of the status of national water quality monitoring programmes in South Africa.

Surface water flow-monitoring networks in South Africa grew from 23 in 1895 in the Cape and Transvaal Colonies to about 1200 at present. In addition, 275 reservoirs and 350 evaporation and rainfall stations are also monitored. In the early days, the South African approach to hydrological services was a spirit of make-do with minimal resources. Rapid growth in gauging stations after the two world wars necessitated a decentralized approach and by the end of the 1970s, four small regional hydrometric offices were operational as integral components of the Hydrology division in the Department of Water Affairs (Keuris, 2003). Up until 1970 monitoring of the quality of South Africa’s water resources was not seen as important.

In the 1970s the demand for water quality data beyond pH and conductivity increased. Previously the absence in national analytical facilities hampered the ability of the government to expand the number of monitoring variables beyond pH and conductivity. With the establishment of Hydrological Research Institute (HRI), which housed the national water laboratories, in 1972 the Department of Water Affairs and Forestry, then the Department of Irrigation, had the ability to start monitoring for a wider variety of water quality variables all over South Africa. Initially the main focus was on the suitability of resource water for irrigation purposes and nutrient levels at reservoirs and hydrometric gauging stations. The national monitoring programme run by the HRI expanded as new monitoring sites were added for research studies and a number of other ad hoc monitoring programmes. By the year 2003 this so-called National Chemical Monitoring Programme had grown into a large white elephant with no set monitoring objectives or a documented design.

In the early 1990s a growing need for a more structured comprehensive national monitoring network in terms biological, bacteriological, toxicity and radioactivity water quality information became apparent. To address those needs Chapter 14 of the National Water Act (Act 50 of 1998), in very generic manner, calls for national water quality monitoring programmes to be established.

Chapter 14 of the National Water Act (Act 38 of 1998):

Section **137**: " (1) The Minister must establish national monitoring systems on water resources as soon as reasonably practicable.

(2) The systems must provide for the collection of appropriate data and information necessary to assess, among other matters -

(a) the quantity of water in the various water resources;

(b) the quality of water resources;

(c) the use of water resources;

(d) the rehabilitation of water resources;

(e) compliance with resource quality objectives;

(f) the health of aquatic ecosystems; and

(g) atmospheric conditions which may influence water resources."

Section **138**: "The Minister must, after consultation with relevant -

(a) organs of state;

(b) water management institutions; and

(c) existing and potential users of water, establish mechanisms and procedures to co-ordinate the monitoring of water resources."

The Water Act requirements and the additional emerging water quality information requirements that preceded the Act led to the initiation of a number of additional national water quality monitoring programmes, namely:

- The National Microbial Water Quality Monitoring Programme (NMMP),
- The National Eutrophication Monitoring Programme (NEMP),
- The National Toxicity Monitoring Programme (NTMP),
- The River Health Programme (RHP) and
- The National Radioactivity Monitoring Programme (NRMP).

The reason for initiating a number of standalone monitoring programmes was because of the nature of the different monitoring variables, which requires differently located monitoring sites, different monitoring techniques, sample shelf life, levels of skills etc., which in turn requires different monitoring programme designs. Table 1.1 summarizes key information of the individual national monitoring programmes.

Table 1.1: Key information on the design and status of the national water quality monitoring programmes

Programme	Design and status summary
National Chemical Monitoring Programme (NCMP)	**Design process:** The programme never went through an official design based on specific information requirements. It is a conglomerate of a number of historical monitoring programmes of which some is not required anymore. There is currently a drive to rationalize the programme based on very specific monitoring objectives. **Monitoring network:** Samples are taken mostly at existing gauging stations by hydrologist servicing the gauging stations and reservoirs. Samples are posted to RQS for basic salts analyses. The programme currently consists of approximately 800 monitoring stations. **Data management:** Data goes directly from the labs to the laboratory information system (LIMS) and then onto the current national water quality database called Water Management System (WMS). **Information reporting:** A very small percentage of the data produced by the programme over the past fifteen years has been used for generating useful water quality information. The first National Water Resource Quality Status Report (Hohls et al., 2002) was produced in 2002. It was, however, difficult to select the relevant monitoring stations, as the monitoring network was not properly designed initially. **Programme management:** The programme is managed through monitoring management components of the WMS. **Current operational status:** The programme is currently being maintained with a strong drive towards streamlining the programme by going through a monitoring objective driven rationalization process. Compliance with scheduled sampling are medium to low.

National Microbial Monitoring Programme (NMMP)	**Design process:** The programme went through a well-planned and documented programme design. A Conceptual Monitoring Programme Design was produced by the IWQS in July 1996. The Conceptual Monitoring Programme Design was tested during a pilot implementation study that commenced in January 1997 in two areas in KwaZulu Natal and Gauteng (a joint IWQS and CSIR venture funded partly by the WRC). Based on the said pilot study an NMMP Implementation Manual was produced (Murray, 1999). The NMMP Implementation Manual was revised in 2002 to reflect problems identified during the initial stages of implementation (DWAF, 2002). **Monitoring network:** The implication of the non-conservative behaviour of microbes (both pathogens and indicators of faecal pollution) is that it would be almost impossible, without large investments in resources, to sample at representative locations on a national "grid" to obtain an overall picture of the microbial quality of surface water resources in South Africa. The NMMP was thus designed to focus on potential high risk areas where there would be a high possibility of the water being faecally polluted and where it would pose a major risk to the health of water users in that area (Venter, *et al*, 1998). The main monitoring variable is either *E. Coli* or Feacal Coliforms depending on the capability of the laboratory. Samples are taken on weekly or bi-weekly basis and analysed at the closest laboratory that can be used. Samples must be kept cool and analysed within 12 hours. (DWAF, 2002). Local stakeholders such as local government, Department of Health (DOH), DWAF, etc., take the samples. **Data management:** The remote data entry facility of the WMS is not functional yet and as a result all external laboratories have to send the data via electronic mail to RQS where it is read into the WMS. All data are double checked before it is made available for download from the WMS. **Information reporting:** Each Water Management Area (WMA) receives a status report for their area every second month. A national annual assessment will be produced as soon as sufficient data are available. **Programme management:** Each WMA has a regional co-ordinator who is responsible for the day to day operation of the programme in their area. The regional co-ordinators all reports to the national co-ordinator who is ultimately responsible for programme as a whole. **Current operational status:** The programme has already been implemented in 11 WMAs and will be fully implemented in all 19 WMAs by 2008.
National Eutrophication Monitoring Programme (NEMP)	**Design process:** A large number of South African impoundments have being monitored since 1986 (Van Ginkel *et al.*, 2000). The monitoring programme was known as the Trophic Status Project. The NEMP, however, were only formalized after a complete redesign of the programme in 2000-2001. This culminated into the NEMP Implementation Manual (Murray et al., 2001).

	Monitoring network: The current focus is on reservoirs where samples are normally taken close to the dam wall. Samples are sent to RQS where they are analysed for total phosphate and Chl-a. Depending on the regional requirements more variables can be analysed for. In some instances visual monitoring are also performed. The samples are normally taken by the organization responsible for the operation of the reservoir. **Data management:** Data are normally fed directly into the LIMS from where it is send to the WMS. **Information reporting:** Annual regional reports and annual national reports are produced and distributed to all stakeholders. **Programme management:** As with the NMMP each WMA has a regional co-ordinator that is responsible for the day-to-day operation of the programme in their area. The regional co-ordinators all reports to the national co-ordinator who is ultimately responsible for programme as a whole. **Current operational status:** The programme is in the process of being implemented countrywide. 80 reservoirs have already been included in the monitoring programme.
National Toxicity Monitoring Programme (NTMP)	**Design process:** The first phase of the design process, namely: A Needs Assessment and Development Framework for a Tested Implementation Plan for the Initialization and Execution of the NTMP, has been completed (DWAF, 2003). The conceptual design stage is currently in the planning phase. **Monitoring network:** Not formulated yet. **Data management:** Not formulated yet. **Information reporting:** Not formulated yet. **Programme management:** Not formulated yet. **Current operational status:** N/A
National Radioactivity Monitoring Programme (NRMP)	**Design process:** As with the NTMP the first phase of the design process, namely the monitoring needs assessment, has been completed. The conceptual design phase is currently underway. **Monitoring network:** Not formulated yet. **Data management:** Not formulated yet. **Information reporting:** Not formulated yet. **Programme management:** Not formulated yet. **Current operational status:** N/A

National Aquatic Ecosystem Monitoring Programme (NAEMP) A.K.A River Health Programme (RHP)	**Design process:** The RHP was the first national monitoring programme that went through a well-planned design and implementation process. In 1996 the RHP design framework (Hohls, 1996) was produced, outlining the specific information requirements. A testing phase culminated into the River Health Implementation Manual (Mangold, 2001). **Monitoring network:** As with the NMMP, the nature of the variables being measured requires a very specific set of criteria for selecting of sample sites. As a result sites are more than often not situated the same as the other national monitoring programmes. Data from mostly *in situ* observations by specialists are used in a number of different indices, such as invertebrate index, fish index, riparian index etc. **Data management:** Unlike with the other national monitoring programmes the data produced by the RHP can not be accommodated by the WMS. All data from the RHP are stored on the Rivers Database. This is a direct result of the nature of the data derived from the biological surveys and indices. **Information reporting:** Reporting regularly on the state of the aquatic systems being monitored is regarded as priority by the RHP management team. A number of State of Rivers reports have already been produced. This is probably the most important factor leading to the success of the RHP. **Programme management:** The programme is currently implemented by all provinces or regional DWAF offices through mainly voluntary teams lead by a provincial champion. The provincial champions are co-ordinated through a national co-ordinator. **Current operational status:** The programme is currently undergoing review and being re-designed to be inline with the latest legislative requirements, the national monitoring framework (DWAF, 2004) and the DWAF 5 year monitoring plan. The programme has recently entered a phase called the National Coverage Phase during which it will be attempted to assess all major South African rivers.

The national monitoring programmes above were or are all being developed as separate entities by a number of different specialists. Initially there were no national monitoring framework within which these programme can be developed or can function. The lack of such a framework has led to inconsistency between programmes in terms of funding, management styles, integration of programmes, terminology, standardized quality control and auditing procedures etc. RQS has recognized the need for such a framework and is currently in the process of finalising the design of such a framework. The said framework will also help clarify the non-specific monitoring requirements of the National Water Act.

Chapter Two: Information Requirements and Monitoring Objectives

2.1. Introduction

The SA GEMS/Water monitoring network will feed into a more strategic (spatially and temporally) level of resource assessment than the national monitoring programmes and will, therefore, aim to, as far as possible, extract the relevant data from the national monitoring programmes. During the design process the national monitoring networks have been used as a basis for site selection, variable selection and data management. The number of sites is significantly less than for the national networks. However, where the existing national monitoring programme cannot accommodate the requirements of the GEMS design, recommendations have been made to amend those aspects of the relevant national monitoring programme.

In designing the monitoring programme a four step approach was used, namely, 1) determine information and data needs, 2) set monitoring objectives, 3) Determine monitoring programme design criteria based on monitoring objectives and data needs, 4) Design programme based on design criteria. Figure 2.1 illustrates the design approach that wis be used.

RQS has set one very specific guideline within which the SA GEMS/Water monitoring programme must operate, namely that the operational resources for this programme must be integrated with national monitoring programmes run by RQS, as limited additional funding will be available.

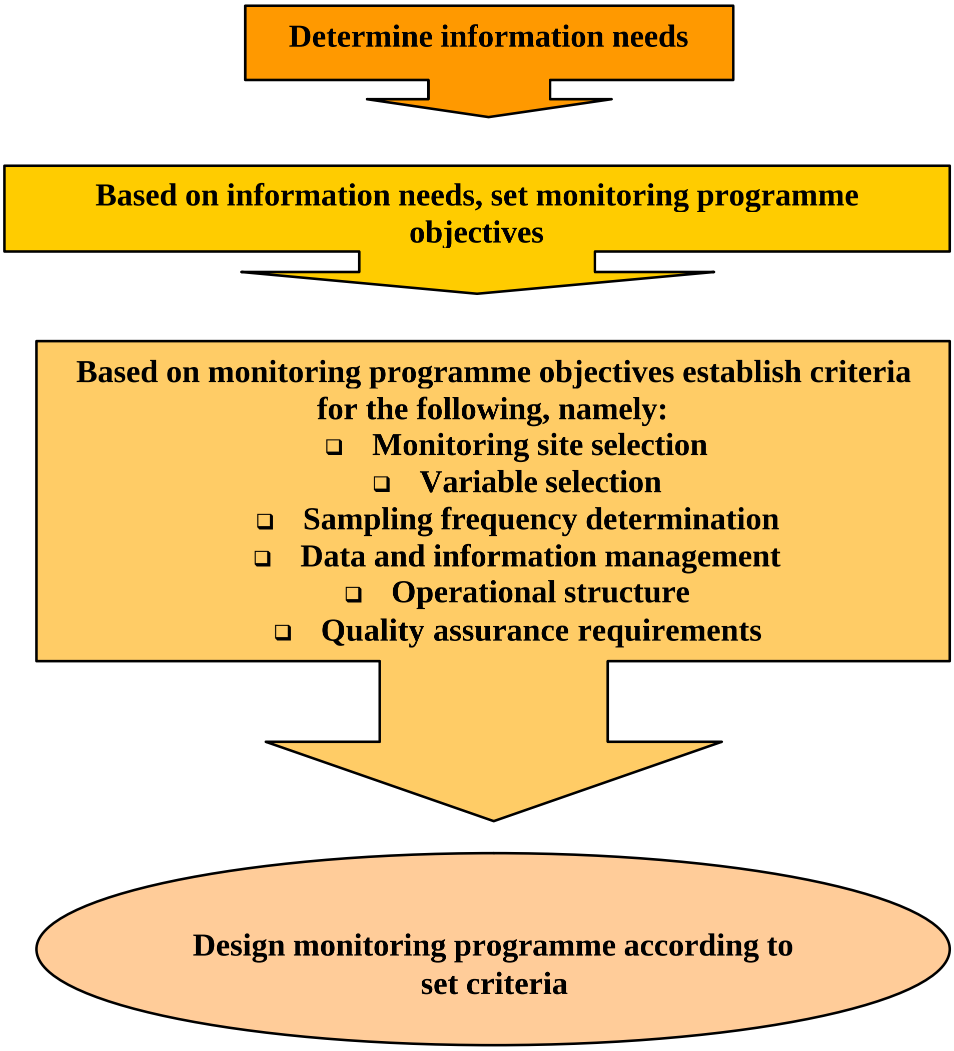


Figure 2.1: Four step design process used and documented in this conceptual design.

Of the 101 countries participating in this global monitoring programme, a large number have well designed and documented national monitoring programmes. However, it appears that none of those countries have a well documented design for their GEMS programmes. This might, therefore, be the first purposefully well documented design. The GEMS head office in Burlington, Canada did, however, produce an operational guide in 1992 to help countries select their sample sites and variables according to GEMS requirements (GEMS/Water, 1992). Although this document is outdated it still reflects, in a generic way, the main GEMS/Water requirements.

2.2. Evaluation of Information and Data Needs

In order to set specific objectives for the SA-GEMS/Water monitoring programme, one needs to clearly understand the requirements of the end users of this programme's product. The product can either be raw data, information derived from the data, or both. The importance of knowing exactly what the end users want cannot be over emphasized (Van Niekerk *et al.*, 2002)(Macdonald *et al.*, 1991). Often when starting with the design of a monitoring programme questions like "How do I collect a water quality sample?" or "How do I handle the data?" are asked, rather than asking "Why do we want to monitor?" (Sanders *et al.*, 1987). The purpose of this section is, therefore, to identify and analyze the information and data needs of the end users of the UNEP GEMS/Water monitoring programme.

In the past a number of different UN and other agencies have produced global and regional freshwater quality assessments, such as GEMS/Water, Global International Waters Assessments (GIWA), World Water Assessment Programme (WWAP), Global Environmental Outlook (GEO), Vital Water Graphics (VWG) etc. According to the UNEP/Division of Early Warning Assessment's (DEWA) Water Assessment Strategy (July, 2002), the goal of all water assessment efforts is to ensure that there is water for all, as enshrined in Agenda 21 Chapter 18.7 ***"To satisfy the freshwater needs of all countries for their sustainable development"***. As the largest international environmental organization the UNEP put the above strategy in place for achieving the water assessment requirements for achieving this Agenda 21 goal. DEWA's mandate (UNEP/DEWA, 2002) is to;

- "Analyse the state of the global environment;
- "Assess global and environmental trends;
- "Provide policy advice, early warning and information on environmental threats; and

- "Catalyse and provide international cooperation and action, based upon the best scientific and technical capabilities available."

The proposed strategy aims to put a framework in place to strengthen links between the various global assessment bodies. The roles and responsibilities set out in the strategy are fairly vague, but it is clear that, as in the past, the GEMS/Water global monitoring network and database (GLOWDAT) will serve as the main data and information resource for future global water resource assessments. The SA-GEMS/Water monitoring programme, therefore, serves as the primary source of data that will be transmitted to the GLOWDAT. The various agencies including GEMS/Water will then utilize the data from the GLOWDAT to generate useful information in the form of global and regional water quality assessments. The GEMS/Water office in Burlington, Canada is responsible for the day-to-day operation of the global monitoring network, data quality assurance and data dissemination to other agencies. GEMS/Water works in partnership with the Global Runoff Data Centre in Koblenz, Gemany. Together they strive to create a single port of entry for global water quality and quantity data. Figure 2.2 illustrates this relationship between South Africa and global resource water quality assessments (Fraser *et al.,* 2001).

2.2.1. Information needs

Although each individual organization involved in global and regional freshwater assessments has its own specific reasons for doing the assessments, it has been found that the various assessments tend to produce the following types of information, namely (WHO, 1991);

- Information on the levels and trends in critical water quality indicators in freshwater resources;
- Information on natural freshwater qualities in the absence of significant direct human impact;
- Information on the fluxes (loads) of toxic substances, suspended solids, nutrients and other pollutants to the continent/ocean interfaces.

The most common global water quality issues that are being reported on by GEMS/Water, GIWA, GEO and the WWAP are as follows (GIWA, 2002; WWAP, 2002; VWG, (http://www.unep.org/vitalwater/); UNEP pops minutes, 2002)

- Nutrient loading,
- Salinity (Macro constituents and trace metals),
- Suspended solid transport,
- Faecal pollution (Microbiological),
- Persistent organic pollutants (POP) and
- Acidification

The SA-GEMS/Water monitoring programme will be supplying the raw data to GLOWDAT from where it will be used to generate a number of different information products by the various organizations mentioned before. It is, therefore, important to understand and document the types of data required to produce the information. It is not possible to cater for all the individual assessment body's data needs as new global assessments are initiated on a regular basis. The aim of the section below is, therefore, to establish a standard data package that must be produced by the programme in order to try and meet the needs of current and future global water quality assessments.

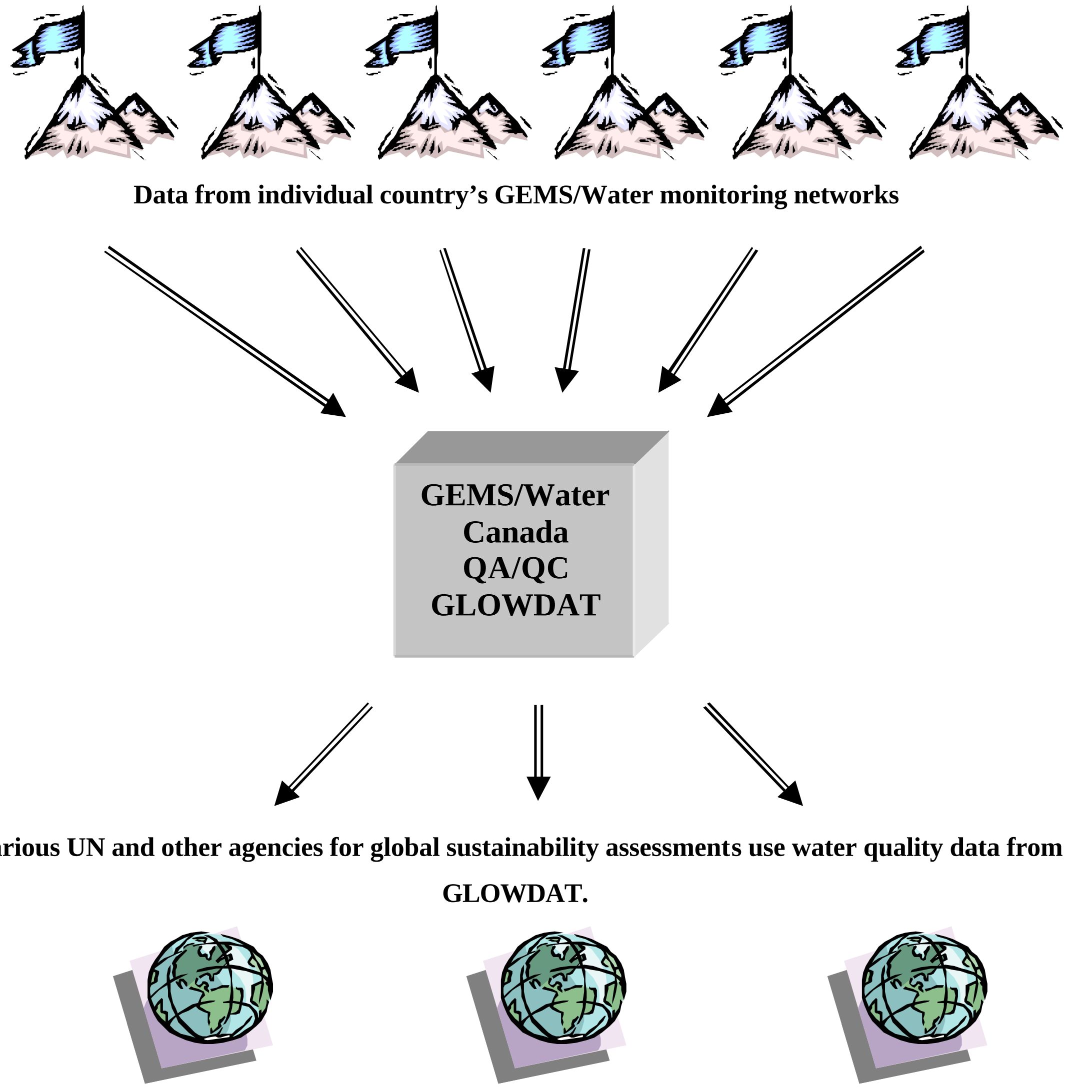


Figure 2.2: Data and information flows from individual countries to global assessments.

2.2.2. Data requirements

The aim of this section is to define the end product, namely data, of the SA GEMS/Water monitoring programme that will be transmitted to the GLOWDAT. Table 2.1 below gives a breakdown of the identified information requirements and a discussion on the implications thereof.

Table 2.1 : Breakdown and discussion of identified information requirements.

Information requirement	Breakdown	Data requirements
Information on the levels and trends in critical water quality indicators in freshwater resources;	"Level"	Quantitative water quality data must be produced to help determine status and changes.
	"Trends"	In order to statistically detect trends in water quality with confidence the data needs to comply with specific requirements. The detection of global and national trends will also require long-term data sets.
	"Critical water quality indicators"	The selected water quality variables should be sufficient to help detect the status and trends in nutrient loading, suspended solid transport, salinisation, faecal pollution and POPs. Although each assessment body uses there own indicators to assess the severity of the different types of water quality problems mentioned, the variables to be measured must be a standard set of variables.
Information on natural freshwater qualities in the absence of significant direct human impact.	"Natural freshwater qualities"	Data on the baseline water quality are needed for reference and natural trend detection purposes.
	"Absence of significant direct human impact"	The data should not be indicative of significant human impacts, but representative of un-impacted conditions.
Information on the fluxes (loads) of toxic substances, suspended solids, nutrients and other pollutants from	"Fluxes (loads)"	The water quality data for this requirement needs to be linked with flow data in order to produce loads.

major river basins to the continent/ocean interfaces.	"Toxic substances, suspended solids, nutrients and other pollutants"	The data produced must be of such a nature that it can at least be used for load calculations of POPs, suspended solids, nutrients and major salts.
	"Major river basins to the continent/ocean interfaces"	This implies that the data for this information requirement needs to be representative of the water quality that exits the globally significant catchments situated in South Africa.

Based on the discussion above the data requirements, for the GLOWDAT, that must be produced by the SA GEMS monitoring programme are formulated as follows;

- All data needs to be quantitative in nature.
- Long term-data sets must be produced.
- All data must be globally comparable.
- The data needs to meet the basic requirements for statistical trend and central tendency analyses.
- The dataset needs to contain data on the most common variables used to indicate the severity of the following water quality issues, namely nutrient loading, suspended solid transport, salinisation, faecal pollution, acidification and POPs occurrence.
- The dataset needs to contain data on the baseline (un-impacted) water quality that can be used for comparisons with impacted sites and natural trend detection.
- The dataset needs to contain water quality data, representing the freshwater outflow of globally significant catchments in South Africa to the ocean, that can be used for calculating loads of nutrients, major salts, suspended sediment and POPs to the ocean.

The above data requirements will be used in the next section to establish the SA GEMS monitoring programme objectives. The data requirements and objectives will then be used to design the monitoring programme.

2.2.3. Monitoring Programme Objectives

The setting of clear objectives for any project or programme is of extreme importance, as the objectives will give clear direction and set very specific boundaries for the development and operation of the programme (Vos *et al.*, 2000). It is also important that the clients of the monitoring programme (GEMS/Water) confirm that the defined objectives reflect their needs.

The following factors were considered in formulating the SA GEMS/Water monitoring programme objectives, namely;

- All data requirements identified in section 2.2. and
- the DWAF requirement that the operational resources for the SA-GEMS/Water monitoring programme must be integrated with existing national monitoring programmes being operated by RQS, as limited additional funding will be available for additional monitoring.

Based on the above requirements, two proposed versions of objectives for the SA GEMS/Water monitoring programme have been formulated as depicted in Figure 2.3 and Figure 2.4 below. The main distinction between the two sets of proposed objectives is that the first set (Figure 2.3) is very specific regarding the types of water quality issues for which monitoring data will be produced. Although those are the issues identified under the section describing the global information requirements, the issues of importance can change over time and with the SA GEMS/Water monitoring programme being anticipated to be a long term programme the data requirements from UNEP GEMS/Water might change over time. The second set of proposed objectives (Figure 2.4) is, therefore, more centred on the concept of adaptability with regard to the global water quality issues.

Both the proposed sets of objectives were presented to the UNEP GEMS/Water office in Canada for their comments. It was agreed that the more generic set of objectives as depicted in Figure 2.4 was to be used as the objectives for the SA GEMS/Water monitoring programme.

To provide the UNEP GEMS/Water programme with credible, globally significant and comparable data (producible by existing national monitoring programmes) on:

1) the levels of nutrients, suspended solids, major salts and POPs, that enters the ocean from the Orange River Catchment, for use in global river flux calculations;

2) the levels of variables required for the detection of trends in nutrient loading, suspended solids transport, faecal pollution and POPs in major catchments and impacted areas;

3) the levels of water quality variables at monitoring sites representing natural conditions in un-impacted areas.

Figure 2.3: First set of proposed objectives for the SA GEMS/Water monitoring programme

To provide the UNEP GEMS/Water programme with credible, globally significant and comparable data (producible by existing national monitoring programmes) on:

1) the levels of variables, indicative of the global water quality issues of concern, that enters the ocean from the globally significant South African catchments, for use in global river flux calculations;

2) the levels of variables required for the detection of trends in global water quality issues in major local catchments and impacted areas;

3) the levels of water quality variables at monitoring sites representing natural conditions in un-impacted areas.

Figure 2.4: Second more generic set of objectives that have been agreed upon to be the objectives for the SA GEMS/Water monitoring programme.

Chapter Three: Monitoring Network Design

3.1. Introduction

Before a monitoring network and structure can be proposed it is important that the criteria for sample sites selection, variable selection, sampling frequency determination and all other design issues are well defined. Specific design requirements ensure consistency and act as the backbone of the decision support system for the actual design phase. A record of decision, based on the design criteria, can then be documented during the design phase for future reference.

The design criteria are based on the following, namely;

- SA-GEMS/Water monitoring programme objectives (formulated in section 2.3);
- UNEP GEMS/Water Operational Guide (WHO, 1992);
- SA National Water Quality Monitoring Programme requirements;
- Workshop; and
- Other relevant literature i.e. Information from other participating countries.

The SA-GEMS/Water monitoring programme objectives together with the UNEP GEMS/Water Operational Guide (WHO, 1992) clearly distinguish between three different types of data requirements, namely;

- Global river flux to the oceans;
- General water quality status and trends (including impacted areas), and
- Baseline water quality.

As a result of the nature of the different types of data required, it is inevitable that the minimum requirements for the network design will differ.

There is also a clear requirement for both drainage-related (rivers) and storage-related (major reservoirs) water quality data. Each one of these resource types also requires a different approach towards designing the monitoring network.

The design of the monitoring network will, therefore, be dealt with separately for each of the three different data requirements in terms of each of the two resource types as indicated in Table 3.1. The design of the data management, operational structure and the quality assurance plan are addressed in chapters four and five.

Table 3.1: Monitoring network design outline.

	Monitoring Network Design					
	Sample site selection		Variable selection		Sampling frequency determination	
Data type requirement	Rivers	Reservoirs	Rivers	Reservoirs	Rivers	Reservoirs
3.2 Global river flux to the oceans						
3.3 General water quality trends, incl. impacted areas						
3.4 Baseline water quality						

- Indicates that reservoirs have not been considered for the specific type of data requirement.

3.2. Global River Flux to the Oceans

The specific programme objective that is addressed in this section is as follows, namely:

Objective:

To provide the UNEP GEMS/Water programme with good quality, globally significant and comparable data (producible by existing national monitoring programmes) on:

> *the levels of variables, indicative of the* ***global water quality issues of concern****, that* ***enters the ocean*** *from the* ***globally significant South African catchments****, for use in global river* ***flux calculations****.*

In this section the above programme objective will be addressed by selecting sampling sites, variables to be analyzed and a monitoring frequency based on the requirements of the objective.

3.2.1. Sample Site Selection

In order to ensure that the sample sites are positioned such that the samples or measurements taken at that point are representative of the system being monitored a two tiered approach (Sanders *et al.*, 2000 and Cavanagh, 1998) has been used, namely; Step 1) Selecting sites on a macro level. This step identifies catchments within which the sites should be placed and the approximate placement within the catchment; and Step 2) Selecting sites on a micro level. In this step the exact placement within the section of the river is specified.

Macro site selection:

It is clear from the objective being addressed that the sample site must be placed at the outflow of all globally significant catchments. The question is, however, how to select a globally significant catchment. It is estimated that approximately 60 to 70 global river flux monitoring sites will be required worldwide to ensure global coverage (WHO, 1992).

In South Africa four levels of catchments have been identified namely; primary, secondary, tertiary and quaternary (Midgley *et al.*, 1990). There are 22 primary catchments in South Africa, labelled A to X (Map 1). Each primary catchment has been divided into a maximum of 9 secondary catchments. Each of the secondary catchments consists of a maximum of 9 tertiary catchments. Each tertiary catchment has then been divided into a maximum of 12 quaternary sub-catchments. Map 2 shows the boundaries of the South African catchment hierarchy.

The catchment hierarchy in South Africa is well defined and it is important to understand the significance of this hierarchy in terms of water quality monitoring before our globally significant catchments can be identified. As discussed earlier in the report the national water quality monitoring programmes produces strategic information (both spatially and temporally) on the water resources of the country. This implies that the larger catchments are monitored over the long term to identify national water quality status and trends issues. The level of detail in the information being produced is lower than that being produced by catchment monitoring programme where high a level of detail is required for catchment management purposes. The level of detail in catchment monitoring programmes goes down to quaternary level (Van Niekerk, 2002). Figure 3.1 illustrates this concept.

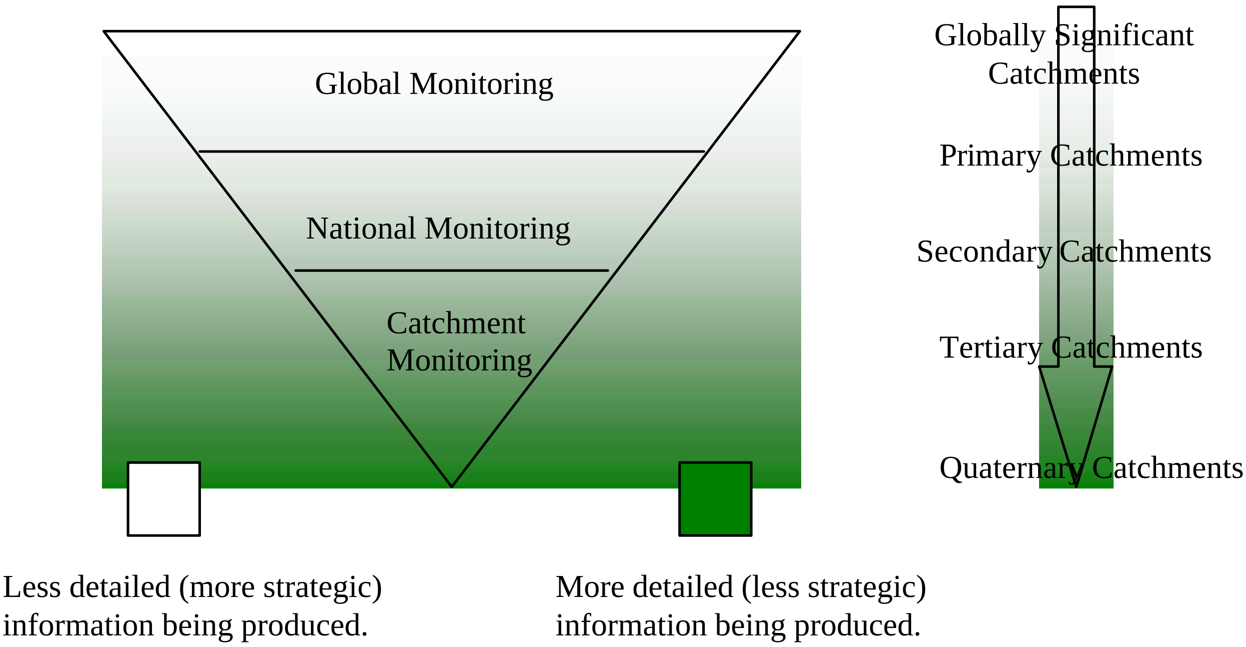
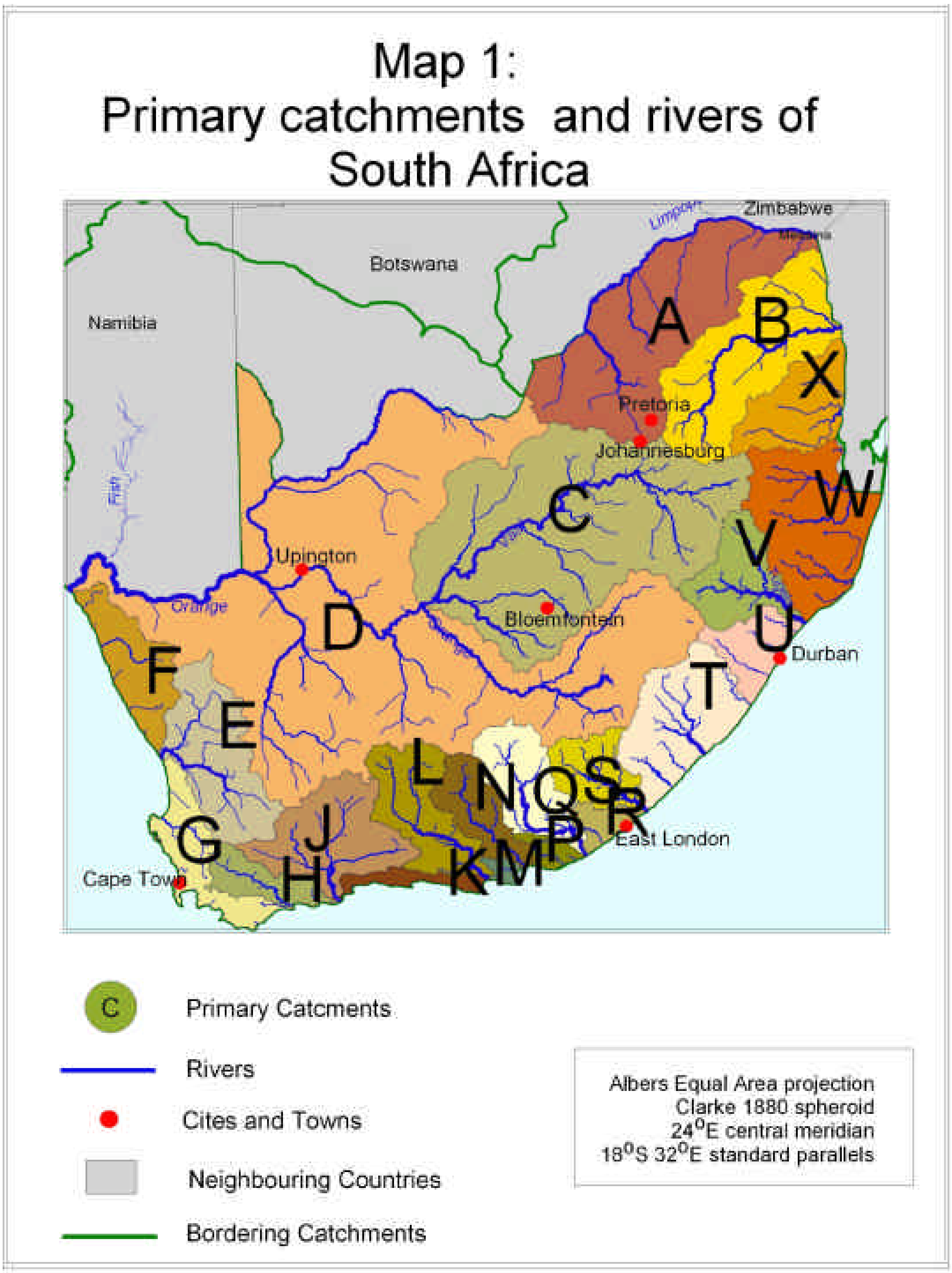
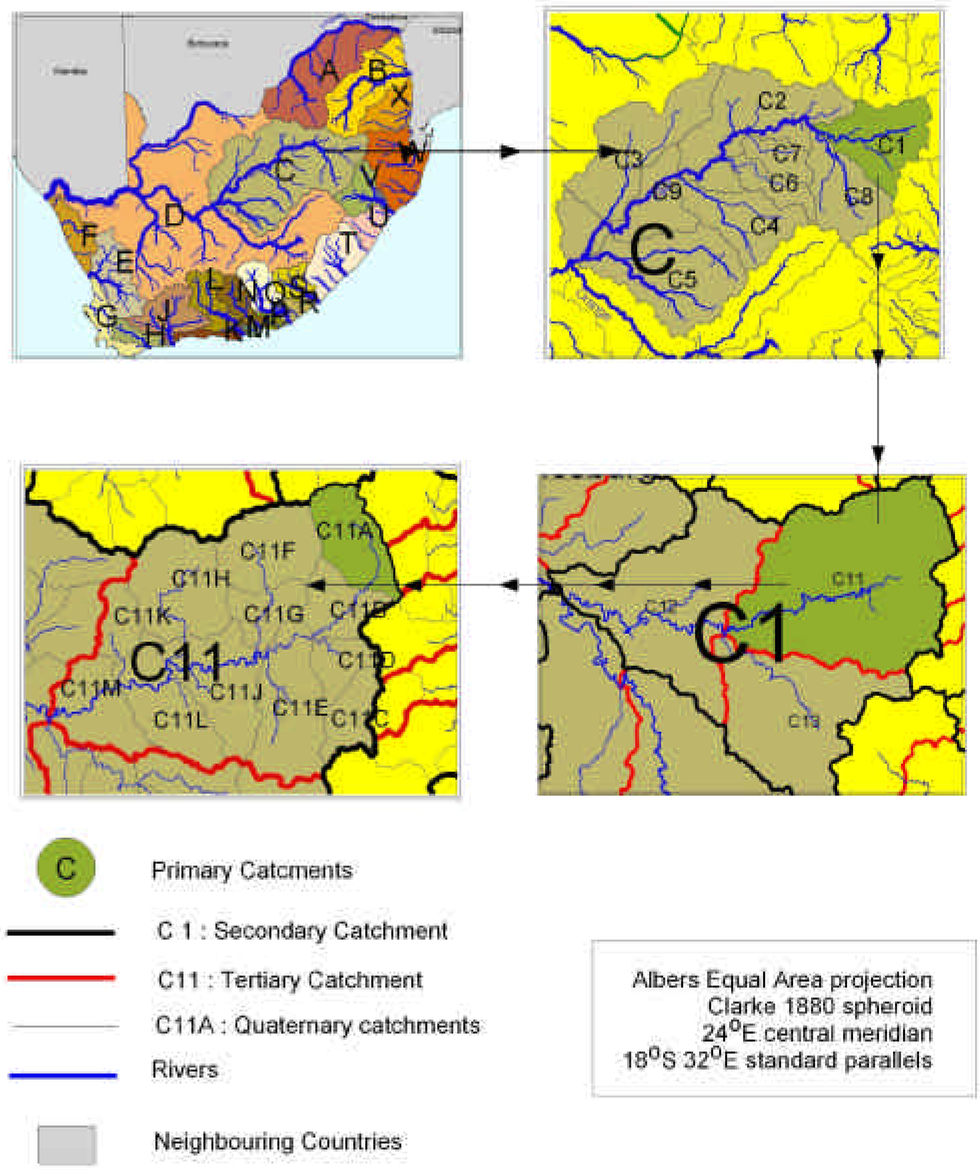


Figure 3.1: Linking catchment hierarchy with different levels of monitoring.


Map 1:
Primary catchments and rivers of South Africa
Zimbabwe
Botswana
Namibia
Orange
Upington
Pretoria
Johannesburg
Bloemfontein
Durban
East London
Cape Town
A
B
X
W
C
V
U
T
D
F
E
L
N
Q
S
R
P
G
J
H
K
M
C
Primary Catcments
Rivers
Cites and Towns
Neighbouring Countries
Bordering Catchments
Albers Equal Area projection
Clarke 1880 spheroid
24°E central meridian
18°S 32°E standard parallels

Map1

Map 2:
Catchment hierarchy of South Africa



Map2

The Global Runoff Data Centre (GDRC) produced a document in 1996 titled "Freshwater Fluxes from the Continents into the World Oceans, Based on Data of the Global Runoff Data Centre". In this report 161 monitoring stations situated at the exit of the world's major catchments were used. The GRDC has in the mean time updated this list to 181 river gauging stations draining into the world's oceans (www.bafg.de/grdc.htm). The UNEP Vital Water Graphics has identified 261 river basins (catchments) in the world of which they consider 26 to be major river basins. Africa contains 12 of the 261 rivers and 6 of the major river basins (www.unep.org/vitalwater/freshwater.htm). The Annotated Digital Atlas of Global Water Quality, produced by GEMS/Water (www.gemswater.org), uses a list of 82 major river basins of which 7 are in Africa. The 82 watersheds represent major world rivers, or smaller rivers that have regional significance. The river basins that have been identified for Africa as being globally significant are summarizes in Table 3.2 below.

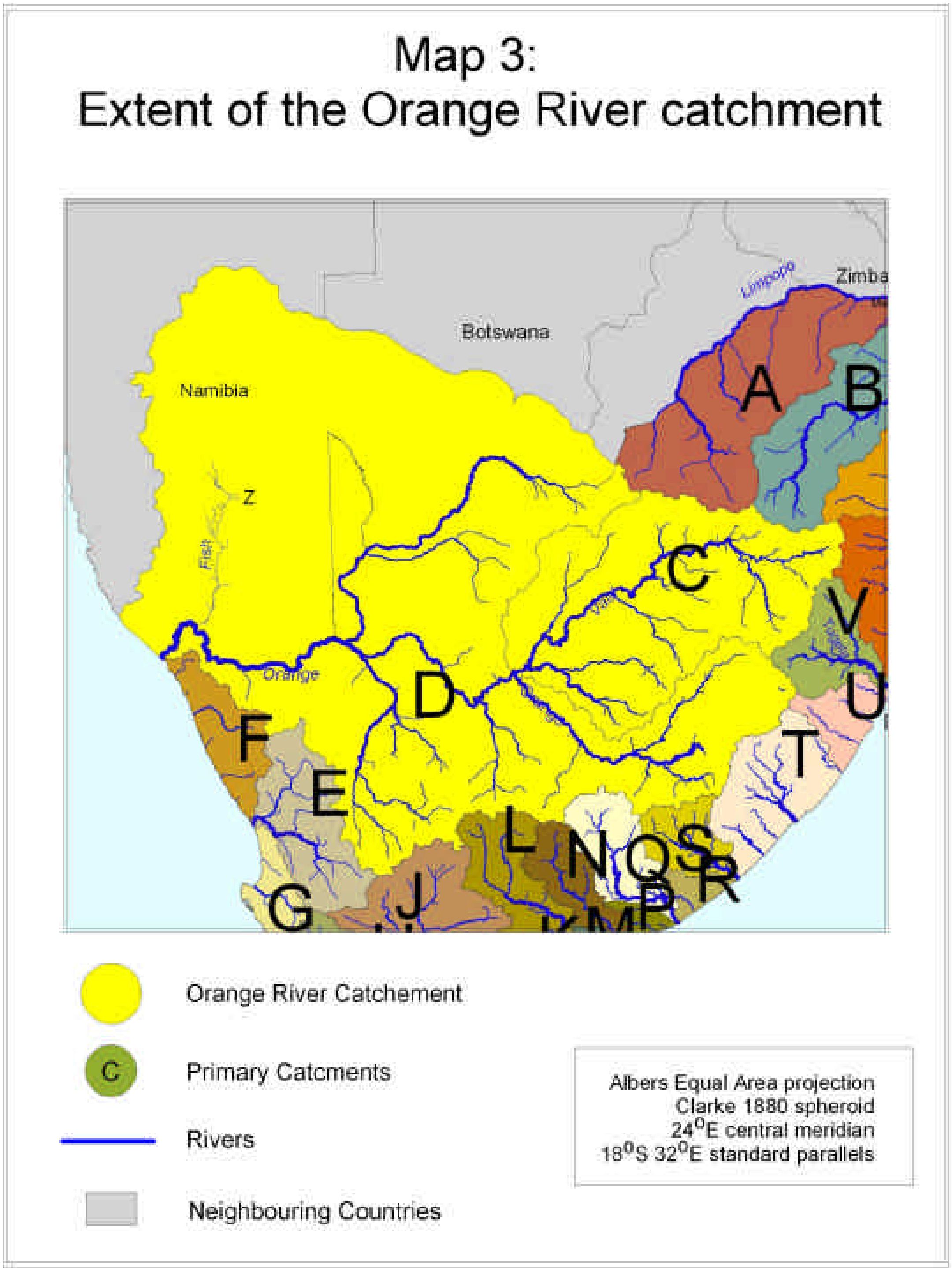
Table 3.2: Globally significant river basins in Africa as identified by GEMS/Water, Vital Water Graphics and the GRDC.

Globally Significant River Basins in Africa			
No.	**GRDC Basins**	**GEMS Basins**	**Vital Water Graphics**
1	Zaire	Chari	Senegal
2	Niger	Niger	Volta
3	St Paul	Nile	Niger
4	Sanoga	Orange	Chad
5	Kouilou	Senegal	Juba
6	Volta	Zaire	Turkana
7	Oueme	Zambezi	Ogooue
8	Gambie		Congo
9	Orange		Zambezi
10	Sebou		Okavango
11	Cross		Limpopo
12	Nyong		Orange
13	Tana		

Globally Significant River Basins in Africa			
No.	**GRDC Basins**	**GEMS Basins**	**Vital Water Graphics**
14	Ogooue		
15	Senegal		
16	Zambezi		
17	Limpopo		
18	Rufiji		
19	Juba		
20	Save		

It is clear from the Table above that the Orange River catchment is considered as a globally significant catchment by the largest global water resource assessment bodies. Although the Limpopo is also considered by two of the three assessment bodies the river mouth is not in South Africa and is therefore not considered as a globally significant South African catchment. The part of the Limpopo catchment covering South Africa has however been considered for trend monitoring later in this design document.

The Orange River catchment's drainage area covers South Africa, Namibia and Botswana, although a very small percentage of flow originates in Namibia and Botswana (Midgley *et. al.*, 1990). The Orange River catchment (Map 3) consists mainly of primary catchments C & D (South Africa) and catchment Z (Namibia/Botswana).



Map 3:
Extent of the Orange River catchment

Map3

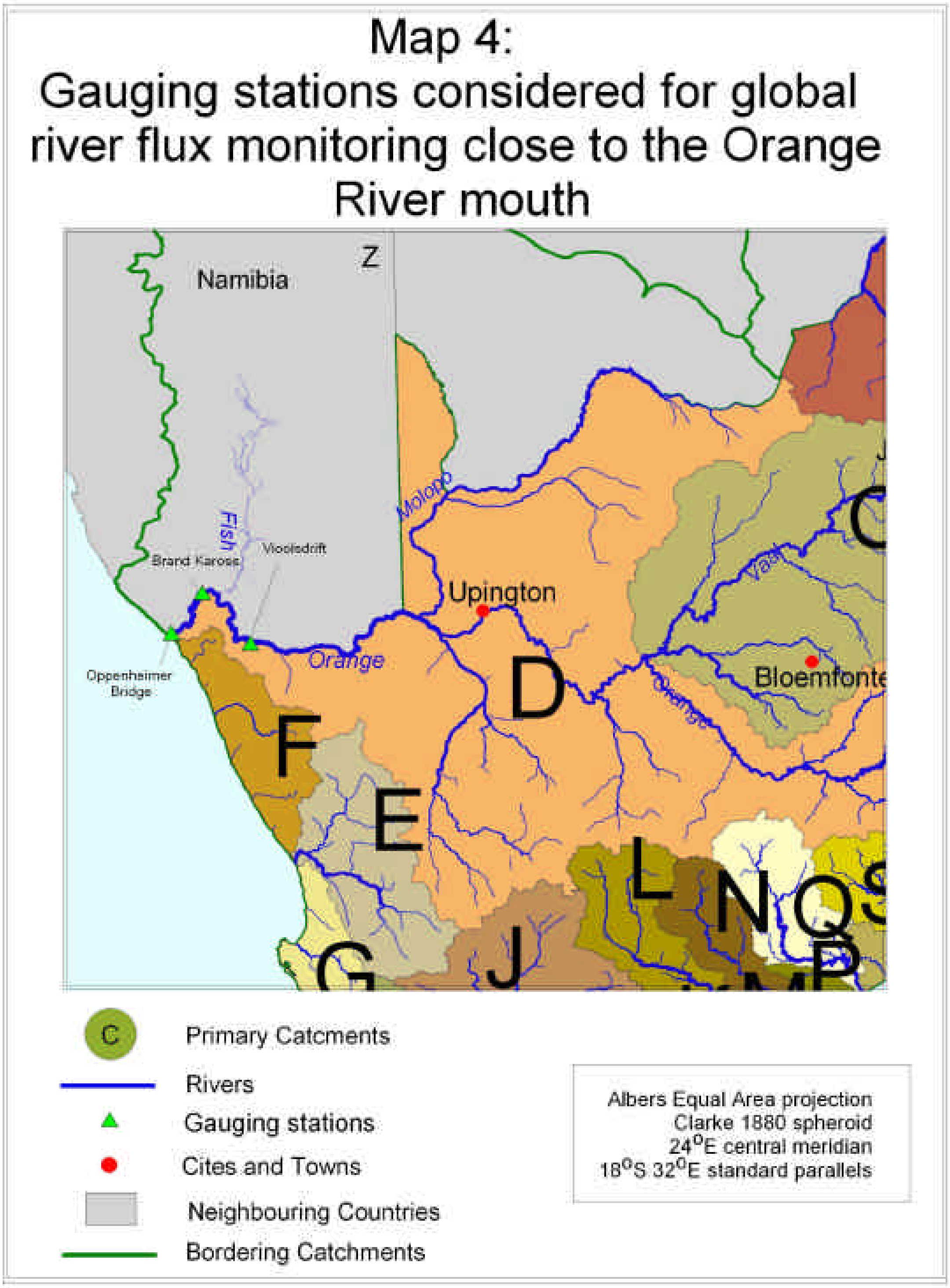
Micro site selection:

In order for the global river flux to the oceans monitoring to produce representative data and information, the monitoring sites need to be placed as close to the ocean as possible. The fact that it is a freshwater monitoring programme does, however, dictate that there should not be any tidal or marine influence on the water at the monitoring site. It is also important to ensure that there is complete mixing of the water column at the sampling site. This will ensure that one sample will be representative of the water column.

Normally when selecting a sample site for monitoring general trends in the water quality of a catchment one ensures that there is no immediate upstream impact as this might give the skewed impression of the general water quality in the catchments (Bartram and Balance, 1996). This is especially true for trend monitoring. However, the objective for global river flux to oceans monitoring is to determine what enters the oceans of the world. Immediate upstream impactors should, therefore, not influence the placement of monitoring sites for this type of monitoring.

The fact that the water quality data generated for that site will be used to determine fluxes of water quality variables to the oceans dictates that readily available water quantity data should be available for the same monitoring site. This implies that the monitoring site must be situated at an existing operational river flow gauging station. The flux calculations will be performed by international organizations and it is thus important that the flow data are available on the GRDC database in Germany. A gauging station from which data are transmitted to the GRDC (including SADC-HYCOS) on a regular basis should be used.

Other important aspects such as accessibility of the site, availability of samplers and logistical problems play a major role in ensuring a sustainable monitoring programme. Reliability of the sampling process at a specific station can be evaluated by determining the percentage of scheduled samples that were actually taken in the recent past.


Map 4:
Gauging stations considered for global river flux monitoring close to the Orange River mouth
Namibia
Z
Fish
Vioolsdrift
Brand Karoos
Oppenheimer Bridge
Molopo
Upington
Orange
Vaal
Bloemfonte
D
F
E
G
J
L
N
Q
C
Primary Catcments
Rivers
Gauging stations
Cites and Towns
Neighbouring Countries
Bordering Catchments
Albers Equal Area projection
Clarke 1880 spheroid
24°E central meridian
18°S 32°E standard parallels

Map 4

Based on the above, three gauging stations were identified as potential river flux samples sites (Map 4). An evaluation of the three was conducted to identify the most appropriate site. Table 3.3 below summarizes the evaluation process.

Table 3.3: Evaluation of three potential samples sites for global river flux monitoring.

Criteria	**Vioolsdrift**	**Brand Kaross**	**Oppenheimer Bridge**
GRDC gauging station? (SADC-HYCOS station?)	Yes (Yes)	No (Yes)	No(No)
Part off current national water quality network?	Yes	Yes	Yes
Sampling performance for water quality monitoring from Jan 2001 to June 2003. (number of samples scheduled : number of samples taken = percentage)	169:144=85%	34:4=11%	155:33=21%
Percentage coverage of Orange River catchment	87%	99.36%	99.4%
Situated close to river mouth	No	No	Yes
Tidal influence	Non	Non	Non

GRDC gauging station?

Viooldrift gauging station is the only station on the GRDC station catalogue and has been used for a global river flux report titled "Freshwater Surface Water Fluxes into the World Oceans, Marginal and Inland Seas"(GRDC, 1998). As with Brand Karros, Vioolsdrift is also a SADC-HYCOS station.

Sampling performance for national water quality monitoring network?

This is an extremely important issue as there is no use in setting a required sampling frequency if it is not going to be adhered to. The adherence to sampling requirements at Vioolsdrift is much higher than the other two stations witch is an indication that there is a stable monitoring structure in place.

Percentage coverage of Orange River catchment?

Although Vioolsdrift is situated close to Brand Kaross the percentage catchment coverage by Brand Kaross is much higher that Viooldrift. The reason for this is that the Fish River draining a part of the Z catchment from Namibia drains into the Orange River between Vioolsdrift and Brand Kaross. Although the percentage catchment area draining to Brand Kaross is larger, the average discharge at Vioolsdrift and Brand Kaross is fairly similar. This is as a result of the fact that the Fish River is a dry river with very little discharge into the Orange River (DWAF Hydrological Information System (HIS)).

Situated close to river mouth?

Although Oppenheimer Bridge is situated closest to the mouth it has not been considered as a GRDC or SADC-HYCOS site as a result of sedimentation problems at the gauging station. According to DWAF Directorate: Hydrological Services, the closest stations to the river mouth that could be considered for international use were Brand Karros and Viooldrift. According to them sedimentation problems closer to the mouth affect the performance of the gauging stations.

Based on Table 3.3 and the discussion above, **Vioolsdrift** has been identified as the most appropriate site for global river flux monitoring.

3.2.2. Variable selection

The monitoring programme objectives clearly state that "global water quality issues of concern" are the focus of global river flux to the oceans monitoring. The globally significant water quality issues have already been identified in section 2.2.1 (information needs) as being the following, namely:

- Nutrient loading,
- Salinity (Macro constituents and inorganic contaminants),
- Suspended solid transport,
- Faecal pollution (Microbiological) and
- Persistent organic pollutants (POPs).

Table 3.4 gives a comparison of the variables required by GEMS/Water for river flux calculations (WHO, 1992), variables currently being analysed for national monitoring programmes and variables that can be added to national programmes. It has been confirmed by the RQS laboratory heads and national programme co-ordinator that those variables can be included in existing national programmes.

Table 3.4: Consideration of variable for potential inclusion in SA-GEMS/Water monitoring programme for global river flux monitoring.

Gems/Water Variables	Used in Existing Monitoring Programme	Comment
General Water Quality		
Temperature	No	Can potentially be included
pH	No	Can potentially be included
Electrical conductivity	Yes	
Dissolved Oxygen	No	Field oxygen meter maintenance is a problem as local farmers are used for sampling
Total suspended solids	No	Can be included
Dissolved Salts		
Calcium	Yes	
Magnesium	Yes	
Sodium	Yes	
Potassium	Yes	
Chloride	Yes	
Sulphate	Yes	
Alkalinity	Yes	
Nutrients		
Nitrate plus nitrite	Yes	
Ammonia	Yes	
Total phosphate as P, unfiltered	Yes	
Ortho phosphate as P	Yes	
Organic Matter		
Chlorophyll *a*	Yes	
Dissolved organic carbon	Yes	
Particulate organic carbon	No	
Inorganic contaminants		For possible future inclusion in the National Toxicity Monitoring Programme. Up until that point it will be included in the GEMS/Water Monitoring Programme.
Aluminium (diss & tot)	No	
Arsenic (diss & tot)	No	
Boron (diss & tot)	No	
Cadmium (diss & tot)	No	
Chromium (diss & tot)	No	
Copper (diss & tot)	No	
Iron (diss & tot)	No	
Lead (diss & tot)	No	
Manganese (diss & tot)	No	
Mercury (diss & tot)	No	
Nickel (diss & tot)	No	
Selenium (diss & tot)	No	
Zink (diss & tot)	No	
Particulate matter		
Aluminium, particulate	No	
Arsenic, particulate	No	

Cadmium, particulate	No	For future inclusion in the National Toxicity Monitoring Programme. In the mean time it will be included in the GEMS/Water programme only for the global river flux station.
Chromium, particulate	No	
Copper, particulate	No	
Iron, particulate	No	
Lead, particulate	No	
Manganese, particulate	No	
Mercury, particulate	No	
Selenium, particulate	No	
Zink, particulate	No	
Organic contaminants (As per Stockholm Convention)		Will be recommended for inclusion in National Toxicity Monitoring Programme. Limited laboratory capability currently available. If this programme comes into affect it will only be in 2008.
Aldrin	No	
Chlordane	No	
DDT	No	
Dieldrin	No	
Endrin	No	
Heptachlor	No	
Hexachlorobenze	No	
Mirex	No	
Toxaphene	No	
Polychlorinated Biphenols (PCB)	No	
Polychlorinated dibenzo-p-dioxins	No	
Polychlorinated dibenzofurons	No	

Table 3.4 above summarizes the final list of variable that will be analyzed for at the proposed global river flux monitoring station. The list of organic contaminants in Table 3.4 will be considered by the NTMP for inclusion as this is a Stockholm Convention requirement of which SA is a signatory. After inclusion in the NTMP those variables must be added to the final set of variable as set out in Table 3.5 below.

Except for temperature and pH all analyses will be performed at the DWAF laboratories at Roodeplaat Dam. Temperature and pH measurements will be taken *in situ* by the sampler to ensure representative data. The analysis methods that will be used by the DWAF laboratory are listed in Table 3.5 below.

Table 3.5: DWAF laboratory methods with corresponding GEMS /Water method number

Water quality Variables	DWAF method number	Method	GEMS method number
General Water Quality			
Temperature	No	Electronic field measurement	02062
pH	No	Electronic field measurement	10301
Electrical conductivity	Method 0101101	Automated Determination of Electrical Conductivity	02041
Total suspended solids	Method 2003002	Dry weight method	10401
Total dissolved salts	Method 5010	Total Dissolved Salts by calculation	non
Dissolved Salts			
Calcium	Method 0020101	Automated Determination of dissolved calcium by Atomic Absorption	20103
Magnesium	Method 0012101	Automated Determination of Dissolved Magnesium by Atomic Absorption	12102
Sodium	Method 0011103	Automated Determination of Sodium with Flame Emission Spectroscopy	11103
Potassium	Method 0019103	Automated Determination of Dissolved Potassium by Flame Emission Spectroscopy	19103
Chloride	Method 0017104	Automated Determination of Dissolved Chloride using Ferric Thiocyanate	Check
Sulphate	Method 0016104	Automated Turbidimetric Determination of Dissolved Sulphate	16302
Alkalinity	Method 0010101	Automated Determination of Alkalinity using Bromophenol Blue	Check
Nutrients			
Nitrate plus nitrite	Method 0007107 Method 0007109	Automated Determination of Dissolved Nitrate by Cadmium Reduction Automated Determination of Dissolved Nitrite	Check
Ammonia	Method 0007106	Automated Determination of Dissolved Ammonium with Indophenol Blue	check
Total phosphate as P, unfiltered	Method 0015003	Automated Determination of Total Phosphorus as Phosphomolybdate	15405
Ortho phosphate as P	Method 0015104	Automated Determination of Dissolved Orthophosphate as Phosphomolybdate	15417
Organic Matter			
Chlorophyll *a*	Method 2002005	Chlorophyll *a* - Spectrophotometric Method	06711
Dissolved organic carbon	Method 0006101	Automated Determination of Dissolved Organic Carbon by UV Oxidation	check

Inorganic contaminants			
Aluminium (diss & tot)	Dissolved: SOP 2001	Dissolved Metals in Water - Sample Preparation for Ion Coupled Plasma	Check
Arsenic (diss & tot)			
Boron (diss & tot)			
Cadmium (diss & tot)			
Chromium (diss & tot)			
Copper (diss & tot)			
Iron (diss & tot)			
Lead (diss & tot)	Total: SOP 2002	Metals Extractable by Acid at Boiling Point - preparation for Ion Coupled Plasma	
Manganese (diss & tot)			
Mercury (diss & tot)			
Nickel (diss & tot)			
Selenium (diss & tot)			
Zink (diss & tot)			
Particulate matter			Check
Aluminium, particulate	No		
Arsenic, particulate	No		
Cadmium, particulate	No		
Chromium, particulate	No		
Copper, particulate	No		
Iron, particulate	No		
Lead, particulate	No		
Manganese, particulate	No		
Mercury, particulate	No		
Selenium, particulate	No		
Zink, particulate	No		

3.2.3 Sampling Frequency for Global River Flux Monitoring

The main purpose of determining an appropriate sampling frequency is to ensure that the statistical data parameters (such as mean or median) derived from a data set are as representative of the actual water system being monitored as possible while at the same time taking into consideration financial and other resource constraints.

The most important factor (statistical parameter) used in setting the ideal sampling frequency is the variability of the water quality within the resource of concern. There is for example generally less variability in the total dissolved solids (TDS) concentration in a river than in the level of faecal indicators such as faecal coliforms. This means that the level of faecal coliforms in the water might be extremely high one day and very low two days later where the TDS concentration might take weeks to change. The variance for each water quality variable (such as TDS, pH, phosphate, nitrate, etc.) differs from each other and are generally unique for individual water resources. The implication of the difference in variance between variables is that more frequent sampling is required for variables with a higher variance such as faecal indicators and total suspended solids (TSS). As a result a specific water quality monitoring site can have several optimum sampling frequencies (Cavanagh *et al*, 1998). The variance of a specific variable is normally a result of a combination of the specific chemical, physical, biological, hydrological characteristics of the water resource, pollution sources and other external influences.

The main factor that complicates the selection of a sampling frequency for the global river flux site is that the data will be used to assist in calculating global loads of total suspended solids (TSS) to the oceans. The problem is that TSS is extremely variable and in South African conditions an estimated 90% of annual TSS loads can take place in 10% of the time (Looser, 2003). The highest TSS loads take place during extreme storm events that can be over in hours or days (Moon and Dardis, 1998). This is normally the case during the rainy season (high flow period). The implication of this is that if a sampling frequency of once a month, as recommended by Harris *et al* (1992) for South African conditions, is adopted then there is a high probability that the monthly sampling events will miss the short periods when the biggest percentage of loads occur. The data will then give a false indication of the actual TSS loads.

The proposed monthly sampling frequency (Harris, *et al.*, 1992) was aimed at the South African National River Water Quality Monitoring Programme. The programme was, however, designed to be a status and trend monitoring programme where the variance in pH and TDS data over 13 years from seven stations were used to determine the frequency. The aim was to select the highest frequency where no serial correlation occurred. The use of statistical methods for central tendency and trend analyses such as Sen's Slope, Mann-Kendall trend analyses and Seasonal Kendal test requires that there must be no serial correlation (also known as auto correlation) in the data set. Chapman (1996) defines autocorrelation as follows, namely: "The presence of autocorrelation in a series means that a data point is significantly affected by the adjacent point. The basis for the series may be time or space". As traditional statistical methods are based on random non-correlating data points this can lead to statistical tests losing their validity. The implication thereof is that one should sample as often as possible to ensure that truly representative data are generated without sampling too often as to cause auto correlation in the data set and thereby loose validity of the statistical methods used to analyse the data. This can also be waste of resources.

The method used by GEMS/Water for calculating loads from globally significant catchments is purely based on the annual means of water quality variables and annual water discharge means (Annotated Digital Atlas of Global Water Quality produced by GEMS/Water (www.gemswater.org). The purpose of this section is, therefore, to determine a sampling frequency that will enable the data user to do an estimation of the mean with a prescribed degree of accuracy.

Based on the availability of historical data the method below, as proposed by Sanders *et al.* (2000) and Ward *et al.* (1990), was used to determine a single most appropriate sampling frequency. This was done for all variables except TSS. As a result of the unique seasonal behaviour, extreme variability and lack of historical data the sampling frequency for TSS was determined separately.

TSS

Based on the high variability of TSS weekly samples will be taken in order to build up a dataset that can be used to statistically determine the optimum sampling frequency. Weekly sampling is also recommended by the WHO (1991), GEMS/Water (1992) and Looser (2003). During a field visit to the current sampler at Vioolsdrift it was confirmed that the sampler would be able to take the sample on a weekly basis. The national laboratory at RQS also confirmed that they would be able to analyse the samples on a weekly basis. As a result of the distinct seasonality it is recommended that a stratified sampling approach be taken when statistically determining the sampling frequency. This means that the low flow and high flow periods be analysed separately in order to determine separate optimum frequencies. This should help limit resource use during low flow periods.

Sampling frequency (excluding TSS)

Based on the recommendations of Sanders *et al.* (2000) and Ward *et al.* (1990) the following steps were followed in determining an appropriate sampling frequency for data that will be used for estimations of means, namely:

1. Variables for which at least 5 years of data (Jan 1997 to Dec 2001) was available for Vioolsdrift were identified. Those variables were pH, Electrical Conductivity, Dissolved Phosphate as P (PO4-P), Magnesium (Mg) and Total Dissolved Alkalinity (TAL-Diss).

2. The five datasets were then tested for serial correlation using the Rank Von Neumann statistical procedure (Gilbert, 1987). The tests were performed for weekly, bi-weekly and monthly data sets. Table 3.6 below gives an indication of the high level of correlation that was found in the individual data sets.

Table 3.6: Serial correlation in data sets.

	Z_R for Weekly	Z_R for Bi-weekly	Rv for Monthly
pH	6.41 #	3.966 #	1.629
PO4-P	8.081 #	4.193 #	1.392
EC	11.51 #	6.505 #	1.372
TAL	11.92 #	7.469 #	1.143 #
Mg	11.1 #	6.127 #	1.592
Significant correlation (#) occurs where the calculated Z_R value is greater than the Z_{1-a}. Where a = 0.005 Z_{1-a} = 2.575. For datasets with less than 100 data points (monthly) the calculated Rv value must be lower than the Rva value to proof serial correlation. The Rva value where a = 0.005 is 1.334			

The high level of correlation in the datasets can to large extend be contributed to the catchment size. Large catchments are generally less reactive to hydrological change than smaller catchments (Bartam and Balance, 1996). This was already an indication that the ideal sampling frequency would be less than bi-weekly.

New data sets consisting of monthly data points were prepared for further analyses. Although TAL showed slight correlation even with monthly sampling it was decided that the general level of independence in the new data set would be sufficient for further analyses.

3. The third step was to test for seasonality in the data sets and to remove seasonality if required. Seasonal variation in water quality implies that the behaviour of water quality can be predicted over a period of twelve months. Seasonal variation can negatively impact on the accuracy of methods used to determine random variation in the data set. As the next step was the

determination of variance in the data sets it was important to identify and address the issue of seasonality in the data set.

The significance of seasonality was tested using the Kruskal-Wallis test (Helsel and Hirsch, 2002) at the a = 0.05 significance level. Two seasons namely April to August and September to March were used to separate data sets. The results are depicted in Table 3.7 below.

Table 3.7: Results of seasonality tests.

Variable	Kruskal-Wallis statistic (H)	Seasonal variation
PO_4	1.699	No seasonality
EC	3.648	No seasonality
TAL	0.440	No seasonality
pH	0.287	No seasonality
Mg	2.069	No seasonality
Significant seasonality occur where the calculated Kruskal-Wallis statistic (H) is higher than the tabulated chi-squared value (3.841) at a significance level of 5%.		

It was clear from the results indicated in Table 3.7 that no significant seasonality was embedded in the various datasets.

4. The next step was to use the prepared data sets to calculate the optimum sampling frequency. As the data produced by the monitoring at Vioolsdrift will mainly be used for calculating means, the formula below was used and is based on the selection of a sampling frequency which could result in a desired confidence interval around the annual mean of a specific water quality variable (Sanders, 1987).

$$N \geq \left[\frac{2 * t(confidence)}{Error}^2 * Variance \right]$$

Where: N = number sample required
Error: = required confidence interval around the mean
Variance = standard deviation^2

The calculation was based on the requirement that if the data are used for calculating means, there should be a 95% certainty that the calculated mean should not be more than 7.5% below or above the population (true) mean. Table 3.8 shows the results of the calculations.

Table 3.8: Results of N determinations

Variable	Sample mean	Sample variance	Confidence interval width, 15%	Number of sample required for a 95% confidence level.
EC	39.03	112.99	5.85	= 51
TAL	117.3	338.19	17.60	= 17
pH	8.383	0.01999	0.13 (1.5%)*	= 19
Mg	13.37	13.344	2.01	= 51
PO_4	0.03361	0.00032	0.005	= 194

* The confidence interval width for pH was set at 1.5% as result of the fact that pH is merely a anti log of the free hydrogen ion concentration in the water. As a result the variability of pH is much lower than the actual free hydrogen concentration.

It is clear from Table 3.8 above that each variable requires a different number of samples in order to calculate the sample mean with a high degree of certainty that the sample mean lies within a specified range around the true mean. The high number of samples required for PO_4 is a direct result of the variability in the laboratory analyses. The sample variance used in the calculation includes any influence that can increase or decrease the sample variance.

Although an optimum sampling number of samples has been calculated above, the reality is that the final data users will have their own requirements in terms of confidence level, confidence interval width and the number of years over which they might want to calculate the means.

As was proven earlier, monthly sampling is the highest sampling frequency that one can use to avoid serial correlation. This confirms the findings of Harris *et al.* (1994) that monthly sampling for South African rivers is the optimum to avoid serial correlation in the final dataset. The implication of not knowing what the final N required by the data users is, is that the highest possible frequency of **monthly** should be used. This is also the prescribed sampling frequency from GEMS/Water (WHO, 1992). The final data users do, however, need to know what the implications of monthly sampling will be in terms of the sampling period required for mean analyses.

It will for example not be possible to calculate the mean for different variables, using the same sample size (number years), with the same confidence interval width and confidence level. See example below.

Example

If an international organization wants to use this data set consisting of monthly samples to calculate the mean loads over a four year period using PO_4, TAL and EC data, the confidence in the calculated mean EC would be much higher than that of the mean PO_4 for a specified confidence interval width (15%).

From: $$N \geq \left[\frac{2 * t(confidence)}{Error}^2 * Variance \right]$$

T(confidence) can be derived as follows:

$$t(Confidence) = \frac{Error}{2} \sqrt{N / Vairance}$$

Where N = 4 * 12 (months) = 48
A dataset consisting of 48 samples will be used for EC, TAL and PO_4.
Variance from Table 3.8 for each variable.
Confidence interval width (error 15%) from Table 3.8 for each variable.

From the above formula the confidence level can be calculated for each of the variables as depicted below:

EC: Confidence level = 95%
TAL: Confidence level = 99%
PO_4: Confidence level = 70%

It is clear from the above that it is not possible to have the same confidence in the calculated means for different variables over the same time period. The data users should take this into account when using the data.

3.3. Global Water Quality Trend Monitoring

The objective that will be addressed in this section is as follows, namely:

Objective:
To provide the UNEP GEMS/Water programme with good quality, globally significant and comparable data (producible by existing national monitoring programmes) on:

> *the levels of variables required for the detection of* ***trends*** *in* ***global water quality issues*** *in* ***major local catchments & impoundments*** *and* ***impacted areas****.*

In this section, as in section 3.2, a specific programme objective will be addressed by selecting sampling sites, variables to be analyzed and a monitoring frequency based on the requirements of the objective.

The data generated through monitoring at the identified trend stations will be used to detect long-term global changes (trends) in water quality relating to a variety of pollution sources and land uses (WHO, 1992 and Fraser, 2003). This applies to major rivers and dams. The data may also be used for water quality status determination.

Cavanagh, *et al.* (no date) describes water quality trend monitoring as a commitment that extends over a long period (minimum 10 years) to ensure that true trends are detected. They also emphasize the requirement for consistency in terms of sampling frequency, location, time of day samples are collected and analytical techniques that are used. It is, therefore, extremely important to put as much effort as possible into the initial network design and to ensure that all the programme requirements are strictly adhered to throughout the monitoring period.

The seven water quality issues that were identified by GEMS/Water as globally significant for trend monitoring are:

- Organic wastes from municipal sewage discharges and agro-industrial effluents.
- Eutrophication of surface waters as a result of point and non-point input of nutrients and organics.
- Irrigation areas which are threatened by salinization and polluted irrigation return waters.
- Agro-chemical use, fertilizers and pesticides leading to surface water contamination.
- Industrial effluents containing a variety of toxic organics and inorganics
- Mining effluents and leachates from mine tailings affected surface water on a large scale.
- Acidification of lakes and rivers resulting from the long-range atmospheric transport of pollutants.

The above global water related problems are also a fair reflection of the general water quality issues in South Africa. The SA-GEMS/Water trend monitoring network has therefore been designed to supply data representing all the above global water issues in order to help track global trends in those issues and at the same time give a fair reflection (on a very strategic level) of the spatial variation in water quality.

One of the most important aspects that was considered during the design was the existing national monitoring networks. Although there are some aspects, such as monitoring of organic pollutants, which are not currently addressed by the national networks, the existing monitoring networks could sufficiently support the recommended SA-GEMS/Water trend monitoring network for rivers and dams.

This section has been subdivided as follows;

Section 3.3: Global Trend Monitoring

3.3.1: Sample site selection

River network

Dam network

3.3.2: Variable selection

River network

Dam network

3.3.3: Sampling Frequency

River network

Dam network

3.3.1. Sample site selection

One of the implications of the SA-GEMS/Water monitoring programme supplying data to the global monitoring programme is that it is very strategic in terms of spatial distribution of sample sites. The current number of sites globally is approximately 900 distributed over more than 100 countries (UNEP, 2004). This comes to an average of about 8 sites per country. In reality some countries have 20-30 sites where others only have 1 site. It mainly depend the country's drainage regime, commitment and available capacity.

The challenge, therefore, was to identify a small number of sites, compared to the 800 sites in the national chemical monitoring network that would be sufficient for tracking long term trends in the abovementioned global water quality issues.

The only truly objective way to select the sample sites was to make use of a combination of physical data and the extensive pool of tacit knowledge embedded in the minds of water quality managers and scientists that have been involved in national and regional water quality monitoring over many years. The following steps were followed during the sample site selection process, namely;

i. Draft criteria for sample site selection were established.
ii. A workshop was held to finalise the criteria and based on the criteria propose the appropriate sample sites. The combined number of years experience in the operation and design of regional and national monitoring programme at the workshop was more than 200 years. The proposed sites were then reviewed by the GEMS/Water Director and Programme Manager in Canada.

iii. The areas represented by the identified monitoring sites were then superimposed on the seven water quality management regions as delineated by Dallas, *et al.* (1998) to confirm that placement of the sites are representative of the spatial variance in water quality in South Africa.

iv. The proposed monitoring sites were then discussed with the regional water quality managers to ensure full objectivity.

The final criteria used and identified sample sites are discussed in the sections below.

River network

During a specialist workshop held on 17 February 2004 criteria for the identification of river trend sites the following guidelines were agreed on and used, namely;

- Sites had to represent the drainage from medium sized catchments (WHO, 1992). For trend monitoring, GEMS/Water typically views a large catchment as > 100 000 km^2 and a small basin typically as < 10 000 km^2. Medium sized catchments are, therefore, assumed to be < 100 000 km and > 10 000 km^2. In the South African catchment hierarchy the highest level of catchments, namely the primary catchments, falls within this range. On a spatial scale, this is more strategic than the recommended use of tertiary catchments for the National River Water Quality Monitoring Assessment Programme (Harris, *et al*, 1994) and the National Water Quality Assessment (Hohls, *et al*, 2003) that also used tertiary catchments as a basis for sample site selection.

- All stations must be placed at or close to existing flow gauging stations. It is generally believed that no meaningful assessment of water quality data is possible without associated hydrometric data (Chapman, 1996). The gauging stations should, as far as possible, be SADC-HYCOS or Global Runoff Data Centre (GRDC) stations. This enables the GLOWDAT to extract hydrometric data from the GRDC database in Germany (Personal request from the GEMS/Water Programme Manager (A Fraser) in Canada).

- In the event where a choice had to be made between a site that contributes hydrological data to the SADC-HYCOS project and a site at a gauging station where historical water quality data is available, the GEMS/Water office in Canada requested that the site with historical water quality data be selected.

- Where a dam is situated at the outflow of a catchment the site had to be placed at the inflow or upstream of the dam. This would prevent the dam from impacting on the characteristics of the catchment runoff water.

- Sites did not have to be placed in all primary catchments. This specifically applies to smaller coastal catchments.

- The sample site network should enable long term monitoring of all the water quality issues mentioned below. One trend station can be placed to cover a single water quality issue or a combination of issues. It will not be possible to cover all areas where water quality problems occur, but the most critical areas in the country should be covered.

    - Organic wastes from municipal sewage discharges and agro-industrial effluents.
    - Eutrophication of surface waters as a result of point and non-point input of nutrients and organics.
    - Irrigation areas which are threatened by salinization and polluted irrigation return waters.
    - Agro-chemical use, fertilizers and pesticides leading to surface water contamination.
    - Industrial effluents containing a variety of toxic organics and inorganics.
    - Mining effluents and leachates from mine tailings affected surface water on a large scale.
    - Acidification of lakes and rivers resulting from the long-range atmospheric transport of pollutants.

Based on the above guidelines a total of 16 river trend sites were identified at the workshop. An additional two stations were added based on the recommendations of the GEMS/Water Director's review comments. Table 3.9 below lists the sites and should be viewed together with Map 5

Table 3.9: Proposed river trend monitoring sites.

Site name	WMS ID number	Primary catchment	Water management regions
Trend stations for drainage of the interior of South Africa (Orange and Vaal river systems).			
D8H003Q01 At Vioolsdrift on Orange	101888	D	Arid interior Upper Orange/Vaal
D3H008Q01 at Marksdrift on Orange River	101824	D	Arid interior Upper Orange/Vaal
C9H024Q01 At Schmidtsdrift (Weir) on Vaal River	101770	C	Upper Orange/Vaal
C2H007Q01 At Pilgrims Estate Orkney on Vaal River	90618	C	Upper Orange/Vaal
Trend stations for drainage of catchments through neighboring countries into the ocean. Primary catchments A (Limpopo river), B (Olifants river) and X (Komati river).			
A2H0012Q01 At Kalkheuwel on Crocodile River	90164	A	North East
A5H006Q01 At Botswana Sterkloop on Limpopo River	90340	A	North east
A7H008Q01 Downstream of Beit Bridge on Limpopo River	90375	A	North East
B7H007Q01 At Oxford on Olifants River	90503	B	North East
X2H036Q01 At Komatipoort Kruger National Park on Komati River	102979	X	North East
Trend stations for catchments in the coastal regions of South Africa			
V5H002Q01 At Mandini on Tugela River	102779	V	East Coast
U2H055Q01 At Inanda Location Egugwini on Mgeni	87822	U	East Coast
S7H004Q01 At Area 8 Springs B on Groot-Keirivier	102568	S	Eastern Cape Drought Corridor
R2H027Q01 At Mhlabati Needs Camp on Buffalo River	102522	R	Eastern Cape Drought Corridor
Q9H018Q01 At Matomela's Reserve Outspan on Great Fish River	102487	Q	Eastern Cape Drought Corridor
H7H006Q01 At Swellendam on Breë River	102119	H	Southern and Western Coast
G1H036Q01 At Vleesbank Hermon Bridge on Berg River	101939	H	Southern and Western Coast

Site name	WMS ID number	Primary catchment	Water management regions
E2H003Q01 At Melkboom on Doring River	101903	E	Southern and Western Coast Arid Interior

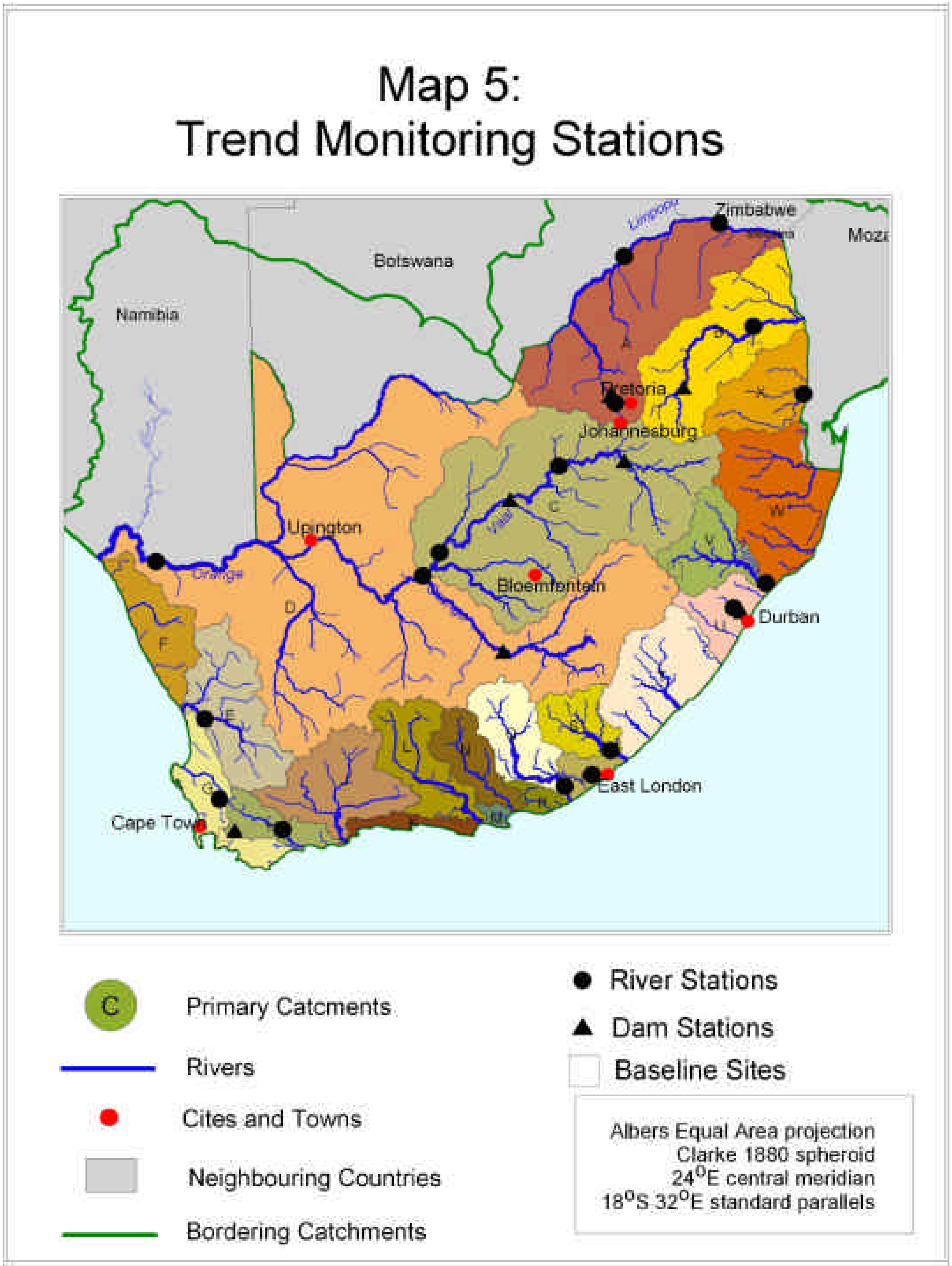
It is important that monitoring at these sites not only represent runoff from impacted catchments, but also natural variation in water quality on national (spatial) scale. The sites were therefore superimposed on the seven Water Quality Management Regions (WQMR) (Dallas, *et al.* 1998). The delineation of the seven WQMR were based on chemical water quality data and refined using the Bioregions as proposed by Brown *et al.* (1996). All seven WQMRs are fairly represented (see Table 3.9 above).

The next step was to perform an audit of the sampling performance of the National Chemical Monitoring Programme (NCMP) in order to determine whether sampling are performed as scheduled at the sites identified in Table 3.9 above. As indicated in Table 3.10 below the number samples taken for macro constituents were generally lower than the number of macro samples that were scheduled to be taken for the period Jan 2000 to Dec 2003. This issue needs to be addressed by the NCMP to ensure that the sampling frequency prescribed in this section will be adhered to. Sites of particular concern are C9H024Q01, A5H006Q01, A7H008Q01, B7H007Q01, H7H006Q01, G1H036Q01 and E2H003Q01.

Table 3.10: Sampling performance (taken:scheduled = percentage) for identified river trend sites from Jan 2000 to Dec 2003.

Site name	Sampling performance	Site Name	Sampling performance	Site name	Sampling performance
D8H003Q01	169:195 =87%	A7H008Q01	35:52 =67%	R2H027Q01	29:31 =93.5%
D3H008Q01	183:200 =91%	B7H007Q01	77:184 =42%	Q9H018Q01	104:105 =99%
C9H024Q01	69:172 =40%	X2H036Q01	178:190 =94%	H7H006Q01	25:49 =51%
C2H007Q01	201:206 =98%	V5H002Q01	44:49 =88%	G1H036Q01	113:206 =55%
A2H012Q01	205:209 =98%	U2H055Q01	Not available	E2H003Q01	58:194 =30%
A5H006Q01	28:52 =54%	S7H004Q01	48:56 =86%		

In general the sample sites are well all distributed geographically. The old Transkei area is, however, not well represented as a result of a lack in active national monitoring sites in that area. It is recommended (see chapter six) that this area be given special attention during the revision of the NCMP. SA-GEMS/Water requires a site in the lower reaches of the Mzimvubu River as a minimum.



Map 5

Dam/Reservoir Network

The main guideline, used at the site identification workshop, to identify dams for inclusion in the global monitoring network was the dam's strategic importance (economically and socially) in terms of water use. The spatial distribution of the dams in South Africa was also taken into account. A total of six dams were identified during the workshop. Based on comments from the GEMS/Water Director in Canada the Hartebeespoort Dam was also included in the list of Dams. Table 3.11 below lists the dams (with reasons for inclusion) and should be viewed together with Map 5. The specific monitoring site that was identified for each dam are the sites used for National Eutrophication Monitoring Programme and the National chemical Monitoring Programme.

Table 3.11: Dams proposed for inclusion in the GEMS/Water Monitoring Programme

Site name	WMS site ID	Reasons for inclusion
A2R001Q01 Hartbeespoort Dam on Crocodile River	90240	Although the Hartbeespoort Dam was not identified as being of strategic importance to regional economy it was included on the request of the GEMS/Water. The dam is one of the most Hypertrophic dams in the world and is currently being investigated for potential rehabilitation options. The Dam is also extensively used for irrigation and regulates water for downstream irrigation.
C1R001Q01 Vaal Dam on Vaal River: near dam wall	90604	The Vaal Dam was identified as the most strategically important dam in South Africa. It was originally designed to serve the reef complex and provide water to the Vaal/Harts irrigation scheme. Currently it is being extensively utilized by Rand Water for domestic and industrial water supply purposes to Gauteng, the economic hub of South Africa.
C9R002Q01 Bloemhof Dam on Vaal River: near dam wall	101774	Bloemhof Dam plays an important role in relieving the pressure on the Vaal Dam downstream of the Vaal Dam. The main purpose of the dam is to store and regulate water for irrigation

		(including the Vaal-Harts scheme) purposes downstream.
U2R004Q01 Inanda Dam on Mgeni River: near dam wall	102669	Inanda Dam was identified as the most strategically important dam in the Mgeni system in terms of water quality. Large quantities of water are abstracted and used for domestic and industrial purposes in an economically important area.
D3R002Q01 Gariep Dam on Orange River: near dam wall	101834	The Gariep Dam is the largest dam in the country. Large volumes of water are pumped from the dam to the Fish/ Sunday river systems for irrigation. The dam plays a major role in storage and regulation of irrigation water for downstream use in the Orange River.
H6R001Q01 Theewaterskloof Dam on Riviersonderend: Near Dam Wal	102112	The Theewaterkloof Dam is the most strategic water storage facility in the Western Cape. Water from the dam gravitates through 35 km of tunnels to supply the Cape Metropolitan Area (including Cape Town) with water.
B3R002Q01 Loskop Dam on Olifants River: near dam wall	90462	Loskop Dam was mainly identified as important as a result of its use for irrigation (export market), recreation, and domestic purposes. Potential future developments also played a role.

The national monitoring programmes currently responsible for dam monitoring are mainly the NCMP and the NEMP. As with the trend sites for rivers an audit of sampling performance of these programmes was conducted for each of the dam sites identified (see Table 3.12 below). The two programmes make use of the same sites identified above.

Table 3.12: Sampling performance (taken:scheduled = percentage) at identified dam monitoring sites for the period Jan 2000 to Dec 2003.

Dam Site	Sampling Performance	Dam Site	Sampling Performance
C1R001Q01 Vaal Dam	418:1078 = 39%	A2R001Q01 Hartebeespoort Dam	2162:3552 = 61%
C9R002Q01 Bloemhof Dam	361:1124 = 32%	H6R001Q01 Theewaterskloof Dam	29:49 = 60%
D3R002Q01 Gariep Dam	213:1024 = 21%	B3R002Q01 Loskop Dam	165:761 = 22%

The performance for sampling at Inanda Dam is not included in Table 3.12 above. Umgeni Water monitors Inanda Dam and the data had not been fed into the DWAF database yet resulting in an audit result of 0% performance. It was however confirmed that there is a high sampling performance at Inanda Dam. It is clear from the audit results in Table 3.12 that the sampling performance at the dams is unacceptably low. A breakdown of the percentages showed that both the NCMP and the NEMP contributed to the low performance levels. It is recommended that the national programmes give specific attention to the sites, as the data from these sites will be used on an international level.

3.3.2. Variable selection for rivers and dams

Variable selection as part of the design of a monitoring programme is normally directly related to the information requirements of the end users, while at the same time being influenced by the availability of resources. For long term trend monitoring of resources the questions that need to be answered are generally one of two or both, namely:

- Are the water quality issues of concern getting better or worse?
- Are there new emerging water quality issues?

To answer the first question it is possible to develop a set of indicator variables that can be used to economically monitor trends in the issues of concern. This is typically the level of monitoring conducted by the national programmes. The NEMP uses, for example, only Chl-a, and TP to monitor the trends in trophic status of South African dams.

To answer the second question the number of variables that need to be included in the design of the monitoring programme can be impractically high. New emerging water quality issues are normally not identified by long-term trend monitoring, but by specific effects on the water users (including the ecosystem) which then leads to research and the development of appropriate monitoring programmes. A good example is the current research being done on endocrine disruptive compounds

(EDC). Plans are to include the monitoring of EDCs in the National Toxicity Monitoring Programme (NTMP) which are currently in the design phase.

The problem of selecting the appropriate variables for trend monitored on a global scale is not difficult to imagine. As discussed earlier the GEMS/Water will also be supplying data to a number other organizations that will use the data for global assessments. It is therefore not possible to be specific regarding the final information products and the related variables required. In 1990 Gems/Water held a meeting in Leningrad during which a team of experts proposed an updated list of variables for the global monitoring programme (WHO, 1990).

As with the section on variable selection for global river flux monitoring, the purpose of this section is to identify which variables, required by GEMS/Water, can we supply data on and which variables should be recommended for inclusion in the national programmes. Table 3.13 below gives an indication of the variable requirements and the ability of the national programmes to supply data on those variables.

Table 3.13: Variable requirements compared to the possibility of provision.

Gems/Water Variables	Used in Existing Monitoring Programme	Comment
General Water Quality		
Temperature	No	Must be investigated for inclusion in national programme.
pH	No	Currently only in laboratory. Must be investigated for inclusion in national programme.
Electrical conductivity	Yes	
Dissolved Oxygen	No	Field oxygen meter maintenance is a problem
Total suspended solids (rivers)	No	It will be recommended to the NCMP that TSS be included for at least the GEMS sites.
Transparency (Secchi)(dams)	Yes	
Dissolved Salts		
Calcium	Yes	
Magnesium	Yes	
Sodium	Yes	
Potassium	Yes	
Chloride	Yes	
Sulphate	Yes	
Alkalinity	Yes	
Nutrients		
Nitrate plus nitrite	Yes	
Ammonia	Yes	

Total phosphate as P, unfiltered	Yes	
Ortho phosphate as P	Yes	
Silica reactive	?	
Organic Matter		
Chlorophyll *a*	Yes	Only at dam sites. NEMP only active at dams.
Dissolved organic carbon	Yes	
Particulate organic carbon	No	
BOD	No	Must be investigated for future inclusion in a national programme.
COD	No	
Microbial pollution		
Faecal coliforms	No	The National Microbial Monitoring Programme (NMMP) currently focuses only on impacted areas and not on a catchment level. It will however be proposed that the NMMP expand their activities to at least the SA/GEMS sites. The nature of the indicator variables used is such that monitoring at the outflow of catchments will not give a representative view of the catchments. The occurrence of the organisms is normally very localized.
Total Coliforms	No	
Inorganic contaminants		For potential future inclusion in the National Toxicity Monitoring Programme or other programmes. This group of variables are currently not part a national programme.
Aluminium (diss & tot)	No	
Arsenic (diss & tot)	No	
Boron (diss & tot)	No	
Cadmium (diss & tot)	No	
Chromium (diss & tot)	No	
Copper (diss & tot)	No	
Iron (diss & tot)	No	
Lead (diss & tot)	No	
Manganese (diss & tot)	No	
Mercury (diss & tot)	No	
Nickel (diss & tot)	No	
Selenium (diss & tot)	No	
Zink (diss & tot)	No	
Organic contaminants (As per Stohckholm Convention)		Will be recommended for inclusion in National Toxicity Monitoring Programme. Limited laboratory capability currently available. If this programme come into affect it will only be in 2008.
Aldrin	No	
Chlordane	No	
DDT	No	
Dieldrin	No	
Endrin	No	
Heptachlor	No	
Hexachlorobenze	No	
Mirex	No	
Toxaphene	No	
Polychlorinated Biphenols (PCB)	No	
Polichlorinated dibenzo-p-dioxins	No	
Polichlorinated dibenzofurons	No	

It is clear from Table 3.13 above that only a few variables can be included in the SA/GEMS/Water design. The DWAF is however in the process of designing new national programmes and will soon embark on the revision of the National Chemical Monitoring Programme during which recommendation from this design will be considered. Table 3.14 below lists the final set of variables that will be included in the SA-GEMS/Water to start with. More variables can be included as soon as it has been incorporated in a national programme.

Table 3.14: SA-GEMS/Water trend monitoring variables with analytical methods references.

Water quality Variables	DWAF method number	Method	GEMS method number
General Water Quality			
Electrical conductivity	Method 0101101	Automated Determination of Electrical Conductivity	02041
Total suspended solids	Method 2003002	Dry weight method	10401
Transparency		Field measurement with 30 cm Secchi disk	02076
Dissolved Salts			
Calcium	Method 0020101	Automated Determination of dissolved calcium by Atomic Absorption	20103
Magnesium	Method 0012101	Automated Determination of Dissolved Magnesium by Atomic Absorption	12102
Sodium	Method 0011103	Automated Determination of Sodium with Flame Emission Spectroscopy	11103
Potassium	Method 0019103	Automated Determination of Dissolved Potassium by Flame Emission Spectroscopy	19103
Chloride	Method 0017104	Automated Determination of Dissolved Chloride using Ferric Thiocyanate	Check
Sulphate	Method 0016104	Automated Turbidimetric Determination of Dissolved Sulphate	16302
Alkalinity	Method 0010101	Automated Determination of Alkalinity using Bromophenol Blue	Check
Nutrients			
Nitrate plus nitrite	Method 0007107 Method 0007109	Automated Determination of Dissolved Nitrate by Cadmium Reduction Automated Determination of Dissolved Nitrite	Check
Ammonia	Method 0007106	Automated Determination of Dissolved Ammonium with Indophenol Blue	check
Total phosphate as P, unfiltered	Method 0015003	Automated Determination of Total Phosphorus as Phosphomolybdate	15405

Ortho phosphate as P	Method 0015104	Automated Determination of Dissolved Orthophosphate as Phosphomolybdate	15417
Organic Matter			
Chlorophyll *a*	Method 2002005	Chlorophyll *a* - Spectrophotometric Method	06711
Dissolved organic carbon	Method 0006101	Automated Determination of Dissolved Organic Carbon by UV Oxidation	check

3.3.3 Sampling Frequency for Trend Monitoring

In section 3.2.3 (Sampling Frequency for Global River Flux Monitoring) an attempt was made to determine the most appropriate sampling frequency for the generation of data that will be used to estimate the mean of specific water variables with a certain amount of confidence. The goal of this section is to propose an appropriate sampling frequency that would enable the end users of the data to test for trends with a high statistical power.

The current sampling frequency used by the national chemical monitoring network ranges from weekly to quarterly. This is not based on a statistical design but mostly the visiting frequencies of the hydrologists responsible for hydrometric data collection and maintenance at the gauging stations. Water quality samples for the national chemical network are mostly taken by those field hydrologists. As mentioned before, a more formal scientifically-based conceptual design for a national river monitoring network was completed in 1994 (Harris, *et. al.*) This design has, however, not yet been implemented and it is proposed that the proposed sampling frequency for trend analyses be adopted for this SA GEMS/Water. For dam sampling it is proposed that the sampling frequency of the National Eutrophication Monitoring Programme (NEMP) be adopted. A short discussion of the proposed river and dam sampling frequencies follows.

Rivers

The abovementioned conceptual design by Harris proposes a sampling frequency of monthly for trend monitoring on a national level. This was based on electrical conductivity data from 7 stations countrywide over a period of 13 years. The study confirmed that a monthly sampling frequency would be sufficient to avoid serial correlation in the dataset and also allow for the detection of a change (linear trend) equivalent to two times the standard deviation after two years of monitoring. It would therefore be possible to detect a trend with 24 samples with a significance of 0.10 and a statistical power of 0.90.

To confirm the monthly sampling requirement, in order to avoid serial correlation, data from four proposed SA-GEMS trends sites were used to test for serial correlation of electrical conductivity (EC). The sites are Kalkheuwel on Crocodile River, Komatipoort on Komati River, Matomela's on the Great Fish River and Marksdrift on the Orange River. Even at a monthly sampling interval the EC shows slight correlation at Marksdrift, Kalkheuwel and Komatipoort. No serial correlation was evident at a monthly sampling interval at Great Fish River. Two distinct trends (95% confidence) were detected using the Seasonal Kendal test at Komatipoort (upwards) and Great Fish River (downwards) using weekly data over a five year period. Using monthly data the same trends were detected with 90% confidence. The same procedure was used to propose a revised sampling frequency for USGS monitoring sites in the South Plate River basin in Colorado. That study indicated that the sampling frequency can even go as low as quarterly. The New Zeeland national trend monitoring programme also found that monthly sampling for long term trend monitoring is sufficient for detecting long term trends (Ward, *et al.,* 1990).

It is therefore confirmed that the proposed monthly sampling interval for rivers (Harris, *et al.,* 1994) is the most appropriate frequency to avoid serial correlation and still be able to detect trends with a high level of confidence. The GEMS/Water (WHO, 1992) recommended sampling frequency for trend detection is also monthly.

Dams

The National Eutrophication Monitoring Programme (NEMP) schedules sampling to take place on a two weekly basis (DWAF, 2002). GEMS/Water recommends that sampling for eutrophication issues take place on a monthly basis including twice monthly during summer (WHO, 1991 and WHO, 1992). This is direct result of the ability of algal communities to change over short periods in terms of algal biomass, chl-a concentrations and species diversity.

GEMS/Water and the New Zealand design propose a much lower sampling frequency for issues other than eutrophication. The New Zealand design proposes bi-monthly sampling and GEMS/Water proposes six monthly sampling. The current sampling frequency at the proposed dam sites is weekly for general salts analyses. This is very high compared to the recommended sampling frequencies. Serial correlation tests that were performed for monthly EC and TP data at Gariep Dam and Hartbeespoort Dam indicated that even on a monthly frequency serial correlation occurred. This means that the current weekly sampling interval for major salts analyses is too high. The nutrient data from the macro samples is however required for use with data from the two weekly Chl-a samples.

Based on the above discussion it is proposed that macro (including nutrient samples) be taken together with Chl-a samples on a two weekly basis and not a weekly basis. It should however be kept in mind that even at a two weekly sampling interval there is likely to be serial correlation in the macro data set.

3.4 Global Baseline Monitoring

The objective that will be addressed in this section is as follows, namely:

Objective:
To provide the UNEP GEMS/Water programme with good quality, globally significant and comparable data (producible by existing national monitoring programmes) on:

> *the levels of water quality variables at monitoring sites representing natural conditions in "un-impacted" areas.*

In this section, as in section 3.2 (global river flux monitoring) and section 3.3 (global trend monitoring), a specific programme objective will be addressed by selecting sampling sites, variables to be analyzed and a monitoring frequency based on the requirements of the objective.

The GEMS/Water definition for baseline stations are as follows (WHO, 1992): "Baseline stations are typically located in undisturbed upstream river stretches where no direct diffuse or point sources of pollution are likely to be found. They will be used to establish the natural water quality conditions, to provide a basis for comparison with stations having significant direct human impact, to determine through trend analyses the influence of long range transport of contaminants and of climatic conditions."

3.4.1 Sample site selection

The GEMS/Water Operational Guide indicates that the optimum number of baselines monitoring stations will be 50 sites distributed over all continents (WHO, 1992). The implication is that the number of sites required in South Africa is fairly low. The sites are also limited to upstream river stretches as a result of the absence of natural headwater lakes in South Africa.

The workshop held for the selection of trend monitoring sites also served as a basis for the identification of global baseline monitoring sites for South Africa (see Annexure 1). It was agreed during workshop that although an obvious approach for the distribution of baseline sites would typically be to align it with ecoregion distribution, the low number of baseline sites required would, however, not be able to reflect the baseline conditions in the high number (30) of ecoregions. This is an approach that should be considered by the National Chemical Monitoring network and the National River Health Programme during the redesign phase.

The following criteria were used for the selection of appropriate global baseline monitoring sites, namely:

- All sites must be at least 100 km from major air pollution sources (i.e. cities, industries etc.) (GEMS/Water requirement).
- There should be no apparent upstream point or non-point sources of contamination.
- The sites should be as far downstream as possible from the origin of the river to ensure true representation of natural conditions.
- The sites should geographically be fairly distributed over South Africa.

There were no specific sites identified during the workshop although four catchment areas were identified for further investigation relating to the most appropriate site placement in those catchments. It was felt that to ensure that all the above criteria are met, field visits with local water quality managers should be held to identify the most appropriate sites in the identified catchment areas. The following four areas were identified during the workshop, namely:

- Catchment G10, Jonkershoek, Western Cape;
- Catchment D13, Kraai River, Eastern Cape;
- Catchment V20, Mooi River, KwaZulu/Natal and
- Catchment B60, Treur/Blyde Rivers, Mpumalanga.

Based on site visits to the above catchments, in conjunction with the regional water quality managers, four global baseline monitoring sites were identified: Table 3. 15 gives an overview of the sites and associated information. See annexure 2 for more site details. Only two of the four sites are currently part of the National Chemical Monitoring Programme. It will be recommended that the other two be included as soon possible.

Table 3.15: List of South African global baseline monitoring sites.

Site name	WMS site ID	Reason for inclusion
Jonkershoek at Witbrug on Eerste River	Not registered on WMS	The site represents the water quality of running from an unimpacted catchment in the Jonkershoek Nature Reserve. According to the local water quality managers the stream represents a typical mountain stream in the Western Cape.

Mooi River at Kamberg Nature Reserve	Not registered on WMS	The site represents the water quality of the upper reaches of the Mooi River draining from the Kamberg Nature Reserve on the foothills of the Drakenberg.
B6H001Q01 Blyde River upstream of the Truer River confluence.	90489	The Blyde River upstream of the confluence with the Truer river is regarded as one of the most pristine river stretches in the area. There is also 30 years of historical flow and water quality data available.
D1H011Q01 Kraai River at Roodewal	101795	The Kraai River drains the Drakensberg D13 catchment towards the Orange River. There are very little potential for human impact and 20 years of historical flow and water quality data are available.

3.4.2 Monitoring variables and sampling frequency.

For the purpose of baseline monitoring it is recommended that the same variables as for trend monitoring (section 3.3.2) be used. This is also the recommendation by the GEMS/Water Operational Guide.

Of the four sites that have been identified only one site has sufficient data to test for serial correlation. It is generally accepted that unimpacted sites have less variation in water quality than impacted sites. It can therefore be assumed that the required sampling frequency will not be lower than monthly, as for the trend monitoring sites. It can even be assumed that the required sampling frequency will be lower than monthly. This can however not be confirmed without sufficient data for statistical determination of sampling frequency. It is therefore recommended that a sampling frequency of monthly be implemented up to a point where sufficient data has been collected to perform such tests.

Chapter Four: Quality Assurance

4.1 Introduction

The main function of any water monitoring programme is to ultimately produce data or information that will in some way be used to support water management decisions. The social, environmental and financial implications of making incorrect decisions, as a result of unreliable data or information, can be severe. Unreliable data or information is a direct result of a monitoring programme with a poorly designed or maintained quality assurance programme. In monitoring programmes where more than one organization is responsible for producing data, a high level of comparability is required. This can only be achieved through a well-designed and consistently implemented quality assurance programme (Clark, 2000).

The mere fact that the GEMS/Water Global Monitoring Network receives data from more than one hundred countries and that samples are taken and analyzed by hundreds of individuals and laboratories all over the world suggests that a high level of data error can occur in their database (GLOWDAT). This is a direct result of the low level of control that GEMS/Water has over the monitoring activities that produces the required data.

To address this problem GEMS/Water has undertaken a massive project to "clean up" their database. This is done through a data screening process that feeds any potential data quality queries back to the country of concern, which is then requested to investigate the issues of concern and give feedback to GEMS/Water. Secondly GEMS/Water has also compiled a detailed chapter in their Operational Guide (WHO, 1992) addressing analytical quality control requirements. Although this manual addresses generic monitoring network design requirements to help ensure the production of representative data and laboratory quality control, specific requirements relating to operational quality assurance issues are, however, not clearly addressed. GEMS/Water also runs an international inter-laboratory proficiency scheme for participating laboratories. A number of courses on the design and operation of monitoring programmes are also offered by GEMS/Water.

The main purpose of this chapter is to identify QA gaps in the South African water quality monitoring programmes responsible for producing data that will be submitted to the GLOWDAT. Based on the gap analyses, recommendations are made on ways to enhance the reliability of the data submitted to the GLOWDAT.

4.2 Concepts of quality management in water quality monitoring

The main aim of any quality assurance programme is to ensure that the final product or service conforms to a set of specifications as required by the client. The term quality assurance (QA) refers to an overarching philosophy. A quality management system (QMS) is a tool that is used to operationalise this QA philosophy (US EPA, volunteer doc.). The term quality control (QC) is used to describe specific measures put in place to ensure that process areas, where deviance can occur, are controlled. QC is one of the components in a QMS.

A QMS consists of two main components, namely:

- QC measures, and
- Planning, management and assessment of QC measures.

Typical examples of QC measures are:

- Calibration of pH meters,
- Instrument maintenance,
- Having strict procedures for sample bottle preparation, sampling methods, etc.,
- Checks and balances (such as QC samples and ion balances),
- Training and ensuring competence of samplers, etc. and

- Setting specification for sub-processes such as purchasing, minimum shelf life of samples, minimum shelf life of reference material etc.

Unfortunately a large number of monitoring programmes only address the required QC measures and not the requirement for a complete QMS. It is impossible to ensure continual improvement of your product and QC measures without a proper QMS.

The QMS will typically consist of:

- QC measures (mostly well documented procedures),
- monitoring and management of deviations from the QC measures and product (non-conformance, corrective and preventative action system),
- Quality policy (including management commitment) and quality objectives,
- Regular management review meetings to discuss any issues relating to the QMS,
- A dedicated management representative and a quality co-ordinator,
- Regular audits to assess conformance with all QMS requirements,
- Document and record control,
- Resource management and
- Review of the QMS, etc.

In order to harmonize QA methodologies on a global scale the International Standards Organization (ISO) released the ISO 9000 series of quality management standards in 1987. The series addressed quality management with regard to any development, production or service, including analytical laboratories (Clark, 2000). The latest revision of the series led to the currently widely used ISO 9001:2000 Quality Management Systems – Requirements. The standard does not cover analytical laboratories. For this purpose the ISO/IEC Guide 25 was developed and was recently replaced by the ISO/IEC 17025 standard to address the specific technical requirements relating to laboratory quality management. This standard also puts more emphasis on competence testing of laboratory personnel.

It is important that one has a detailed understanding of the process that needs to be controlled, in this case the water quality monitoring programme. The development of

QC measures must be based on a process analyses that highlights all potential sub-processes that need to be controlled in order to avoid any deviation from the required product specifications. In this case the product is water quality data or information.

Clark (2000) gives a detailed overview of quality assurance in environmental monitoring. Figure 4.1 below is an example of a typical monitoring process with the associated potential sources of errors (examples) that need to be controlled.

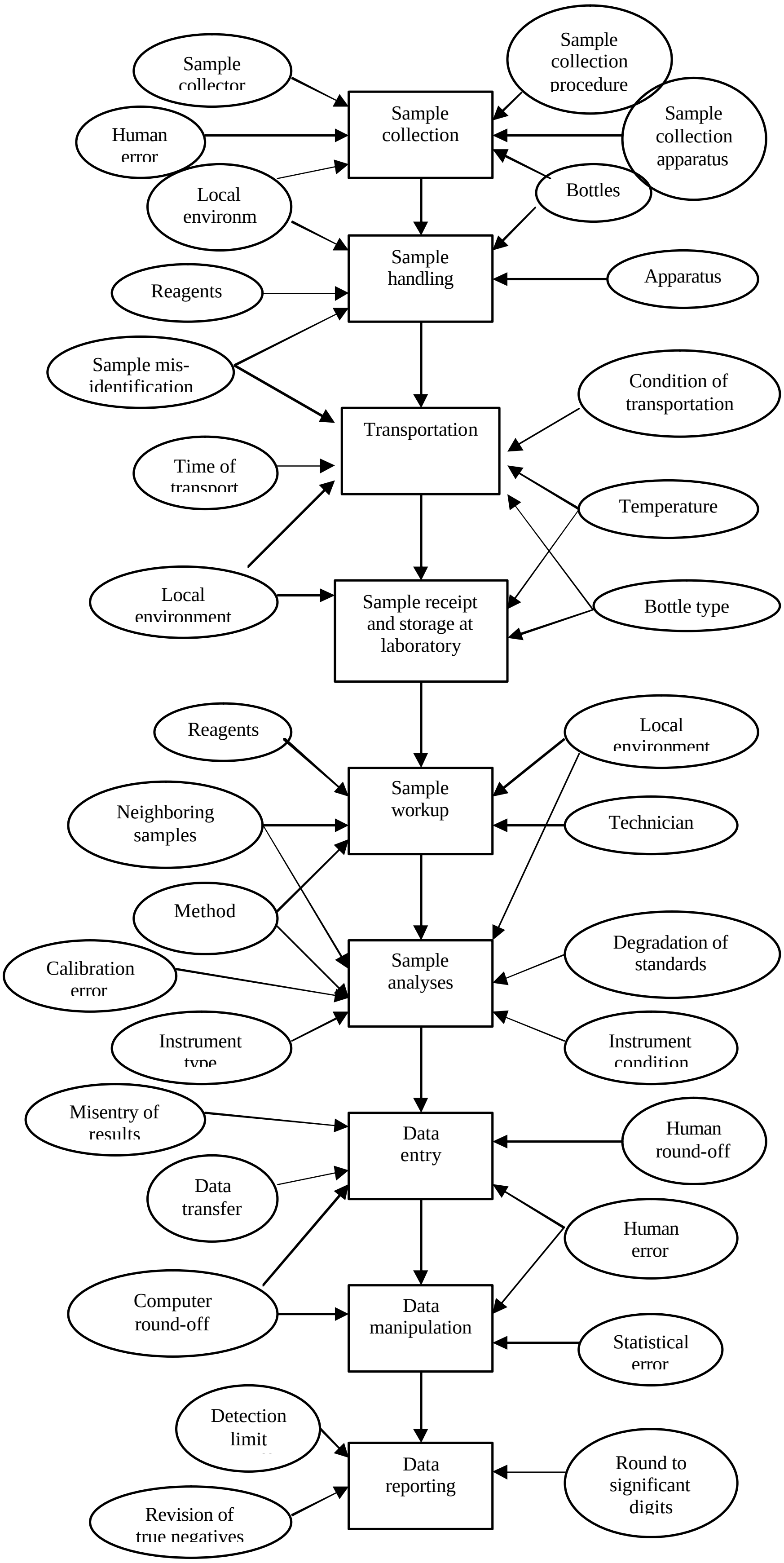


Figure 4.1: An illustration of a typical monitoring process and associated sources of error. Reproduced from Clark (2002)

From the example in Figure 4.1 above it is clear that a large number of potential sampling and analytical errors can occur. It is therefore obvious that a large number of QC measures will be required to prevent those errors from occurring. Planning, management and assessment of those QC measures is critical to ensure that the set quality objectives are met.

Historically more emphasis has been put on the prevention and mitigation of analytical error rather than total error (including sampling). Laboratories are usually managed as an entity separately from associated monitoring programmes. Individual laboratories normally serve a number of different monitoring programmes (including for litigation) and are often run as a commercial entity. The requirement for laboratories to produce credible results has been a long standing requirement that led to the fact that most laboratories have a well established QMS. A large number of laboratories are therefore ISO/IEC 17025 accredited. On the other hand, many monitoring programme operators believe that by using a laboratory with a recognized or accredited QMS, they are able to guarantee the quality of the data or information they produce. This is however an illusion, with all the potential pre-sampling, sampling and post-sampling errors that can occur.

An example of a monitoring programme with a well established QA programme is that of Umgeni Water Board. Their laboratories are ISO/IEC 17025 accredited by SANAS and their sampling programme is ISO 9001:2000 certified by SABS. There are, however, other organizations with similarly well-established QMSs that have decided not to go for certification. This does not imply that their data are any less credible. In most cases the cost involved in maintaining certification status outweighs the benefits and the application of the basic QMS principles is sufficient for the organization to produce data or information of a known quality.

4.3 Quality Assurance in the SA National Water Quality Monitoring

The SA-GEMS/Water objectives as indicated in chapter two clearly commits SA to provide credible water quality data to GEMS/Water. The purpose of this section is therefore to highlight gaps in QA of the programmes contributing data to GEMS/Water. Section 4.4 will then propose a system that, if implemented by the national programs, will enhance the credibility of the data transmitted to GEMS/Water and used for SA information needs.

The national chemical monitoring programme is currently the only programme contributing data to the SA-GEMS/Programme and as a result this document deals specifically with QA issues in the NCMP. Expansion of the proposed QA measures to the other national programmes is, however, addressed in section 4.4. Figure 4.2 below illustrates the main components and current QA status of the NCMP

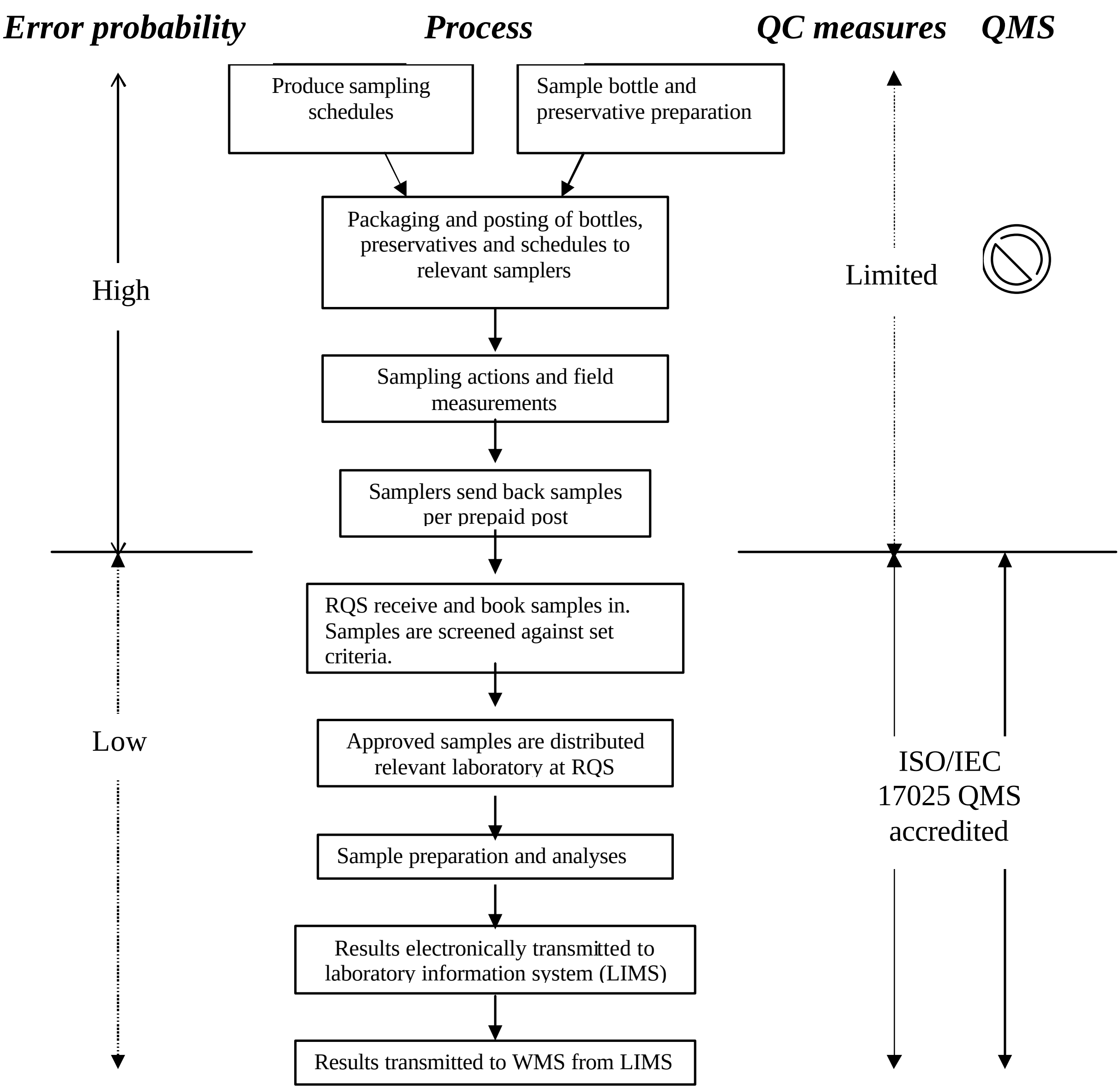


Figure 4.2: Current Quality assurance status in the NCMP

It is clear from Figure 4.2 that the probability of having analytical errors is much lower than that of sampling programme errors. This is a direct result of the fact that the analytical component of the NCMP is well controlled through an accredited QMS. The scope of the laboratory QMS covers all aspects from the point where the sample are logged in at sample reception up to the point the data are transmitted from the LIMS onto the WMS. Some aspects of preservative and sample bottle preparation are also addressed by the laboratory QMS (LQMS).

Figure 4.2 above highlights the requirement for a well established and maintained sampling programme QMS (SQMS). This lack of a SQMS is evident through the large number of incoming problem samples that are rejected or investigated by sample reception on an ongoing basis, namely:

- Containers different from specification,
- Water level less that 50% of container,
- Remarks on sample tags,
- Preservative different from specification,
- Begin depth different from action specification,
- End depth different from action specification,
- Sample taken after hours,
- Sample older than three months,
- Preservative time lapsed,
- Replicated sample,
- Packing error,
- Duplicated sample (Same date and time),
- Sample not scheduled,
- Wrong monitoring point,
- No sampling point,
- No date and time,
- No volume filtered and
- Wrong tag.

Over the period January 2004 to March 2004 an unusually high number of samples (1314) were rejected or investigated as a result of one or more of the above reasons. It is however not always possible to detect all errors. In order to lower the occurrence of detectable and undetectable errors during the sampling process, the following section proposes a QMS to be implemented for the sampling process.

4.4 Proposed Sampling Quality Management System

In order to effectively design the SQMS for the NCMP a process analyses was done by means of a mini workshop and interviews. Section 4.4.1 describes the process with the associated potential errors. Knowing the process and associated potential errors it was then possible to propose a SQMS as described in section 4.4.2 below. The aim was to design a SQMS that will support the management and co-ordination of the programme rather than putting more pressure on an already resource limited programme.

4.4.1 Sampling process analyses

As mentioned earlier the most important function of a QMS is that it should mitigate and prevent any errors that can be controlled. It is, therefore, essential to identify and understand the potential errors associated with the sampling process. The most logical first step was therefore to do a process analyses and secondly to identify the potential associated errors. The sampling process and associated potential errors indicated in Table 4.1 below was formalized by a group specialist involved in the national chemical monitoring programme during a SA-GEMS/Water QA workshop in June 2004.

The number of potential errors clearly indicated the requirement for a SQMS. The process identified in Table 4.1 needs to be controlled through appropriate QC measures. This needs to be done within a well structured and maintained SQMS. Section 4.4.2 describes a proposed SQMS. This document does not propose the QC measures required as this is the responsibility of the monitoring programme manager.

Table 4.1: Sampling process with associated potential errors of the NCMP

Sampling process	Potential errors
1) Sample container purchasing	❑ Caps don't fit ❑ Wrong production material ❑ Contamination ❑ Delay in delivery
2) Sample container preparation (new and existing)	❑ Using the wrong soap for washing ❑ Not rinsing properly after washing ❑ Bottles not washed ❑ Contamination during drying process
3) Preparation of preservative (HgO_2)	❑ Wrong concentration ❑ Wrong volumes ❑ Contamination of preservative ❑ Sealing of ampoule ❑ Wrong ampoule material
4) Tag preparation	❑ Printer problem
5) Schedule preparation	❑ Printer problem ❑ Layout (confusing) ❑ Registration and updating of programme
6) Consignment preparation	❑ Wrong tags or no tags ❑ No strings ❑ Wrong bottles or no bottles ❑ Wrong address ❑ Outdated address ❑ Wrong return boxes ❑ No free post tags ❑ No return address tags
7) Posting of sample material	❑ Inappropriate delivery mechanism ❑ Delivery mechanism not updated ❑ Does not reach sampler ❑ Consignment send back ❑ Damaged consignment ❑ Non-receipt of post as result of non-payment.

Sampling process	Potential errors
8) Storage and handling at receiving office	❑ Bottles used for wrong purposes (sugar, coffee etc.) ❑ Received by wrong person ❑ Samplers do not know that bottles are available ❑ Samplers do not receive bottles ❑ Pile up of sample bottle when not used (dry sites)
9) Sampling	❑ Wrong monitoring site ❑ Wrong position at right site (not representative position) ❑ Wrong sampling action ❑ Wrong timeframe (replicate samples) ❑ Wrong container ❑ Contamination of sample ❑ Disturbance of sediment ❑ Not recording abnormal conditions at site ❑ Preservative not added ❑ Preservative ampoule not put in sample bottle ❑ Wrong tag for site ❑ Sample size to small ❑ Date and time not written on tag ❑ Contamination of bottle or cap. ❑ Lack of sampling equipment (forgot tags, strings etc.) ❑ Tag not tied to container ❑ No flow not recorded ❑ Not using water resistant ink on tags ❑ Caps not properly closed ❑ Sampler have dirty hands ❑ Don't rinse sample bottle before sampling ❑ Duplicate samples taken
10) Sample handling before dispatch	❑ Samples left in heat and sun ❑ Contamination of outside of containers ❑ Rough handling ❑ Delays before posting

Sampling process	Potential errors
11) Dispatch to RQS	❑ Samples lost in postal system ❑ No free mail sticker ❑ Freepost system not known by post office officials ❑ Samples delayed ❑ Samples damaged ❑ Wrong address
12) Sample reception at RQS.	❑ Delays before logging samples ❑ Sample logging errors ❑ Storage of received samplers (heat)

4.4.2 SQMS proposal

The proposed SQMS is based on the main requirements of the ISO 9001:2000 and ISO/IEC 17025 standards. The intention was not to design a SQMS for certification purposes but rather a system that can be maintained with limited resources while at the same time serving the intended purpose.

The SQMS are described in two main documents, namely the Sampling Quality Manual (SQ Manual) and the Sampling Procedures Manual (SP Manual). The reason for including the S (for sampling) in the acronyms (SQMS, SQ and SP) is to avoid confusion with the laboratory QMS, Quality Manual and Procedures Manual.

SP Manual and SQ Manual purpose:

- The purpose of the SP Manual is to describe, in the form of procedures, all QC measures required to check (checks and balances) and control all aspects of the sampling process that can lead to the errors identified in section 4.4.1 above.
- The purpose of the SQ Manual is to address all requirements that will ensure efficient and effective implementation of the QC measures. It basically describes the assessment and management of the QC measures.

Responsibilities:

- The QC measures described in the SP Manual is an integral part of the day to day operation of the sampling process. The responsibility for implementation of those procedures lies therefore with the management of the monitoring programmes.

- The implementation and maintenance of the requirements of the SQ Manual lies with a person or group separate from the process or sampling programme. It is recommended that a full time Quality Manager be appointed to fulfill this role. The SQ Manual and Quality Manager can then in future also link up and serve the QC measures (SP Manuals) of other national monitoring programmes. Figure 4.3 below illustrates the main components and interactions of the proposed SQMS.

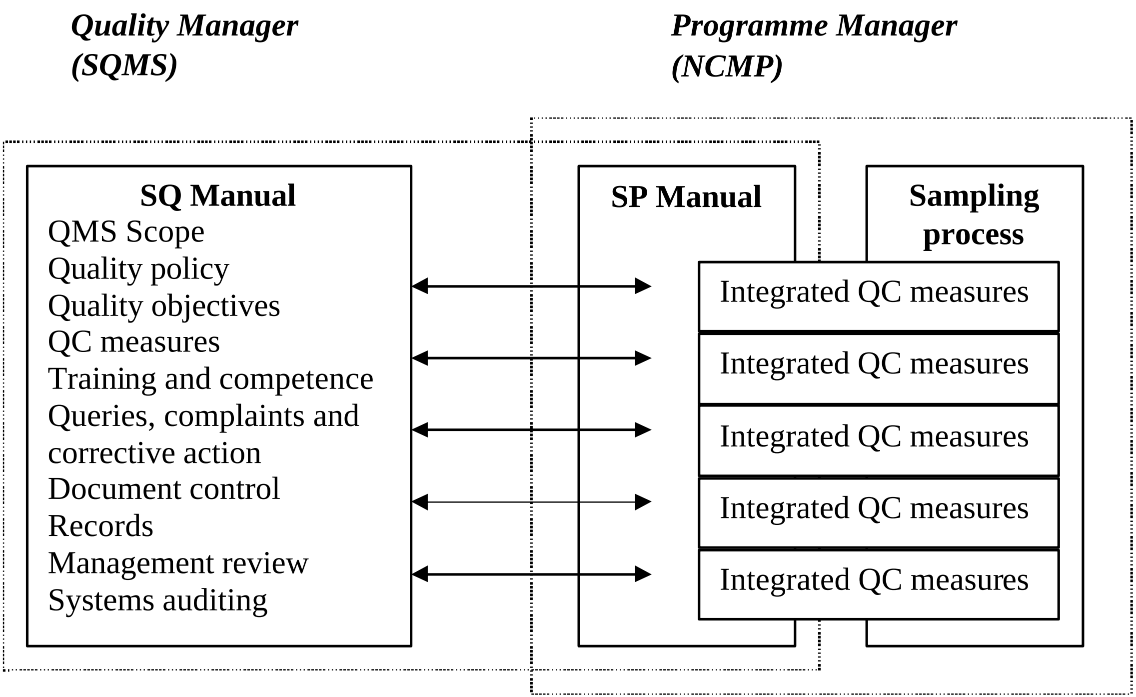


Figure 4.3: Illustration of the main interaction and components of the SQMS

SP Manual

All procedures in the SP Manual must have the following standard headings, namely:

- Procedure name

  The procedure must have unique logic name and number.
- Version number and effective date

This requirement enables the QC manager to ensure that the latest versions are used for operational purposes at all times.

- Definitions

  Ensure that important terms used in this procedure are well defined. For example the difference between the terms *query*, *complaint*, *corrective action* and *preventative action*.
- Purpose

  This topic will describe the scope and intention of the procedure with specific reference to the sub-process that need to be controlled.
- Responsibility

  The personnel responsible for the execution of the procedure must be clearly specified under this section.
- Procedure

  The actual procedure (QC measure) must be specified in detail under this section. Flow charts can also be used if required. The procedure should have sufficient detail of all steps and checks required to avoid the relevant potential errors.
- Training and competence

  This topic should address the specific training requirements for all personnel responsible for the execution of this procedure. The required level of competence must also be addressed.
- Records

  All records that need to be generated through the execution of this procedure must be clearly specified. A typical example is calibration records. Record retention periods must also be specified

All QC measures required for the prevention of potential errors identified in section 4.4.1 needs to be documented in the above format. Below is an example of such a procedure. Documenting specific aspects of the process is also a form of QC as this will ensure continuity with regard to new and acting staff members. This will be the responsibility of the monitoring programme operators with the assistance of the SQ manager.

Resource Quality Services

Sampling Procedures Manual

Procedure name	Complaints, Queries and Corrective Actions
Procedure reference.	SP NSMP 1

Version number	V1.1	Effective Date	2004/06/11

Definitions

Definitions of terminology in this procedure does not necessary reflect the meanings given to these terms by other organization.

Complaint: A complaint is any feedback, from sample reception, regarding a confirmed non-conformance to sample specification. Any person can also lodge a complaint, relating to a confirmed non-conformance to QC requirements.

Query: A query is any feedback to the quality manager regarding a suspected non-conformance (or potential non-conformance) relating to sample specifications or any other QC requirement.

Corrective action: A corrective action is an action taken in response to a complaint or query to address the (potential) problem and/or source of the problem.

Purpose

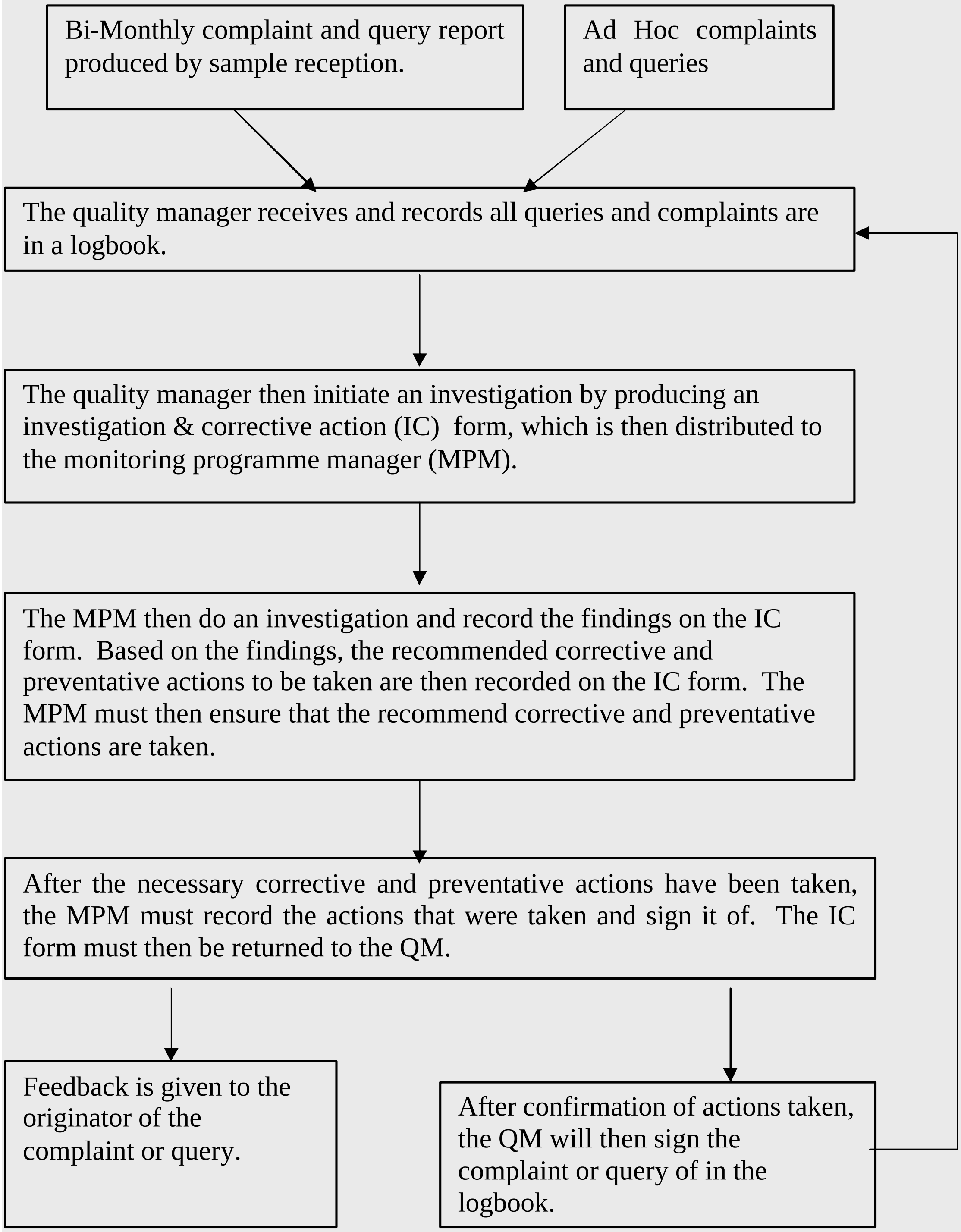
The purpose of this procedure is to describe a system through which all complaints and queries will be logged, investigated and corrective & preventative actions taken. Proper implementation of this system will enhance the effectiveness and efficiency of the SQMS and the sampling process.

Responsibility

The quality manager is responsible for the implementation and operation of this procedure. As reflected in the procedure below, the monitoring programme manager and sample reception also have responsibilities.

Procedure

The actual procedure (QC measure) must be specified in detail under this section. Flow charts can also be used if required. The procedure should have sufficient detail of all steps and checks required to avoid the relevant potential errors.



Training and competence

All personnel must be aware of the requirements of this procedure. The MPM and QM will be actively involved in the system and must know the requirements of the procedure. This procedure must form part of training given to all personnel involved in the monitoring process.

Records

All IC forms must be kept for 15 years as required by SQ manual. A logbook with records of all queries and complaints must be kept for a minimum of twenty years.

SQ Manual

The SQ Manager will be responsible for the overall implementation and management of the SQMS and associated SQ Manual. The manual describes all necessary requirements for the effective management and assessment of QC measures to ensure that the quality objectives are met.

It is proposed that the SQ manual contain (as a minimum) the following topics, namely:

- QMS Scope

  The scope (boundaries) of the QMS must be clearly defined. This will dictate the extent to which the SP manual will be applicable and ensure that there is no confusion regarding the focus of the QMS

- Quality Policy:

  The quality policy should give a clear reflection of the management's commitment towards delivering a product (samples) that comply with the minimum requirements of the client (sample reception) and towards continual improvement of the SQMS. Clear quality objectives must also be stated.

- QC measures

  This section must give an overview of the sampling process, potential associated errors (see section 4.4.1) and references to associated QC measures as described in the SP manual.

- Training and competence

Although the individual procedures in the SP manual address training requirements, this section in the SQ manual must describe the general training and competence requirements. Issues such as training schedules, responsibilities, record keeping, general awareness and other general requirements must be addressed here.

- Queries, complaints, corrective and preventative actions

  It is very important that this section is addressed in detail as not to cause confusion. This section must describe how any queries and complaints are logged, investigated and addressed through corrective and preventative action. This will apply to all aspects of the SQMS. It is recommended that a separate procedure, to be included in the SP manual, be developed for this purpose. This section can then refer to and summarize the relevant procedure.

- Document control

  All documents relating to SQMS must be approved before use. The quality manager must ensure that a mechanism exists to ensure that only the latest versions of procedures are used. This will definitely be a challenge as samplers and other personnel involved are widely distributed over the country. The issue should however not be neglected.

- Records

  The general requirements relating to all records required by this SQMS must be stipulated under this section. Those records include records specified in procedures, audit results, minutes of meetings and other records required by this manual.

- Management review

  Management review meetings must be held on a six monthly interval. The meetings must be attended by the Director: RQS, Deputy Director: Resource Quality Monitoring, Deputy Director: Resource Quality Information, Assistant directors involved and relevant monitoring programme managers. The purpose of the meetings is to discuss various aspects of the SQMS in order to ensure the suitability and effectiveness of the SQMS. The following issues must be reviewed during the meetings, namely

- Sample reception feedback,
- Results of audits,
- Queries and complaints,
- Status of corrective and preventative actions,
- Follow-up actions from previous meetings,
- Changes that could affect the SQMS and
- Recommendations for improvements.

The meetings must be chaired by the Quality Manager and minutes must be kept as required by the SQMS.

- Systems auditing

  Six monthly audits of the entire SQMS must be performed. The audits will assess conformance with all SQMS requirements. The auditors must have sufficient knowledge of the SQMS and the process being audited to ensure objectivity and value edition. The Quality Manager must lead all audits. The audits must act as an effective and reliable tool in support of management policies and controls, providing information that will ensure that objective are met. ISO/FDIS 19011:2000 – auditing guidelines can be used to assist with the planning and execution of audits. All audit findings must be cleared before the next audit. Typical audit finding forms, as used by the RQS laboratory, must be adopted.

Recommendation for the Implementation of the SQMS

It is recommended that the SQMS, as a start, only be implemented in the NCMP as discussed up to now. To ensure the sustainability and effectiveness of the SQMS it should not be attempted to expand to other programmes if sufficient capacity does not exist to do this. A SQMS that is poorly maintained will lead to a false sense of security in terms of data credibility.

The implementation of the SQMS should also not be attempted before a quality manager has been appointed. The implementation of the SQMS should be done in a phased manner. It is recommended that it first be implemented in a single management area (WMA, cluster or province) and then if the system is optimally set up it can be expanded to the rest of the country in a phased manner.

4.5 Total Quality Plan

A number of quality assurance issues have been discussed in the previous sections. The purpose of this section is to summaries and put into perspective the various QA functions and proposals discussed up to now. Up to now three main QA functions, that will be involved in the SA-GEMS/Water operations, have been identified, namely:

- A proposed sampling QMS,
- Laboratory QMS and
- GEMS/Water head office QA functions.

As an additional QA function it is recommended the SA-GEMS/Water representative perform annual audits on the programme responsible for generating the data. The purpose of the audits must be to evaluate the level of conformance with prescribed procedures and methods. These audits can be performed as an integral part of the annual SQMS audits proposed in section 4.4. Figure 4.4 below illustrates the total coverage of the proposed QA functions.

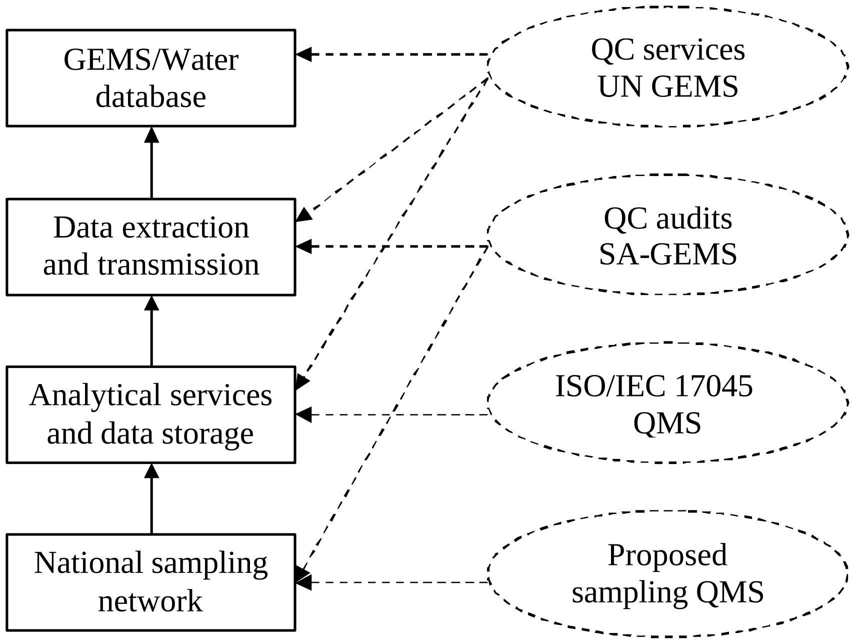


Figure 4.4: Proposed quality assurance structure for SA-GEMS/Water programme

Chapter Five: Operational Requirements and Responsibilities

The purpose of this chapter is to identify the operational requirements and associated responsibilities to ensure that the objectives of the SA-GEMS/Water programme are met in a sustainable manner. To achieve this a monitoring process flow analyses was done as a basis to work from (section 5.2). From this monitoring process flow analyses the operational requirements and associated responsibilities were identified.

5.1 Introduction

In order to identify all operational requirements and the associated responsibilities it is important that the complete process leading up the point of data delivery be well understood. An effective method of describing such a process has been found to be through a process diagram (DWAF, 2002a). A good example of such a process description (Figure 5.1) can be found in the Implementation Manual of the NMMP (DWAF, 2002b).

A number of technical aspects have been addressed in previous chapters. Requirements such as sample site selection, optimum sampling frequency, variable selection and QA requirements have been identified up this point. However, none of these issues have any meaning if they are not part of a holistic operational plan. A well designed and documented operational structure will ensure the long term stability and sustainability of the monitoring programme (Ward, 2003). Although SA-GEMS/Water is ultimately only responsible for the abstraction and transmission of a predefined data package, it will still have a responsibility to ensure that the national programmes responsible for the generation and storage of the data perform as required. This means that the complete process, including that of the data producing programme must be defined.

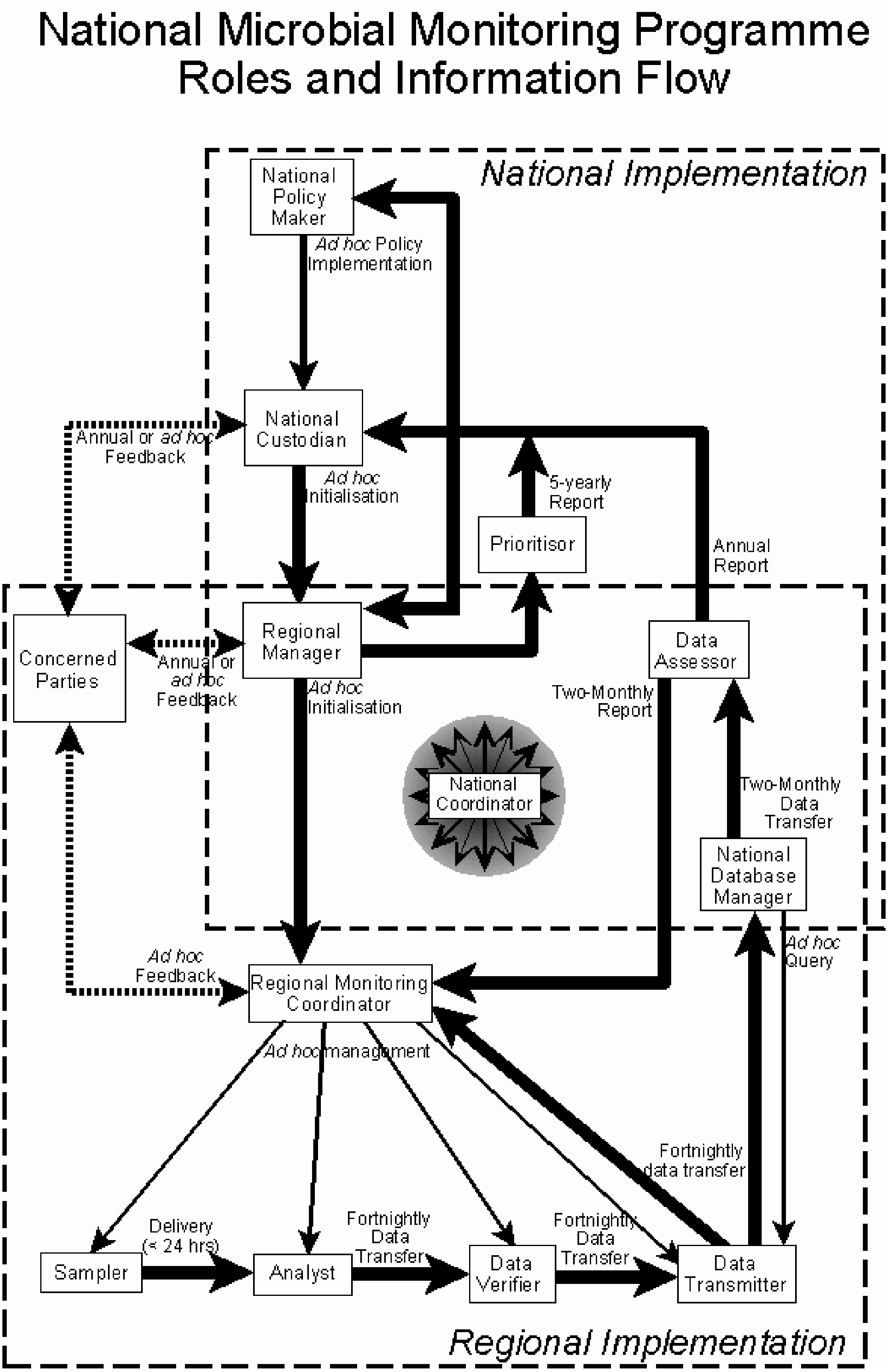


Figure 5.1: Process flow illustration of the National Microbial Monitoring Programme (DWAF, 2002b).

5.2 Operational Process, Roles and Responsibilities

An analyses of the structures and processes that would be involved in the operation of the SA-GEMS/Water programme was done. A total of 13 functions were identified as part of the SA-GEMS/Water process. As illustrated in Figure 5.2 below, the following functions were identified, namely:

- (1) Monitoring management system (WMS),
- (2) Sample administration,
- (3) NCMP national sampling network,
- (4) National laboratory,
- (5) National database (WMS),
- (6) Data extraction from WMS and transmission to global database,
- (7) GEMS/Water programme management,
- (8) Global database,
- (9) GEMS/Water QC functions,
- (10) SA-GEMS/Water QC audits,
- (11) Laboratory QMS,
- (12) Proposed sampling QMS and
- (13) Other national sampling networks.

Functions 1 to 8 constitutes the main operational process from sample scheduling to data entry onto the global database. Functions 9-12 represent supporting QA functions. Function 13 represents the potential future use of other national water quality monitoring programmes. The specific roles and responsibilities associated with each of the components are discussed in more detail below.

(1) Monitoring management system (WMS)

Monitoring management is a component of the WMS that is responsible for the capturing of all national and regional monitoring requirements, the consolidation of those requirements and the production of sampling and measurement schedules. The SA-GEMS/Water sampling and analyses requirements in terms of sample sites, sampling frequency and variables to be analysed, as determined in chapter 3 of this document, will be captured in this system where it will then be consolidated with existing requirements from other programmes. SA-GEMS/Water will be registered as a monitoring programme standing on its own, although in reality it will piggy back on the existing sampling done for the NCMP. The consolidation process ensures that duplicated sampling is avoided. Sampling schedules for the whole country are produced and forwarded to sample administration (function 2).

(2) Sample administration

At sample administration sampling schedules are used to make up consignments of monitoring equipment that includes different types of sample bottles, preservatives, sample bottle tags etc. The consignments are then distributed through the postal system to the national sampling network (function 3).

Sample administration is also responsible for receiving samples back from the national sampling network (function 3) and for logging the samples into the laboratory information system. Samples are checked against specific criteria (see chapter 4) after which the samples are either rejected or send to the laboratory for analyses.

(3) NCMP national sampling network

The NCMP currently consist of approximately 800 sampling sites located at flow gauging stations. Samples are mostly taken by officers responsible for servicing those gauging stations. Sample equipment consignments (including sampling schedules) are distributed from sample administration to samplers all over the country. At this stage sample are taken for SA-GEMS/Water purposes as an integrated part of the extended NCMP monitoring network. All samples are then send back to sample administration (2).

(4) National laboratory

At this stage the samples are analysed for variables as prescribed by the monitoring management system (1). Data is electronically generated on the laboratory information system from where it is transmitted to the (5) national database (WMS).

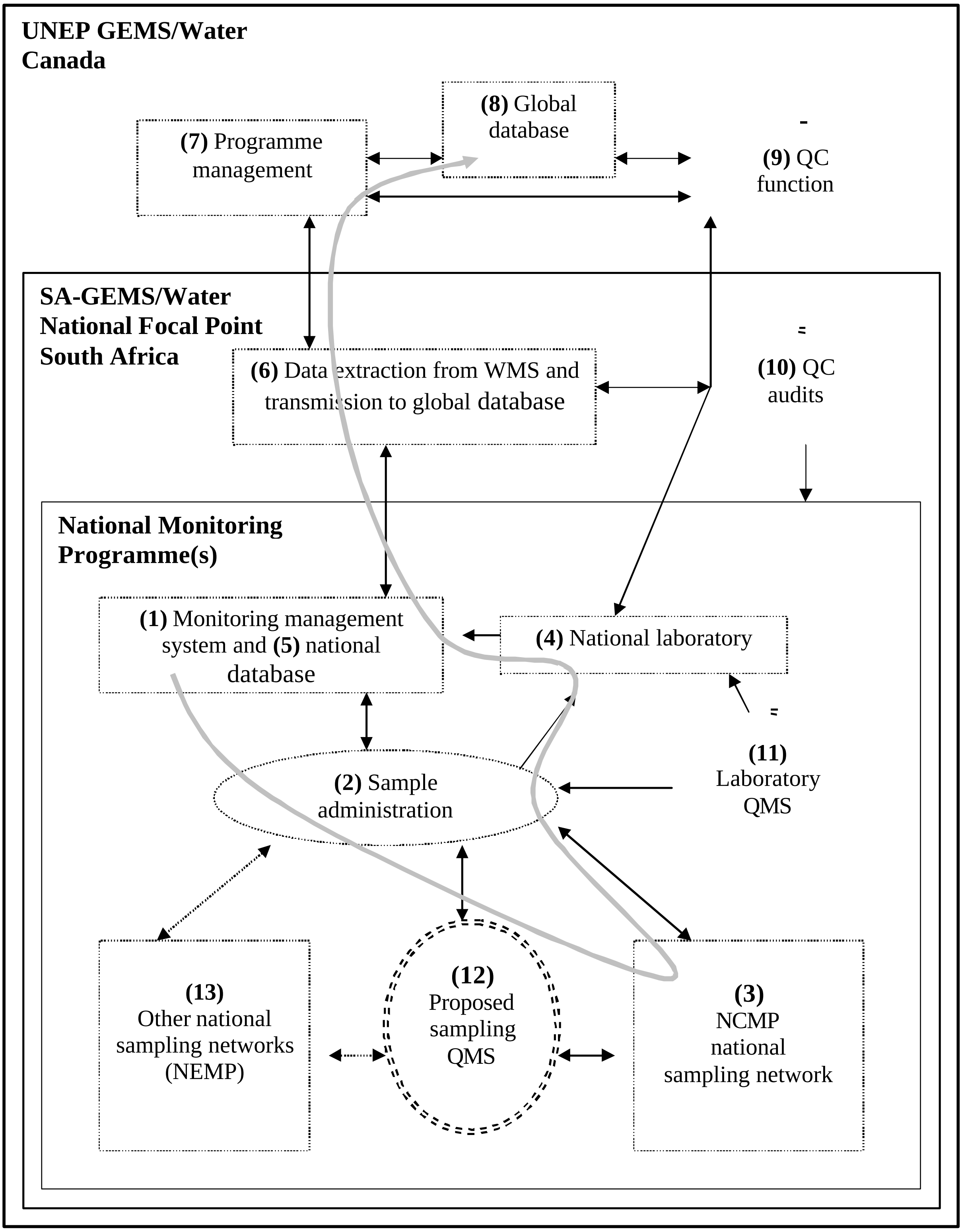


Figure 5.2: Proposed SA-GEMS/Water processes and interactions involved in producing and submitting relevant and credible data to the GEMS/Water global database. The light gray arrow line indicates the main process flow from sample scheduling **(1)** to data entry onto the global database **(8)**. See discussion in section 5.2 for more detail regarding functions and responsibilities of the various functions **(1-13)**.

(5) National database

As with monitoring management the national database is an integral part the WMS. Data are electronically transferred to the WMS where it is stored fore future use by monitoring programme managers and other stakeholders.

(6) Data extraction from WMS and transmission to global database.

At this point the relevant data, as defined in chapter 2 (objectives) and chapter 3 (network design) will be extracted from the WMS and prepared for transmission to the UNEP GEMS/Water head office. Data is captured onto a compact disc after which it is couriered to the GEMS/Water programme management (function 7) in Canada. This is the first component in the operational process that will be the responsibility of the SA-GEMS/Water programme. It will be done on an annual basis and on request. All other functions up to this point (1-5) are the responsibility of the national monitoring programme management.

At this stage the format of the data extracted from the WMS is not compatible with the format required for electronic data capturing onto the global database. Up to the point where a data format converter is available the data will be send to the GEMS/Water programme management where they will have to convert it manually to the required format. It is, however, recommended that such a data format converter be developed by DWAF to ensure a more efficient data transfer mechanism.

(7) UNEP GEMS/Water Programme Management

At this point the responsibility lies with GEMS/Water to ensure that the data are prepared and captured onto the ***(8) global database***, on which all data for the global water quality monitoring programme is stored. GEMS/Water management is also responsible for the extraction and dissemination of data from the global database to other organizations for use in global sustainability reports.

(9-12) Different levels of quality assurance

Refer to chapter 4 for a discussion of the different components of the integrated quality assurance plan.

(13) Other national monitoring programmes

Although the NCMP will initially be the main data source there is a good chance that other programmes such the NEMP and NTMP might be contributing data in future. As discussed before a number of national programmes are currently in the design process and depending on the outcome of their designs they may be able to submit data on variables as identified chapter 3.

Based on the above 13 functions (see Figure 5.2 above) Table 5.1 below indicates the proposed operational requirements and the associated responsibilities.

Table 5.1: SA-GEMS/Water functions and associated operational requirements and responsibilities.

Function	Operational requirements	Responsibilities
(1) Monitoring management system (WMS)	❑ All SA-GEMS/Water monitoring requirements must register in the WMS. ❑ After consolidation with NCMP, monitoring schedules must be produced as normal.	❑ SA-GEMS/Water representative ❑ RQS, Resource Quality Information
(2) Sample administration	❑ Sample bottle consignments must be prepared and send off with schedules as normal. ❑ Sample received back must be processed and screened as normal. ❑ Any complaints or queries must be submitted to the sampling quality manager.	❑ Sample administration officers at RQS
(3) NCMP national sampling network	❑ Samples must be taken thought the normal NCMP monitoring network and returned to RQS sample administration. GEMS/water samples will be taken as an integral part of the NCMP	❑ NCMP National Co-ordinator ❑ NCMP regional c-ordinators ❑ NCMP samplers
(4) National laboratory	❑ Samples must be	❑ RQS laboratory

	analysed for the NCMP as normal	
(5) National database	❑ The data produced by the laboratory must be electronically transmitted to the WMS	❑ RQS laboratory
(6) Data extraction from WMS and transmission to global database.	❑ On an annual basis the data for all variables (see chapter 3) for all the SA-GEMS/Water sites must extracted from WMS. Depending on the size of the data set it must either be sent by e-mail or by mail on a CD. ❑ Data extracted from the WMS must be converted from the WMS format to the global database format, using a data converter developed for this purpose.	❑ SA-GEMS/water representative ❑ RQS, Resource Quality Information
(7) UNEP GEMS/Water Programme Management	❑ Acknowledgement of data received.	❑ UNEP GEMS/Water Programme Manager
(8) Global database	❑ Data are red into database as normal.	❑ UNEP GEMS/Water Data Analyser.
(9) GEMS/Water QC functions	❑ Data are screened against set criteria and potential errors are referred back to country ❑ Annual laboratory proficiency test offered to all participating countries	❑ UNEP GEMS/Water Data Analyser ❑ UNEP GEMS/Water Quality Assurance specialist
(10) SA-GEMS/Water QC audits	❑ Annual audits are performed on data producing national programmes	❑ SA-GEMS/Water representative
(11) Laboratory QMS	❑ ISO/IEC 17025 accreditation	❑ RQS, laboratory quality manager
(12) Proposed sampling QMS	❑ Establish and operate proposed quality management system for sampling (see chapter 4)	❑ Sampling Quality Manager (see chapter 4)
(13) Other national sampling networks	❑ Ensure that GEMS/Water requirements are given to new programmes	❑ SA-GEMS/Water representative

5.3 Resources and Risks

5.3.1 Operational resource requirements

The SA-GEMS/Water programme has been designed to function as an integral part of the existing national monitoring programmes. As indicated in Table 5.1, the only additional two functions that is not part of existing national programmes is that of data transmission to the GLOWDAT on a six monthly basis and annual audits on the national programmes responsible for generating the data. It is therefore estimated that the SA-GEMS/Water representative will need to spend one month per year on SA-GEMS/Water issues. One week every six months for data preparation and transmission and two weeks for an annual audit.

All other resources required for issues such as sampling, analyses, etc. are already allocated to the relevant national programmes. No additional resources will be required for the operation of SA-GEMS/Water.

5.3.2 Risks

Two main risks linked to the sustainability of the programme have been identified, namely; 1) the SA-GEMS/Water representative can leave RQS and 2) the national monitoring programmes do not generate the required data.

The risk of losing the programme representative is not as serious as the second risk identified above. The data transmission function can be performed by the Directorate: Resource Quality Information until a new representative has been identified.

The risk of the national programmes not performing to expectations can be avoided by implementing the quality management system discussed in chapter 4. This will not only minimize the risk for SA-GEMS/Water but also for the national monitoring programmes.

Chapter Six: Recommendations and Conclusion

The purpose of this chapter is to make recommendations to DWAF: RQS on the actions required to ensure that the SA-GEMS/Water objectives would be met in a sustainable manner.

6.1 Recommendations

The recommendations are discussed in six categories hereunder, namely; general, monitoring sites, monitoring variables, sampling frequency, quality assurance and operational requirements.

6.1.1 General recommendations

- In order to ensure full recognition of the SA-GEMS/Water programme the relevant data requirement must be reflected in the objectives of relevant national monitoring programmes.

6.1.2 Sample sites

- It is recommended that all new national monitoring programmes consider including the 27 proposed SA-GEMS/Water monitoring sites in their monitoring network. This applies to the NTMP, NEMP, NMMP.

- Only two of the four baseline monitoring sites (Blyde River and Kraai River) are currently an active NCMP site. It is recommended that the other two proposed sites also be incorporated into NCMP during the revision of the NCMP monitoring network.

- During the identification of the trend monitoring sites it was found that the NCMP lacks active sites in the old Transkei area. In order to ensure that the monitoring sites are spatially better representative of South Africa, it is recommended that this area be given special attention during the revision of the NCMP monitoring network. Special attention must be given to the lower reaches of the Umzimvubu River for potential use in the SA-GEMS/Water monitoring network.

6.1.3 Monitoring variables

- To achieve the objectives of this programme it is recommended that suspended solids monitoring be included in the list of NCMP monitoring variables at Vioolsdrift. This site has been identified as a Global River Flux monitoring site. Suspended Solids load calculations is an important function of this type of monitoring.

- It is recommended that suspended solids monitoring also be done at all SA-GEMS/Water monitoring sites and if possible at all NCMP sites after the revision process. During this study a clear lack in suspended solids data was identified.

- The NTMP must consider including the list of persistent organic pollutants identified in chapter 3.

- A general lack in on site measurements was identified and the potential for on site pH and temperature measurements at NCMP/GEMS sites must be investigated. Identification of long term trends in water temperature have great value in respect of long-term global and regional climate change.

6.1.4 Sampling frequency

- The optimum sampling frequency for all SA-GEMS/Water river sites was determined to be monthly. It is, therefore, recommended that the

NCMP/GEMS sites not be sampled more or less than monthly and TSS at Vioolsdrift weekly.

- The most appropriate sampling frequency for SA-GEMS/Water dam sites was determined to be two weekly (every two weeks).

- In general it was found that the NCMP sites are sampled as frequent as weekly at a large number of sites. In line with recommendations from other studies it is recommended that river sampling be done on a monthly basis. This will avoid serial correlation in the data.

- A low sampling performance was detected at a number of NCMP/GEMS sites. It is critical that this problem be resolved by the NCMP as soon as possible.

6.1.5 Quality assurance

- In general it was found that a large percentage of samples are rejected by sample administration and that a large number of samples are not taken as scheduled. It was found that this is a direct result of the absence of a sampling quality management system (SQMS). To address this problem it is recommended that the SQMS proposed in chapter four be used as a framework for the implementation of a SQMS.

- To ensure the effective establishment and operation of the SQMS it is proposed that a sampling quality manager responsible for the above task be appointed.

- It is also recommended that the national laboratory take part in the UN GEMS/Water laboratory proficiency scheme.

- As part of the SA-GEMS/Water annual activities it proposed that they perform annual audits on the data producing programmes as an integral part of the SQMS audits.

6.1.6 Operational requirements

- To aid the transmission of data from the WMS to the global database in Canada it is recommended that a data conversion application be develop that will convert data in WMS extracted format to the required global database format. This will allow electronic data capturing onto the global database.

- During this study it was found that the general national monitoring programme supporting institutional structures within RQS were fragmented in terms of responsibilities for various aspects of the national programmes. This is especially true for the NCMP. It is recommended that a workshop be held to assist in formulating a structure that will fully support all national programmes in a stable and sustainable manner.

6.2 Conclusion

As part of a new drive to establish national monitoring programmes, DWAF can now also contribute to the realization of Agenda 21 through the implementation of this SA-GEMS/Water design. The content of this document is proof that South Africa has the capability to supply credible and relevant data to the UNEP Global Water Quality Monitoring Programme as an integral part South Africa's national monitoring programmes.

Although a number of potential problems have been identified in this design, the problems should be viewed as challenges. Execution of the above recommendations will ensure a successful SA-GEMS/Water programme.

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Annexure 1
Annexure 2

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