A Strategy for linking South Africa to the Water Programme of the United Nations Global Environmental Monitoring System (GEMS)

by

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Declaration

I, the undersigned hereby declare that the thesis submitted herewith, for the degree Philosophae Doctor, to the University of the Free State contains my own independent work. This work has hitherto not been submitted for any other degree at any other University faculty.

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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
LQMS	Laboratory Quality Management System
NCMP	National Chemical Monitoring Programme
NEMP	National Eutrophication Monitoring Programme
NGO	Non Government Organisation
NMMP	National Microbial Water Quality Monitoring Programme
NRMP	National River Health Programme
NTMP	National Toxicity Monitoring Programme
NWRS	National Water Resource Strategy
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
SASS	South African Scoring System
SADC	South African Development Community
SADC-HYCOS	SADC – Hydrological Cycle Observing System
SQMS	Sampling Quality Management Systems
TSS	Total Suspended Solids
UN	United Nations

UNEP	United Nations Environmental Programme
UNESCO	United Nations Educationa l, Scientific and Cultural Organization
USGS	United States Geological Service
VWG	Vital Water Graphics
WHO	World Health Organization
WMS	Water Management System
WMA	Water Management Area
WWAP	World Water Assessment Programme

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Chapter One: General Introduction

1.1. Background

South Africa and the world's natural resource have been under increasing threat for many years. Natural resources such as mineral deposits, surface and groundwater, natural forests, fertile soils, biodiversity and the atmosphere are being over exploited at an alarming rate. All these resources are closely interlinked and integrated to form the natural environment that forms the basis for man's survival. It is ironic that it is the same species (human) that is responsible for this over exploitation of the natural environment. The basis of this over exploitation lies in peoples individual desires to always be better and have more than others. The basic requirements for sustaining the human species is not enough and this have led to extensive development over the past decades and more so the last decade.

Governments and Non Government Organisations (NGOs) all over the world have come to the realization that at the current rate of over exploitation of our natural resources man is in the process of disrupting extremely complex environmental interactions and balances that need to be in place to ensure favorable living and survival conditions for human kind. To ensure these favorable conditions a large number of Goverments, including the South African Government, are promoting and managing their countries on a principal called sustainable development. Sustainable development can be defined as the ability of current generations to meet their needs without compromising the ability of future generations to meet their needs (Fuggle and Rabie, 1996).

Conservation of the natural environment is an important part of sustainable development. The South African Government regulates and promotes conservation of the environment through various local, provincial and national government departments each with their own legislation and policies, such the Department of Environmental Affairs and Tourism (DEAT), Department of Water Affairs and Forestry (DWAF), Department of Agriculture (DOA), Department of Minerals and Energy (DME), Department of Health (DOH), etc. The task of managing and protecting South Africa's water resources are being performed by the Department of Water Affairs and Forestry (DWAF) although the requirement to protect water resources are also entrenched in the policies and acts of other departments, e.g. DEAT, DOH, DME etc..

Water resource management in South Africa is based on three fundamental pillars, namely: the National Water Policy (DWAF, 1997), the National Water Act (act 38 of 1998) and the National Water Resources Strategy (DWAF, 2004). The National Water Resource Strategy (NWRS) is a fairly detailed strategy on how DWAF gives and will give effect to the said policy and law. The development of the NWRS brings South Africa into full compliance with one of the first targets of the Johannesburg Plan of Action, adopted at the 2002 World Summit on Sustainable Development, namely the development of national water resource management plans. The central objective of managing water resources in South Africa is to ensure that water is used to support equitable and sustainable social and economic transformation and development.

The most fundamental DWAF strategies, objectives, plans, and procedures are based on the following aspects of water resource management (DWAF, 2004) :

- Protection of water resources: Recognizing the need for both resource directed measures and source directed controls in respect of water quantity and quality, as well as the biological and physical dimensions of the resource.
- Water use: A water use authorization system was developed to regulate both water abstraction and any other form of water use that can affect water quality. Chapter 4 of the National Water Act (NWA) regulates water use.
- Water conservation and water demand management: DWAF is developing a National Water Conservation and Water Demand Management Strategy to outline measures and interventions aimed at encouraging and supporting water

institutions and water users to increase efficiency of their water use and reduce their demand for water.

- Water pricing and financial assistance: DWAF is in the process of developing a pricing strategy for water use charges. The NWA empowers the Minister to establish a pricing strategy for any water use as described in section 21 (Chapter 4) of the NWA.
- Water management institutions: One of the NWA's main objectives is to decentralize the responsibility and authority for water resource management. A huge number of resources and effort are being put into the demarcation and establishment of Water Management Areas, Catchment Management Agencies, Water User Associations and Water Forums.
- Monitoring and information systems: The NWA requires that national monitoring systems be established for water resources. Section 1.3.2 of this document expands on the current and future DWAF monitoring initiatives.

DWAF has also recognized over the past ten years the importance of international co-operation with regards to water issues. This involvement ranges from sub-regional (shared water resources), to regional , to continental , to global (United Nations) initiatives. One such initiative is the United Nations Environmental Programme's global water quality monitoring programme that is driven by the Global Environmental Monitoring System/Water Programme (GEMS/Water).

For over twenty years GEMS/Water has been operating as the water resource 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 (UNEP, 2003).

GEMS 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 2002 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 based on the commitment to be inline with Agenda 21 requirements. Chapter 18 (18.39.d) of Agenda 21 requires all States to participate, as far as appropriate, in international water quality monitoring and management programmes such as the GEMS/Water. GEMS/Water made it clear that they do not require DWAF to operationilise a new monitoring programme, but to make use of existing national monitoring programmes. It is, however, necessary to design, establish and sustainably operate a programme for ensuring transmission of globally significant and credible water quality 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 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) was 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 gives 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. Aim and goals of study

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). Whether the global reports such as the World Water Development Report for which the data are used have any form of environmental, social or economical benefits to regions or individual countries are debatable depending on the relevance correctness of the content of those documents. This does, however, not change the fact that reports will be produced and that if credible and representative data from countries are not available the authors of those reports will extrapolate or find data of questionable relevance or credibility somewhere else, as has happened in the past.

If South Africa does commit to providing such data and does not really have the capability of producing relevant and credible data it will have to accept any misrepresentation of its water resources in international reports. As mentioned earlier the United Nations World Water Development Report (UNESCO, 2003) ranked Belgium as the country with the worlds worse surface water quality. Personal discussions with the Belgium GEMS/Water representative (Mr Rudi van Nevel) have revealed that this has caused severe political ructions between Belgium and UNEP. According to Van Nevel, Belgium did supply new more representative data to UNESCO after which a re-assessment was done that placed Belgium in a much better position. The damage was, however, already done. Although much can be said about the global assessment methods the point is that you as a country cannot complain about the outcome of these assessments if unrepresentative or unreliable data was supplied to start with.

The **aim of this study** is, therefore, to conceptually design a scientifically sound strategy that will enable South Africa to provide the UN GEMS/Water with relevant and credible water quality data and to simultaneously assess and debate the capability of South Africa to effectively implement and operate such a programme.

Hypothesis

South Africa has the capability of providing the UN GEMS/Water with relevant and credible water quality data for use in global assessments

In order to achieve the project aim and proof the hypothesis the following specific **project goals** were set:

- To formulate an overarching strategy for linking SA to the UN GEMS/Water programme.
- To develop the SA-GEMS/Water monitoring programme objectives, based on GEMS/Water and DWAF requirements.
- To develop a scientifically sound and sustainable monitoring network (sampling sites, sampling frequencies and monitoring variables) based on SA-GEMS/Water monitoring programme objectives.
- To define a management structure (including quality and data management) that will enable the monitoring programme to produce data that will satisfy the monitoring programme objectives.
- To assess the ability of DWAF to implement and maintain the proposed monitoring programme and to make recommendations on how to achieve this.

1.3. General Approach (Methodology)

This section gives an overview of the overarching process that was used to achieve the project goals. More detailed specifics and references relating to methodologies used are contained in the individual chapters and annexures. During the study two international trips were undertaken during which general discussions relating to this study were held with international stakeholders. The GEMS/Water offices and other UN offices in Canada and Austria were visited in 2003 and 2004 respectively.

1.3.1 Formulation of an overarching strategy to link SA to GEMS/Water

The focus and bulk of the work done in this study is directed towards the development of the various aspects required to supply GEMS/Water with relevant data in a sustainable manner. This work is, however, put into perspective through the formulation of an overarching strategy that for linking SA to the UN GEMS/Water programme in a sustainable manner. This strategy can serve as a tool that other countries can use as guidance for linking to the UN GEMS/Water programme.

The strategy is based on the execution of the four main aspects linking SA with UN GEMS/Water, namely political initiation and interaction, formal agreements and liaison, technical design and alignment, and operational implementation, operation and data submission. See section 6.1.1 for more detail.

1.3.2 Formulating SA-GEMS/Water objectives

Having concise and relevant objectives were seen as critical for the effective design and operation of the SA-GEMS/Water programme. To ensure that the objectives would be concise and relevant it was important to first evaluate and understand the UNEP GEMS/Water (the client) expectations. An analyses of the final information and data requirements from the SA-GEMS/Water clients were done during a visit to the UNEP GEMS/Water office in Burlington, Canada. Based on the requirements and expectations the SA-GEMS/Water objectives were developed. The objectives served as the corner stone of the monitoring programme design and future operational procedures of the programme. The process of achieving this goal is documented in chapter 2 of this thesis. These objectives formulated in chapter 2 were discussed with UNEP GEMS/Water before it was attempted to achieve the following project goals.

1.3.3 Designing the monitoring network

The main questions that had to be answered to achieve this goal was; where to sample?, when to sample? and what to analyse? The process of answering these questions was directed by the programme objectives that were agreed upon.

Various techniques such literature searches, database searches, a geographical information system (GIS), maps of existing national monitoring sites and an expert workshop (annexure 2) were used to identify the most appropriate monitoring sites. In order confirm that the chosen sites were generally representative of flows from the larger catchment areas statistical comparisons of data from sites higher up in the catchments were done. Site visits to all the identified sites were conducted and relevant spatial and temporal site information for the selected sites is captured in annexure 1 of this thesis.

Various statistical methods and results from previous studies were used to determine optimum sampling frequencies that would enable the programme to generate datasets that could be used for detecting trends with a high level of power and confidence, while at the same time avoiding serial correlation in the datasets. Existing national sampling frequencies were also taken into account. The methods used were directly related to the final use of the data.

The selection of variables to be measured or analysed were purely based on a trade-off between the UNEP's wish list and what DWAF can currently provide with their existing national monitoring programmes. The required laboratory methods were also identified (annexure 4).

Chapter 3 gives a detailed account of the methods and outcomes associated with the network design phase.

1.3.4 Defining a management strategy

The main management categories that had to be dealt with to ensure the SA-GEMS/Water objectives can be met, were quality management and operational roles & responsibilities. These are dealt with in chapters 4 and 5 respectively.

The purpose of chapter 4 is to identify any potential issues that can have a negative impact on the credibility of the final data product and to develop a strategy to prevent and mitigate those potential errors. A quality management system (QMS), based on the international quality management standard ISO 9001:2000, was developed to address quality assurance issues. The purpose of the QMS is not only to ensure that quality control (QC) measures, such as calibration etc., exist but also to manage those QC measures. Some of the main tools that were used were interviews and site visits to the Canadian Centre for Inland Water, Umgeni Water and DWAF laboratories. Knowledge obtained during ISO 14001 audits conducted by the author on various organizations also assisted with the formulation of the proposed QMS.

The necessary roles and responsibilities (chapter 5: Operational Requirements) that will be required to achieve the programme objectives were developed inline with existing capacity in DWAF. An effort was made to ensure that as little as possible additional roles and responsibilities were assigned for the operation of the SA-GEMS/Water monitoring programme.

1.3.5 Assessing the DWAF capability and making recommendations

The assessment of DWAF's ability to implement the proposed SA-GEMS/Water monitoring programme was done throughout the study, from the setting of objectives to the development of a monitoring network, a quality management system and operational requirements. All facets of the design phase were based to a large extent on the DWAF capability and existing infrastructure.

Chapter 6 summarises all the shortcomings and associated recommendation that were made throughout this study. The recommendations are aimed at guiding DWAF towards the successful establishment and sustainable operation of the proposed programme. Chapter 6 also concludes with a final discussion on whether the project goals have been achieved and reflects back on the null hypothesis.

1.4. Water quality monitoring and its application in South Africa

It is anticipated that the GEMS/Water monitoring programme 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.

1.4.1 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 literature available gives 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 signaling, 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 the above definitions 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 and Smart, 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 to biological monitoring such as the South African Scoring System (SASS) are generally not considered in global sustainability assessments.

In general South African 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 fulfill 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 (1-5) and their interaction within a monitoring programme.

As illustrated in figure 1.1, all monitoring programmes starts at the point where there is a need for information or data (1). This then results in a design phase (2) that addresses how the data will be acquired (monitoring network), how the data will be managed and stored, how information will be generated (reporting) and what quality management protocols needs to be put in place. The next step is implementation (3) of the design which, depending the magnitude of the programme can take years or days. Implementation then results in an operational monitoring system (4). The operational is the day to day data generation, storage and reporting that can be seen as the production line. These reports are fed back to the information user (1) who at any stage can request for a revision of the programme (2) if it is felt that the data or information that is being produced does not match the information need (1). None of the components (1-4) can function optimally without proper programme management and funding. This issue must receive the necessary attention in the design of any monitoring strategy.

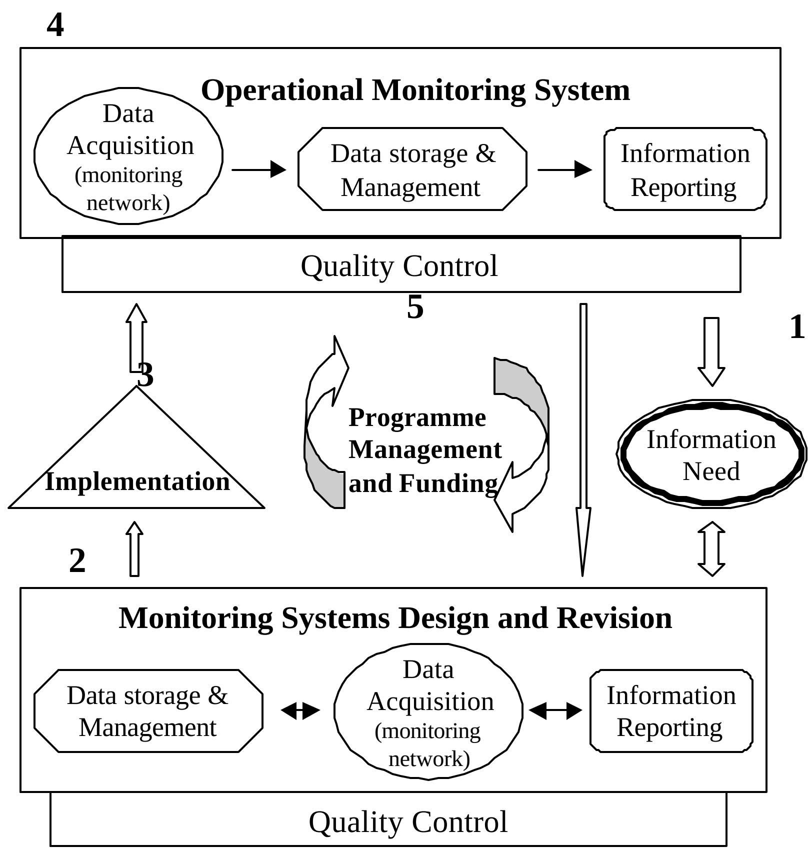


Figure 1.1.: Illustration of the various components within a monitoring programme.

1.4.2 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 fourth 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 1 200 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 water quality monitoring 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. However, 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 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, has grown into a large network elephant with no clear 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, radioactivity water quality information became apparent. To address those needs Chapter 14 of the

National Water Act (Act 38 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 precede d 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 Monitorinmg Programme (NTMP)

- The National Aquatic Ecosystem Health Monitoring Programme or so-called River Health Programme (RHP)
- The National Radioactivity Monitoring Programme (NRMP)

The reason for initiating a number 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, specific 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 is South Africa.

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 small percentage of the data produced by the programme over the past fifteen years has been used for national reporting. Data are, however, extensively used for a variety of water related studies 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 behavior 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 Faecal Coliforms (depending on laboratory capacity). Samples are taken on weekly or bi-weekly basis and analysed at the closest suitable laboratory that can be used. Samples must be kept cool and analysed within 12 hours. (DWAF, 2002b). 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 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 has already been implemented in 13 WMAs and will be fully implemented in all 19 WMAs by 2007.

National Eutrophication Monitoring Programme (NEMP)	**Design process:** A large number of South African impoundments have being monitored since 1986. The monitoring programme was previously 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. 100 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 in the process of being finalised. **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 finalised yet. **Data management:** Not finalised yet. **Information reporting:** Not finalised yet. **Programme management:** Not finalised yet. **Current operational status:** N/A

National Aquatic Ecosystem Health Monitoring Programme (NAEHMP) also known as the 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 at 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 could be developed or could 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 recently finalized a framework titled "Strategic Framework for National Water Resource Quality Monitoring programmes"

Chapter Two: Information Requirements and Monitoring Objectives

2.1. Introduction

The South African GEMS/Water (SA GEMS/Water) monitoring network will feed into a more strategic (spatially and temporally) level of resource assessment than the national monitoring programmes. SA GEMS/Water will, therefore, aim to 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 are 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.

The purpose of this chapter is to develop objectives for the SA-GEMS/Water monitoring programme that will ensure that both the GEMS/Water and DWAF requirements are met. The monitoring objectives serves as a basis for development of the SA-GEMS/Water programme. DWAF has, however, set only one very specific requirement 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.

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 present study might, therefore, be the first purposefully well documented National GEMS 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 (WHO, 1992). Although this document is outdated with a lack in precision relating to the final use of data 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 need 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 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 (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.

It was, however, very difficult to find clear evidence of actual reports that indicates where these types of information were used in global reports.

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 (POPs)
- 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 and often report on similar issues, although for different reasons. The South African NMMP can, for example, only report on the levels of faecal pollution in selected priority areas and not on the general levels of faecal pollution in SA rivers. This will need a microbiological monitoring programme with different monitoring network design. 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.

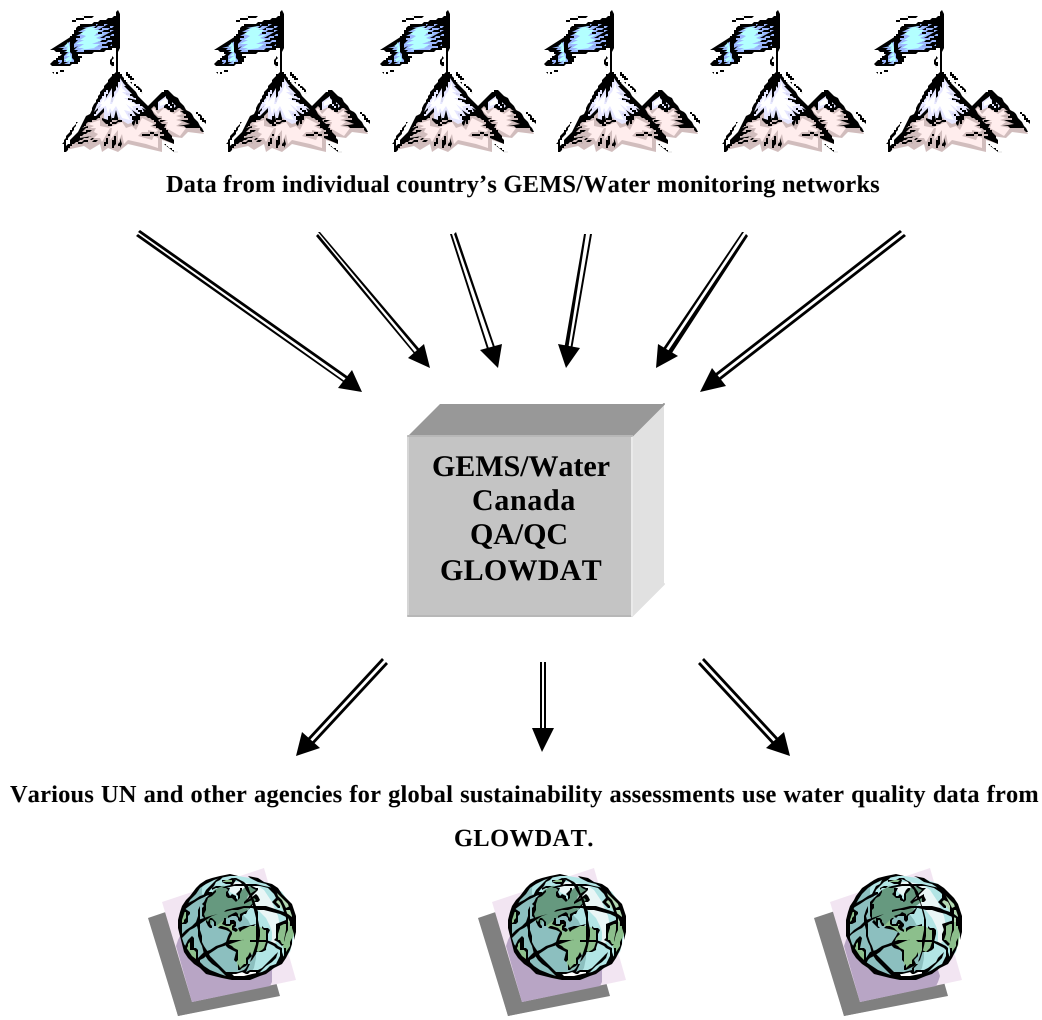


Figure 2.1: Data and information flows from individual countries to global assessments.

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 implication 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" (magnitude)	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 their 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	"Fluxes (loads)"	The water quality data for this requirement needs to be linked with flow data in order to produce loads.

and other pollutants from 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. SA-GEMS/Water 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 table 2.2 and table 2.3 below. The main distinction between the two sets of proposed objectives is that the first set (table 2.2) 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 (table 2.3) is, therefore, more centered 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.

Table 2.2: First set of proposed objectives for the SA GEMS/Water monitoring

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.

Table 2.3: Second more generic set of objectives that has been agreed upon to be 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 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.

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 information, namely;

- SA-GEMS/Water monitoring programme objectives (formulated in 2.2.3);
- 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
Section 3.2 Global river flux to the oceans						
Section 3.3 General water quality trends, incl. impacted areas						
Section 3.4 Baseline water quality						

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

Reservoirs were not considered for baseline monitoring as the purpose of this type of monitoring is to monitor un-impacted system. Reservoirs are generally not seen as natural as systems that are man made. Globally the focus is more on large natural freshwater lakes.

3.2. Global River Flux to the Oceans

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

:

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 *et al.*, 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 sites 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 has been identified namely primary, secondary, tertiary and quaternary (Midgley *et al*, 1994). There are 22 primary catchments in South Africa, namely 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 globally significant catchments can be identified. As discussed earlier in the report the national water resource 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 programmes 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 *et al.*, 2002). Figure 3.1 illustrate s this concept.

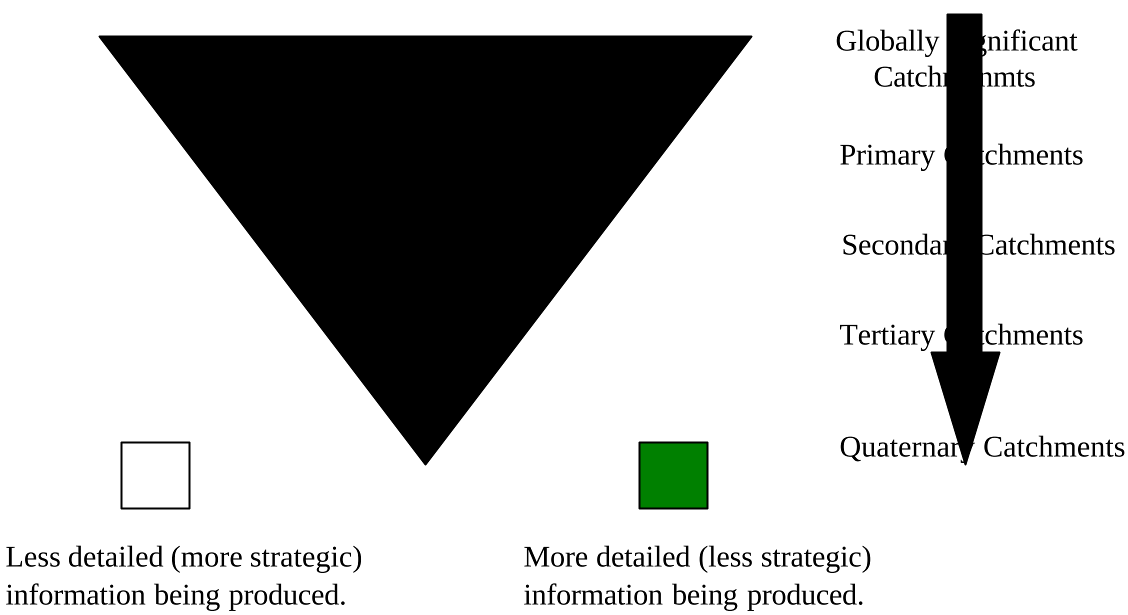
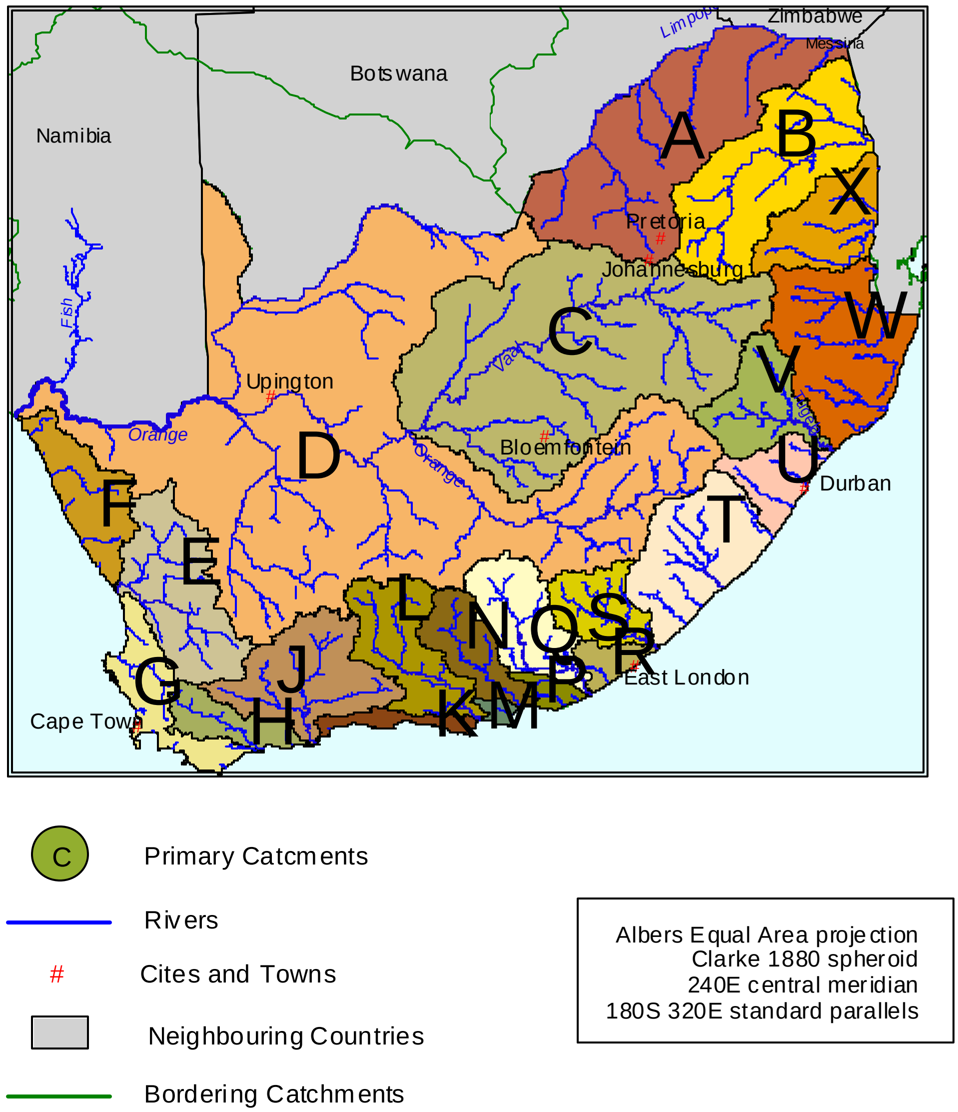
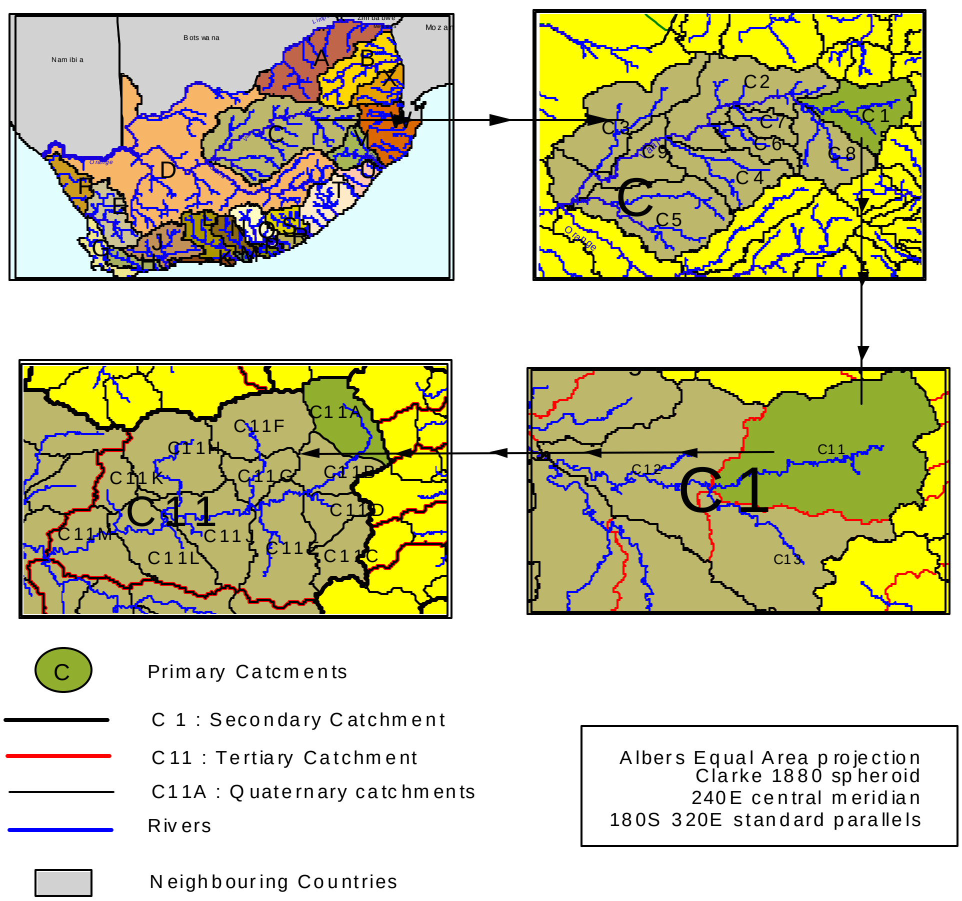


Figure 3.1: Linking catchment hierarchy with different levels of monitoring.

Map 1:
Primary catchments and rivers of South Africa



Map 2:
Catchment hierarchy of South Africa



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 worlds 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.grdc.bafg.de). 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.

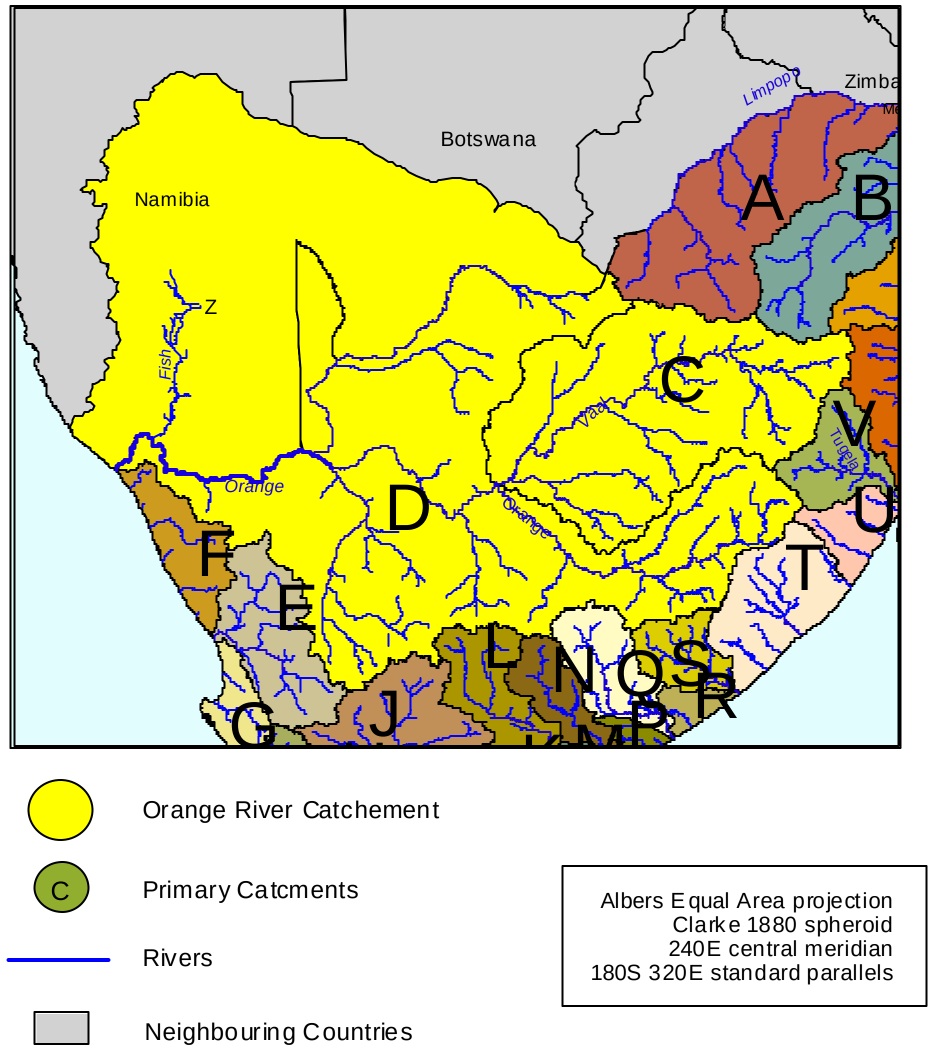
Globally Significant River Basins in Africa			
No.	**GRDC Basins**	**GEMS Basins**	**Vtital Water Graphics**
1	Zaire	Chari	Senegal
2	Niger	Niger	Volta
3 4	St Paul Sanoga	Nile **Orange**	Niger Chad
5	Kouilou	Senegal	Juba
6	Volta	Zaire	Turkana
7	Oueme	Zambezi	Ogooue
8	Gambie		Congo
9	**Orange**		Zambezi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

15	Senegal		
16	Zambeze		
17	Limpopo		
18	Rufiji		
19	Juba		
20	Save		

It is clear from table 3.2 that the Orange River catchment is considered as a globally significant catchment by the largest global water resource assessment bodies. Although the Limpopo catchment 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 a large percentage of South Africa, Namibia and Botswana, although a very small percentage of flow originates in Namibia and Botswana (Midgley, *et al.*, 1990). The Orange River catchments (Map 3) consists mainly of primary catchments C & D (South Africa) and catchment Z (Namibia/Botswana).

Map 3:
Extent of the Orange River catchment



Micro site selection:

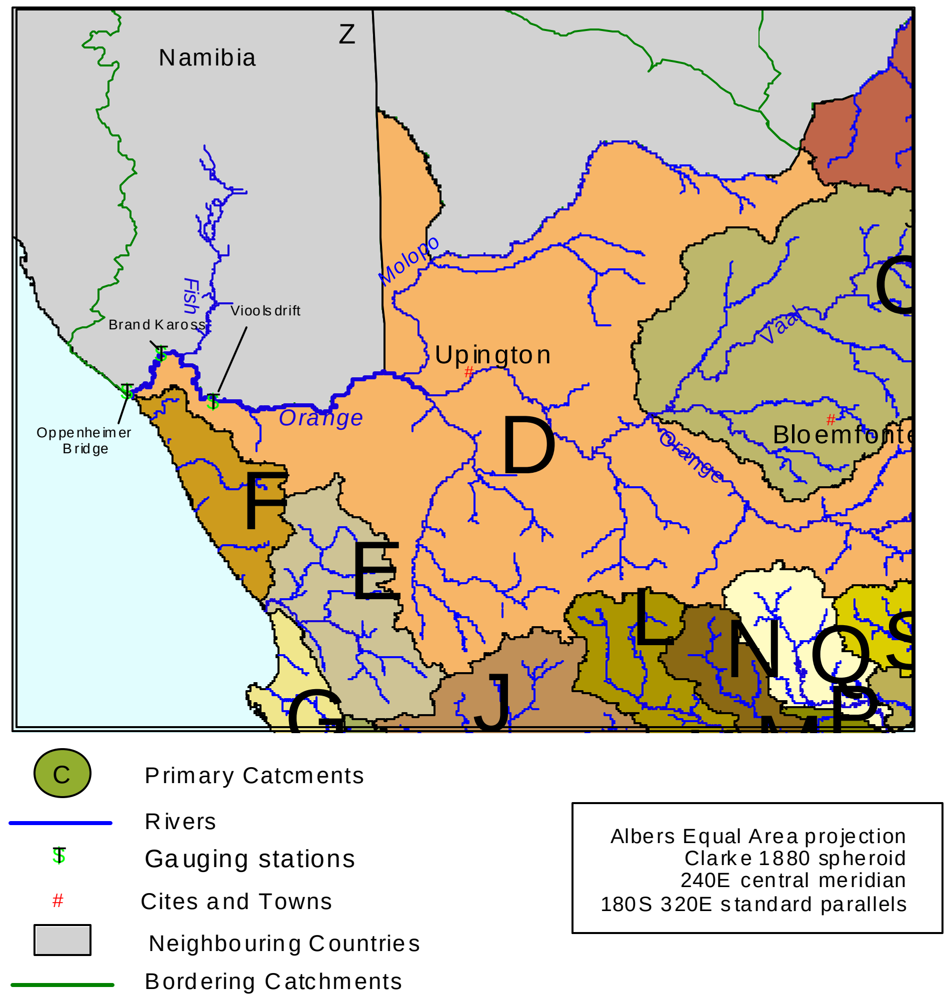
In order for the global river flux to the oceans monitoring to produce representative data and information, the monitoring sites need to be placed as close to the ocean as possible. The fact that it is a freshwater monitoring programme does, however, dictate that there should not be any tidal or marine 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 are 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 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



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	None	None	None

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 Kaross, 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 which 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 catchments 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 an ephemeral river with very little discharge into the Orange River (DWAF Hydrological Information System (HIS)).

Situated close to river mouth?

Although Oppenheimer Bridge is situated the 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: Hydrology the closest stations to the river mouth that could be considered for international use were Brand Kaross 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 has 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)
- 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 programe co-ordinators 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	
Zinc (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 should be included in the GEMS/Water programme only for the global river flux station.
Chrom ium, particulate	No	
Copper, particulate	No	
Iron, particulate	No	
Lead, particulate	No	
Manganese, particulate	No	
Mercury, particulate	No	
Selenium, particulate	No	
Zink, particulate	No	
<u>Organic contaminants</u> (As per Stohckholm Convention)		
Aldrin	No	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.
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	

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 with a summary of all method descriptions in Annexure 3. As far as flow measurements is concerned for load calculations, the chosen site at Vioolsdrift is situated at a flow gauging station and the flow data is available from DWAF and the Global Data Runoff Centre which is a GEMS/Water partner.

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	New code
Dissolved Salts			
Calcium Magnesium	Method 0020101 Method 0012101	Automated Determination of dissolved calcium by Atomic Absorption Automated Determination of Dissolved Magnesium by Atomic Absorption	20103 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	17203
Sulphate	Method 0016104	Automated Turbidimetric Determination of Dissolved Sulphate	16302
Alkalinity	Method 0010101	Automated Determination of Alkalinity using Bromophenol Blue	New code
Nutrients			
Nitrate plus nitrite	Method 0007107 Method 0007109	Automated Determination of Dissolved Nitrate by Cadmium Reduction Automated Determination of Dissolved Nitrite	New code
Ammonia	Method 0007106	Automated Determination of Dissolved Ammonium with Indophenol Blue	07557
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	06101

Inorganic contaminants			
Aluminium (diss & tot) Arsenic (diss & tot) Boron (diss & tot) Cadmium (diss & tot) Chromium (diss & tot) Copper (diss & tot) Iron (diss & tot)	Dissolved: SOP 2001	Dissolved Metals in Water - Sample Preparation for Ion Coupled Plasma	1516
Lead (diss & tot) Manganese (diss & tot) Mercury (diss & tot) Nickel (diss & tot) Selenium (diss & tot) Zinc (diss & tot)	Total: SOP 2002	Metals Extractable by Acid at Boiling Point - preparation for Ion Coupled Plasma	1502
Particulate matter			No code
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		
Zinc, 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, 2004). The highest TSS loads take place during extreme storm events that can be over in hours or days (Moon and Dardis, 1988). 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: "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 a 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), and Looser (2004). 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. Daily flow measurements are available for Vioolsdrift.

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 was identified. Those variables were pH, Electrical Conductivity, Dissolves Phosphate as P (PO_4-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. The test was 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.

	ZR for Weekly	ZR for Bi-weekly	Rv for Monthly
pH	6.41 #	3.966 #	1.629
PO_4-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 (#) occur where the calculated ZR value is greater than the Z 1-a. Where a = 0.005 Z1-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 (Bartram 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 behavior 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, 1992) 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).

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

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 samples 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 are 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: $$N \geq \left[\left(\frac{2 * t(confidence)}{Error} \right)^2 * Variance \right]$$ …….(see page 48)

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 both 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 formula xx 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 he same confidence in the calculated means for different variables over the same time period. The data users should take this consideration into account.

3.3. Global Water Quality Trend Monitoring

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

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 *et al*., 2001). This applies to major rivers and dams. The data may also be used for water quality status determination.

Cavanagh, *et al*. (1998) 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 SA 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. Globally the current number of sites are 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 mentioned global water quality issues.

The only truly objective way to select the sample sites were 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 has 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 networks in SA at the workshop was more than 200 years. See annexure 2 for workshop overview. 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 at Roodeplaat Dam (see annexure 2) 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 view a large catchment as > 100 000 km^2 and a small catchment typically as < 10 000 km^2. Medium sized catchments are, therefore, assumed to be < 100 000 km^2 and > 10 000 km^2. In the South African catchment hierarchy the highest level of catchments, namely the primary catchments, fall within the latter 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*, 1992) and the National Water Quality Assessment (Hohls, *et al*, 2002) 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. (COD)
  - Eutrophication of surface waters as a result of point and non-point input of nutrients and organics. (PO_4^- and Chl-a)
  - Irrigation areas which are threatened by salinization and polluted irrigation return waters. (TDS)
  - Agro-chemical use, fertilizers and pesticides leading to surface water contamination. (POPs)
  - Industrial effluents containing a variety of toxic organics and inorganics. (POPs)
  - Mining effluents and leachates from mine tailings affected surface water on a large scale. (SO_4 and pH)

- o Acidification of lakes and rivers resulting from the long-range atmospheric transport of pollutants. (pH and SO_4)

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. Refer to Annexure 2 (Workshop proceedings) and Annexure 1 (Site information, including spatial and temporal data) for specific site related information.

Table 3.9: Proposed river trend monitoring sites.

Site name	WMS ID	Primary catch.	Comment
Trend stations for drainage of the interior of SA (Orange and Vaal River systems).			
D8H003Q01 AT VIOOLSDRIFT ON ORANGE	101888	D	The hydrometric gauging station at Vioolsdrift receives runoff from 87% of the Orange River Catchment. The remaining 13% drains a dry area between Vioolsdrift and the Orange River mouth. Vioolsdrift gauging station is the closest SADC-HYCOS station to the ocean. This is as a result of the high sediment loads downstream of Vioolsdrift that pr events consistent hydrometric measurements. An audit of current water quality sampling consistency at all potential sites also revealed that sampling at Vioolsdrift was the most consistent of all the potential sites. This site is, therefore, the most appropriate site for inclusion in the Global River Flux monitoring network. As this site has already been identified as the most appropriate site for monitoring loads of water quality constituents from the Orange River catchments. It is therefore also the ideal site for trend monitoring of runoff from the interior of South Africa
D3H008Q01 AT MARKSDRIFT ON ORANGE RIVER	101824	D	This site was included to represent runoff from the Orange River catchment upstream of the Vaal River confluence. The data will represent a mixture of water from the Caledon River, Kraai

			River and Orange River. Two large dams, namely the Gariep and Vanderkloof Dams are situated upstream of the site below the confluences with the Caledon and Kraai Rivers.
C9H024Q01 AT SCHMIDTSDRIFT (WEIR) ON VAAL RIVER	101770	C	Except for the Modder/Riet sub-catchment, this site represents the whole Vaal River system, which can be said to be the hardest working river in South Africa. The Modder/Riet River system joins below the site upstream of the confluence with the Orange River. No suitable site could be found below the Modder/Riet and the confluence with the Orange. The site represents the impacts of large irrigation schemes such as the Vaal/Harts and upstream industrial and mining activities.
C2H007Q01 AT PILGRIMS ESTATE ORKNEY ON VAAL RIVER	90618	C	The purpose of this site is to reflect the combined impacts of the major industrial complexes and mining activities in the upstream catchment of the Vaal River system.
Trend stations for drainage of catchments through neighboring countries to the ocean. Catchments A (Limpopo River), B (Olifants River) and X (Komati River).			
A2H0012Q01 AT KALKHEUWEL ON CROCODILE RIVER	90164	A	This site represents the catchments area of the Crocodile River upstream of the Hartebeespoort Dam. This sub-catchment drains the major economical hub, namely the PWV area. Although it represents a small drainage area it reflects on the typical quality of water draining from a large urban and industrial area. Both the Jukskei and Hennops Rivers are included in this drainage area which also represents drainage from large informal settlements. Large volumes of water that are pumped from the Vaal River system by Rand Water for domestic and industrial purposes also end up in this catchment as sewerage and industrial effluent.
A5H006Q01 AT BOTSWANA STERKLOOP ON LIMPOPO RIVER	90340	A	The Sterkloop site represents drainage from the entire Crocodile (West) Marico Water Management Area and Ngotwane River Catchment in Botswana that includes runoff from Gaberone.
A7H008Q01 DOWN	90375	A	This site represents drainage from South

STREAM OF BEIT BRIDGE ON LIMPOPO RIVER			Africa and Botswana's capital cities together with large agricultural and limited forest areas in the Limpopo catchment. Downstream of this site the Limpopo River flows into Mozambique from where it flows into the Indian Ocean.
B7H007Q01 AT OXFORD ON OLIFANTS RIVER	90503	B	The Olifants River catchments drains extremely mineral rich area which are also characterized by large coal deposits and forest areas. The site therefore represents a drainage area dominated by mining and forestation. The site is situated upstream of the Kruger National Park as no suitable sites could be identified in the National Park.
X2H036Q01 @ KOMATIPOORT KRUGER NATIONAL PARK ON KOMATI RIVER	102979	X	This site is situated immediately downstream of the confluence of the Crocodile with the Komati River before it flows through Mozambique into the Indian ocean. Forestation and protected nature areas largely dominate both Catchments, although some mining activities do occur.
Trend stations for catchments in the coastal regions of South Africa			
V5H002Q01 AT MANDINI ON TUGELA RIVER	102779	V	The Tugela catchment forms part of the group of Kwazulu/Natal catchments that is responsible for the highest Mean Annual Runoff in the country. It originates in the Drakensburg and is characterized by high sediment runoff. The monitoring site is close to where the Tugela enters the ocean.
U2H055Q01 AT INANDA LOCATION EGUGWINI ON MGENI	87822	U	The Mgeni catchment is a hard working catchment characterized by large rural and urban settlements, a high level of industrial development and number of impoundments. Although it is a relatively small catchement compared to the Tugela it was felt that as a result of the high level of development this site should be included.
S7H004Q01 AT AREA 8 SPRINGS B ON GROOT-KEIRIVIER	102568	S	The site represents runoff from the S primary catchment. It reflects the area of interchange between the high rainfall catchments to the north and the low rainfall area to the south. The catchment is characterised by a low level of development. High sediment yield are common in this area.

Q9H018Q01 AT MATOMELA'S RESERVE OUTSPAN ON GROOT-VISRIVIER	102487	Q	The largest proportion (inland) of the Fish River Catchments has a very low occurrence of rainfall. The catchment does however receive large quantities of water from the Gariep Dam in the Orange River system via pipelines. This is mainly for irrigation purposes and further distribution to the Sundays River to the South. Natural saline conditions poses a major problem for irrigation schemes. Except for the lower part of the catchment in the Port Elizabeth area where there are generally a low level of industrial development in the catchment.
H7H006Q01 AT SWELLENDAM ON BREE RIVER	102119	H	The Bree River catchment is the most Western catchment draining to the Indian ocean. Although it has by far the smallest catchment area, it has the highest mean annual precipitation, runoff, and reservoir storage capacity and irrigated land area in the Western Cape. Grape farming and the wine industry are dominant in the catchment. The site represents drainage from one of the most intensively irrigated areas in the country.
G1H036Q01 AT VLEESBANK HERMON BRIDGE ON BERGRIVIER	101939	H	The Berg River catchment is the most Southern catchment draining into the Atlantic Ocean. It is also the catchment with the highest rainfall on the South African West Coast. It is also highly developed in terms grape farming and the wine industry with some degree of forestation. Selecting the ideal site was problematic as limited sites were available to choose from. The lower part of the catchments is known for high salinity values with salt mines impacting on sites in the outflow of the catchments The site that was selected does however reflect the general water quality in the catchment.
E2H003Q01 AT MELKBOOM ON DORINGRIVIER	101903	E	This site represents only the Doring River sub-catchment in the greater Olifants/Doring catchments. The is a direct result of a lack of operational gauging stations that form part of the national water quality monitoring network. This was, however, not seen as a problem as the main areas of

			concern relating to water quality lies within this sub-catchment.

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 7 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. All seven WQMR are fairly represented (se Table 3.9 above). Site J4H002Q01 in lower reaches of the Gourits River was also proposed for inclusion. There were, however, talks that that site might be closed and it was proposed that the site be included after this matter has been resolved.

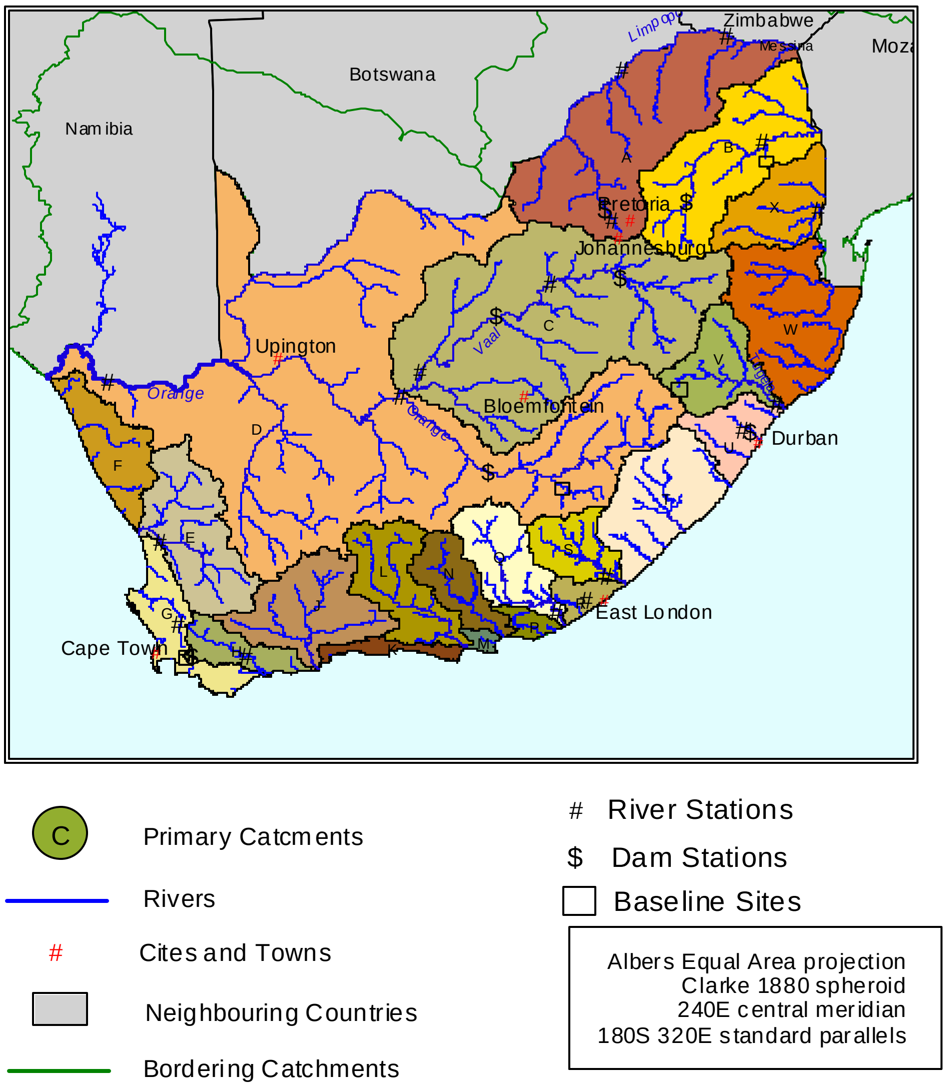
The next step was to perform an audit of the sampling performance of the National Chemical Monitoring Programme (NCMP) in order to determine whether sampling are performed as scheduled at the sites identified in Table 3.9 above. As indicated in Table 3.10 below the number samples taken for macro constituents 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 (scheduled:taken = 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	195:169=87%	A7H008Q01	52:35=67%	R2H027Q01	31:29=93.5%
D3H008Q01	200:183=91%	B7H007Q01	184:77=42%	Q9H018Q01	105:104=99%
C9H024Q01	172:69=40%	X2H036Q01	190:178=94%	H7H006Q01	49:25=51%
C2H007Q01	206:201=97.6	V5H002Q01	49:44=89.8%	G1H036Q01	206:113=55%
A2H012Q01	209:205=98%	U2H055Q01	Not available	E2H003Q01	194:58=30%
A5H006Q0	52:28=54%	S7H004Q01	56:48=86%		

In general the sample sites are well distributed geographically. The T primary catchment 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:
Trend Monitoring Stations



As an addition measure to confirm that trends detected at the chosen sites are not site specific, but represent changes in the catchment, trends in electrical conductivity from sites upstream of the chosen GEMS sites were compared with trend at the chosen GEMS sites. Sites with at least 25 years of electrical conductivity data were used to perform linear trend analyses using the Seasonal Kendall trend test and Seasonal Kendall Slope Estimator (see annexure 4 for method details). The Seasonal Kendal test was chosen rather that the Mann Kendall trend test to account for seasonality (Griffith *et al.*, 2001). The means of the GEMS and upstream sites of five-year periods over the 25 year periods were also compared. Three major river catchments with sufficient data, namely Tugela, Lower Orange and Great Fish were used for comparing data from the chosen GEMS site with upstream sites. The upstream sites were all a minimum of 100 km upstream of the chosen GEMS sites, although still in the lower part of the catchment. Results are depicted in tables 3.11 to 3.13 and figures 3.12 to 3.17 below.

It was found that there are clear correlations between the selected GEMS sites and upstream sites in terms of linear 25 year trends and shorter term changes in salinity. The Great Fish River shows a statistically significant negative trend in salinity at both sites. Both sites have a slope of around – 4 EC units per year with salinity peaking in 1987 after which a general decline started (Fig. 3.2). Both the GEMS and upstream site in the Lower Orange river showed a statistically significant upwards trend of around 0.6 EC units per year over the 25 year period. Both sites indicated short term increases in salinity around 1985 and 1994 with an increased variability in the data over the last 10 years of the data record. Individual increases and decreases in five year means also corresponded. A statistically significant trend in EC could not be detected in either the GEMS or upstream site of the Tugela River. The slope at both sites were less that 0.01 EC units per year.

It was therefore concluded that the GEMS sites in all three rivers are sufficiently representative of the catchments and would be sufficient for detecting globally significant trends. Although sufficient data was not available to test all the selected GEMS river sites it is assumed that the other GEMS sites would also be able to detect significant upstream changes in salinity. This argument is only valid for conservative variables and not for a non-conservative variable such as *E. coli*.

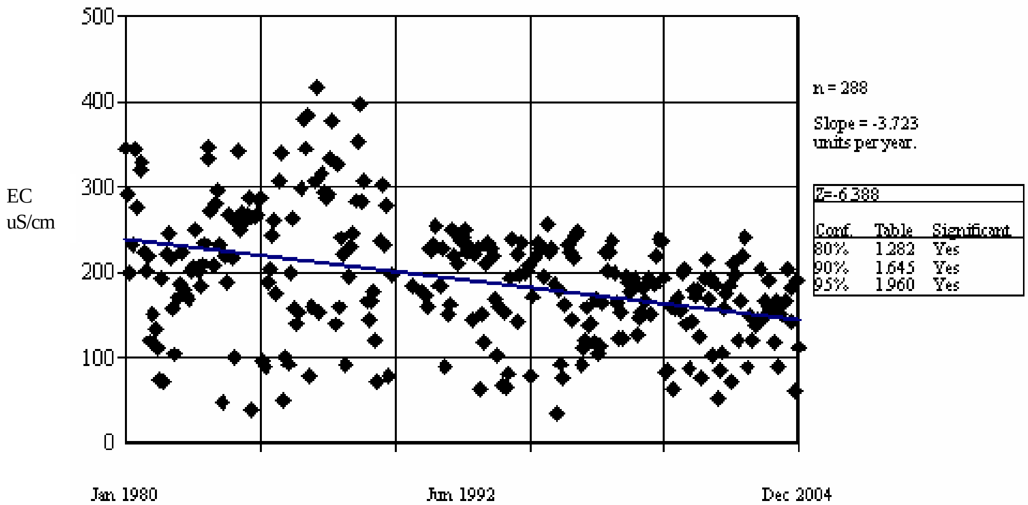


Figure 3.2: Results of the Seasonal Kendall trend test of electrical conductivity for the GEMS site on the Great Fish River.

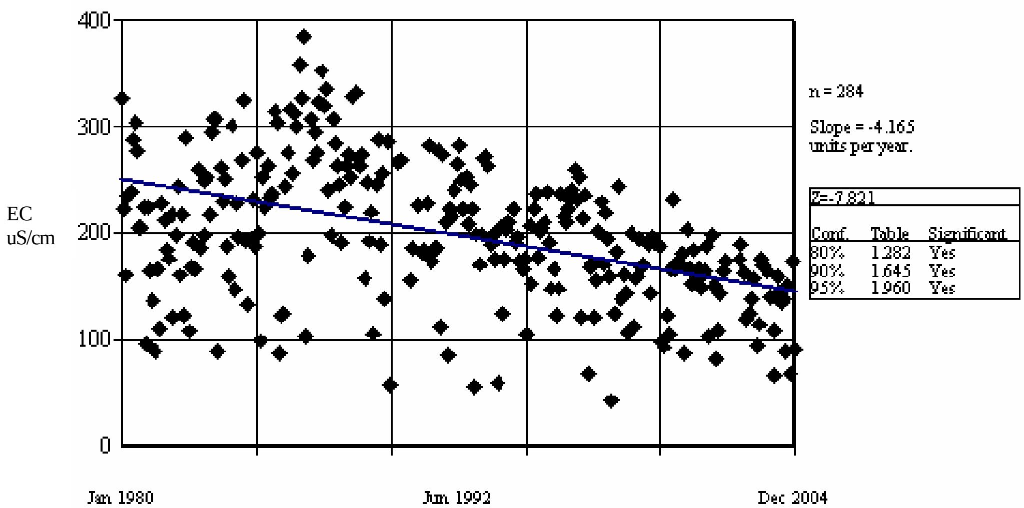


Figure 3.3: Results of the Seasonal Kendall trend test of electrical conductivity for the upstream site on the Great Fish River.

Table 3.11: Results of mean calculations in the Great Fish River

Site	Stat results 1980 - 1984	Stat. results 1985 - 1989	Stat. results 1990 - 1994	Stat. results 1995 - 1999	Stat. results 2000 - 2004	Stat. results 1980 - 2004	Est. slope 1980-2004	SKT Signif. Trend p<0.005
GEMS	**219.6** (74.9)	**227.4** (95.5)	**187.6** (53.1)	**175** (50)	**150** (45.08)	**191** (72.5)	-3.96	Yes
upstream	**209** (60.9)	**251** (69.5)	**203.6** (53.1)	**181** (45.9)	**144.6** (37)	**198** (65)	-4.17	Yes

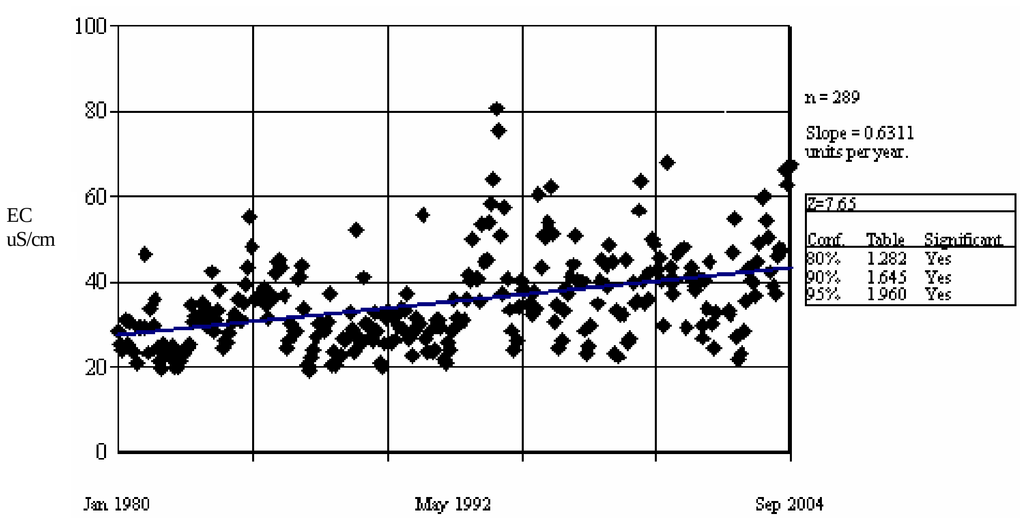


Figure 3.4: Results of the Seasonal Kendall trend test of electrical conductivity for the GEMS site on the Lower Orange River.

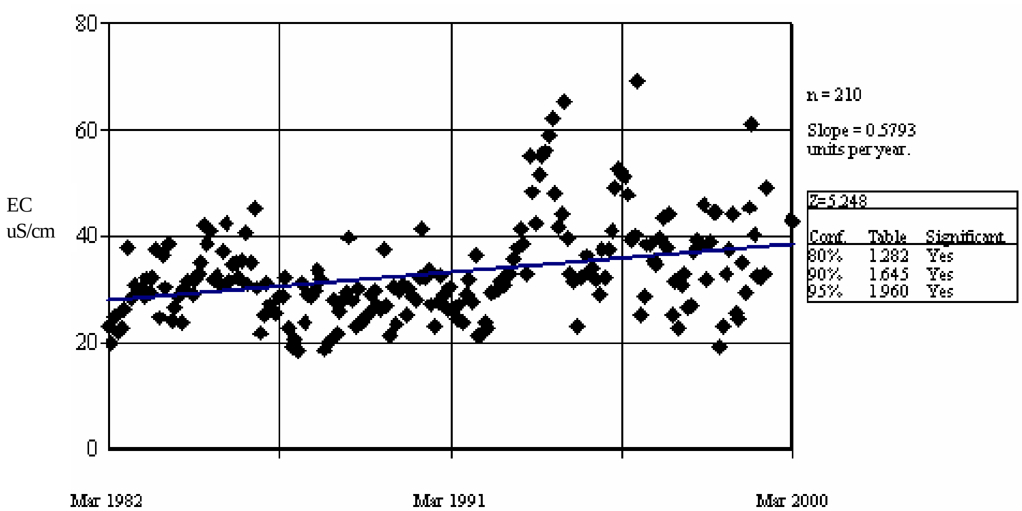


Figure 3.5: Results of the Seasonal Kendall trend test of electrical conductivity for the upstream site on the Lower Orange river.

Table 3.12: Results of mean calculations in the Lower Orange River

Site	Stat results 1980 - 1984	Stat. results 1985 - 1989	Stat. results 1990 - 1994	Stat. results 1995 - 1999	Stat. results 2000 - 2004	Stat. results 1980 - 2004	Est. slope 1980-2004	SKT Signif. Trend p<0.005
GEMS	**29.7** (7.3)	**31** (7.4)	**36.4** (12.7)	**39.4** (9.9)	**43.1** (12.3)	**35.7** (11.3)	0.66	Yes
Upstream	**28.5** (5.6)	**28.9** (5.9)	**34.9** (10.5)	**37.5** (9.7)	**43.05** (0.4)	**32.5** (9)	0.62	Yes

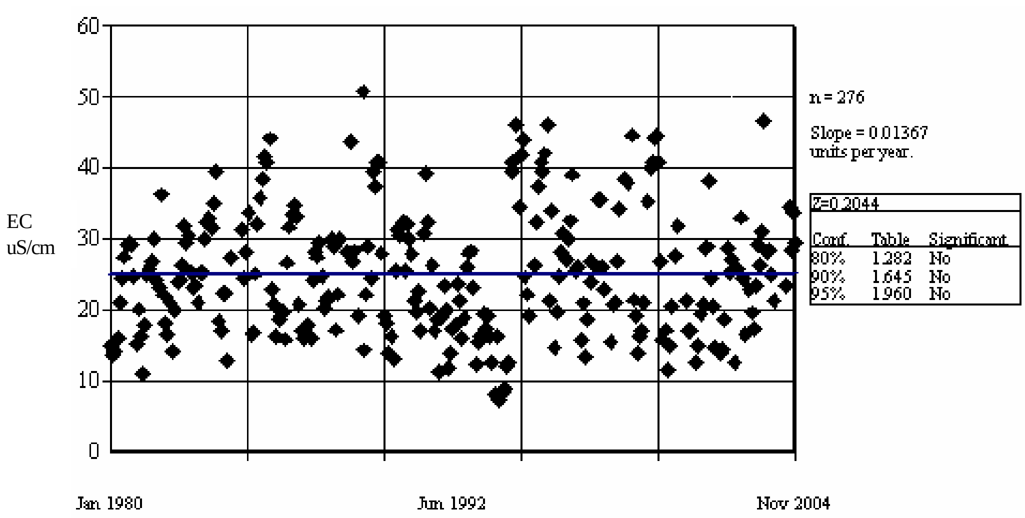


Figure 3.6: Results of the Seasonal Kendall trend test of electrical conductivity for the GEMS site on the Tugela River.

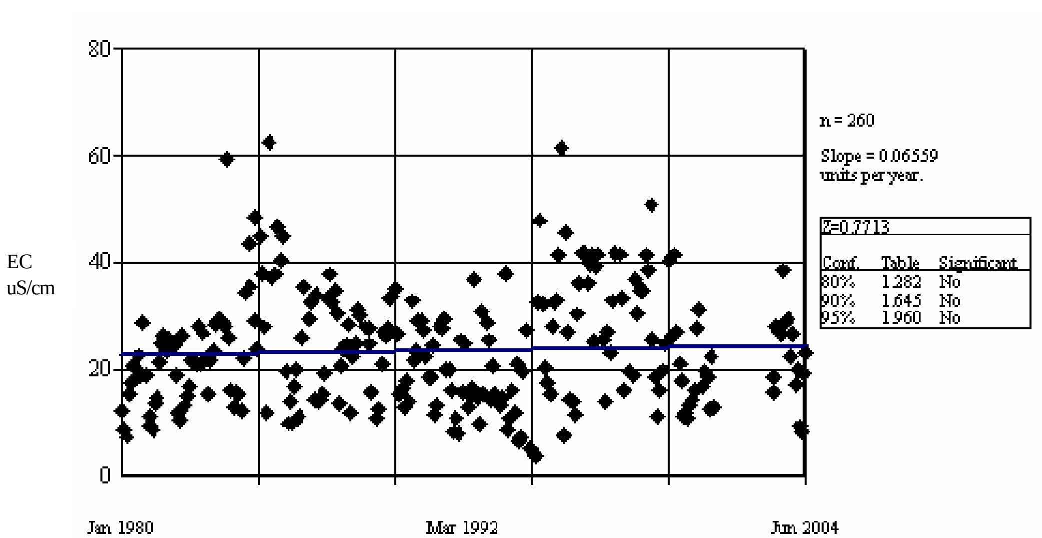


Figure 3.7: Results of the Seasonal Kendall trend test of electrical conductivity for the upstream site on the Tugela River.

Table 3.13: Results of mean calculations in the Tugela River

Site	Stat results 1980 - 1984	Stat. results 1985 - 1989	Stat. results 1990 - 1994	Stat. results 1995 - 1999	Stat. results 2000 - 2004	Stat. results 1980 - 2004	Est. slope 1980-2004	SKT Signif. Trend p<0.005
GEMS	**24** (6.4)	**27.3** (8.9)	**22.2** (9.5)	**27.5** (9.1)	**23.6** (7.4)	**25.3** (9.3)	0.02	No
Upstream	**22.3** (9.9)	**27.3** (14.3)	**19.3** (9)	**29.6** (11.4)	**19.9** (7.5)	**24** (11.6)	0.06	No

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 3.14 below lists the dams (with reasons for inclusion) and should be viewed together with Map 5. Refer to Annexure 2 (Workshop proceedings) and Annexure 1 (Site information, including spatial and temporal data) for specific site related information. 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 3.14: Dams proposed for inclusion in the GEMS/Water Monitoring Programme

Site name	WMS site ID	Reasons for inclusion
A2R001Q01 HARTEBEESPOORT DAM ON CROCODILE RIVER	90240	Although the Hartebeespoort 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 the PWV area that form the economical 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 purposes. 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: NR DAM WAL	102112	The Theewaterkloof Dam is the most strategic water storage facility in the Western Cape. Water from the dam gravitates through 35km 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.

Although experts in the workshop selected only seven dams, it does not imply that those are the only dams of strategic importance in SA. 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 3.15 below). The two programmes make use of the same sites identified above.

Table 3.15: Sampling performance (scheduled: taken = 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	1078:418 = 39%	A2R001Q01 Hartebeespoort Dam	3552:2162 = 61%
C9R002Q01 Bloemhof Dam	1124:361 = 32%	H6R001Q01 Theewaterskloof Dam	49:29 = 60%
D3R002Q01 Gariep Dam	1024:213 = 21%	B3R002Q01 Loskop Dam	761:165 = 22%

The performance for sampling at Inanda Dam is not included in Table 3.12 above. Umgeni Water monitors Inanda Dam and the data has 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 3.15 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 variable 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 difficulty 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 3.16 below gives an indication of the variable requirements and the ability of the national programmes to supply data on those variables.

Table 3.16: Variable requirements compared to the possibility of provision.

Gems/Water Variables	Included in Existing Monitoring Programme	Comment
General Water Quality		
Temperature	No	Must be investigated for inclusion in national programme.
pH	Yes (lab)	Currently only in laboratory. Must be investigated for inclusion during field sampling 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	Yes	
Organic Matter		
Chlorophyll *a*	Yes	Only at dam sites. NEMP only active at dams.
Dissolved organic carbon	Yes	
Particulate organic carbon	No	
BOD	No	.
COD	No	Must be investigated for future inclusion in a national programme
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		
Aluminium (diss & tot)	No	For potential future inclusion in the National Toxicity Monitoring Programme or other programmes. This group of variables are currently not part a national programme.
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 limited number of variables can be included in the SA/GEMS/Water design. 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 3.17 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 they have been incorporated in a national programme.

Table 3.17: 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	
Ammonia	Method 0007106	Automated Determination of Dissolved Ammonium with Indophenol Blue	
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	

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 means 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 has been completed in 1992 (Harris *et. al.*) This design has, however, not been implemented yet and it is proposed that the proposed sampling frequency of monthly be adopted for trend analyses 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 et al., 1992, 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 Groot-Visrivier and Marksdrift on 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. This confirms that a monthly sampling frequency will be adequate, as even longer datasets will be used for global trend detection. Results of the Seasonal Kendal tests are depicted in figures 3.8 to 3.11. See annexure 4 for Seasonal Kendall test. 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 Zealand 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.

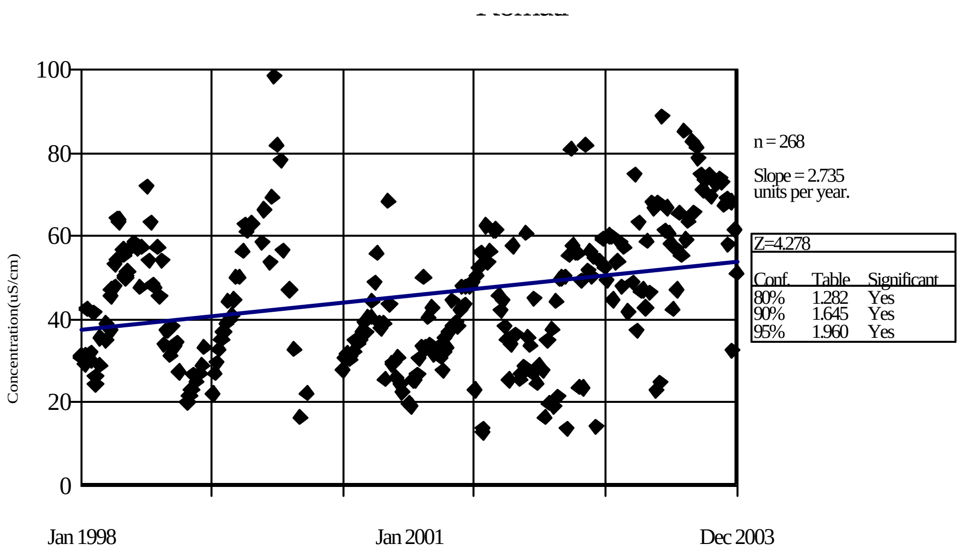


Figure 3.8: Significant upward trend in electrical conductivity in the Komati River, detected with a sampling frequency of weekly over a five year period.

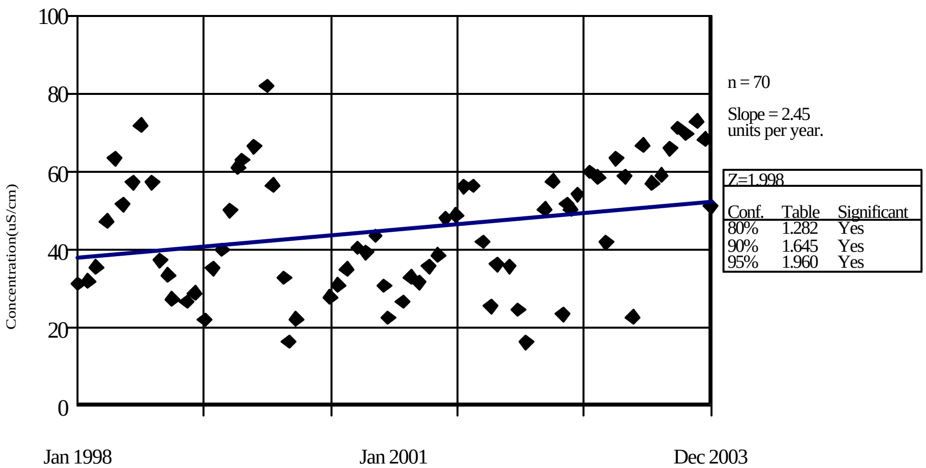


Figure 3.9: Significant upward trend in electrical conductivity in the Komati River, detected with a sampling frequency of monthly over a five year period.

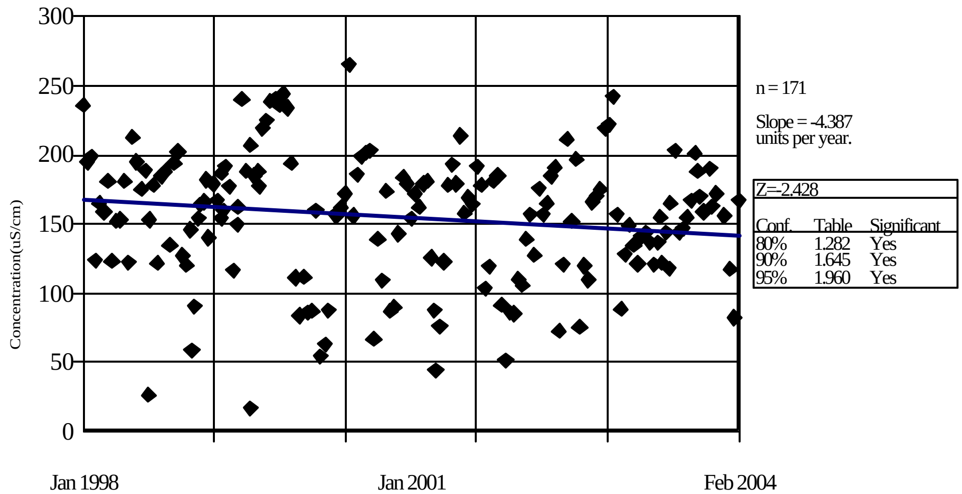


Figure 3.10: Significant upward trend in electrical conductivity in the Great Fish River, detected with a sampling frequency of monthly over a five year period.

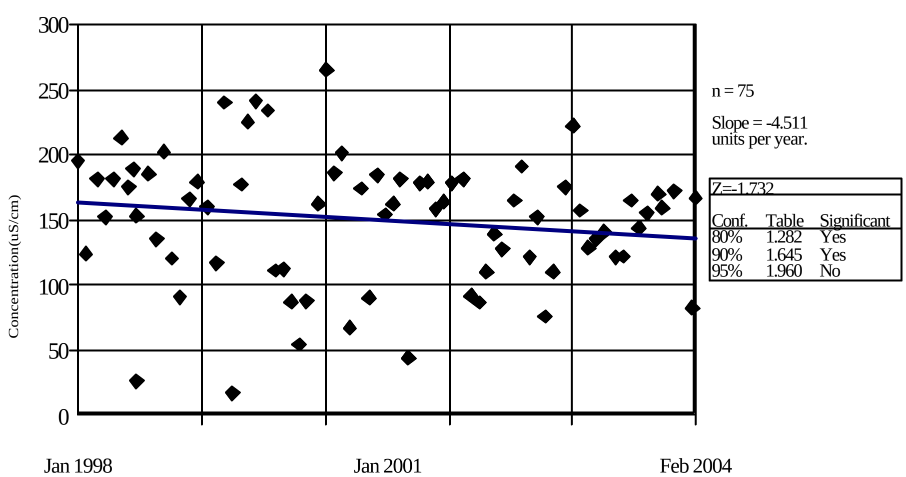


Figure 3.11: Significant upward trend in electrical conductivity in the Great Fish River, detected with a sampling frequency of weekly over a five year period.

Dams

The National Eutrophication Monitoring Programme (NEMP) schedules sampling to take place on a two weekly basis (DWAF, 2002a). 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 are 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 Hartebeespoort 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 station 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 2).

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 together 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
- 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. 18 gives an overview of the sites and associated information. See annexure 1 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 3.18: 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 Drakensburg 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 has les 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 (USEPA, 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.

- 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.
- 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 of utmost importance that one has a detailed understanding of the process that needs to be controlled. In this case the process being the water quality monitoring programme. The development of QC measures must be based on a process analyses that highlights all potential sub-processes that needs to be controlled in order to avoid any deviation from the required product specifications. In this case the product being 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 needs to be controlled.

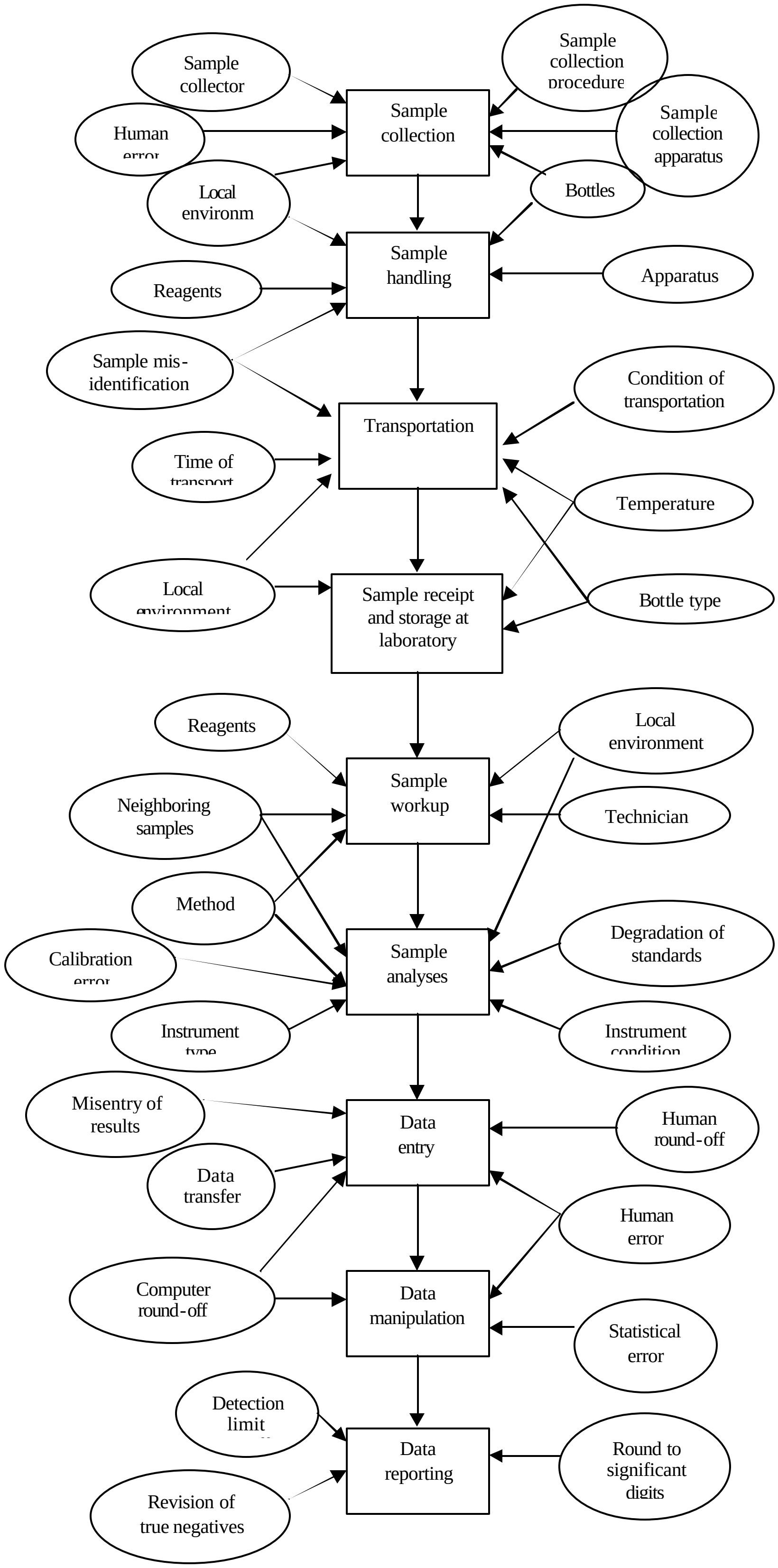


Figure 4.1: An illustration of a typical monitoring process and associated sources of error. Reproduced from Clark (2000)

From the example in Figure 4.1 above it is clear that there is a large number of potential sampling and analytical errors that 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, there are a large number of monitoring programme operators that believe 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 the their data are any less credible. In most cases the cost involved in maintaining certification status outweighs the benefits. In most cases the application of the basic QMS principles are 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

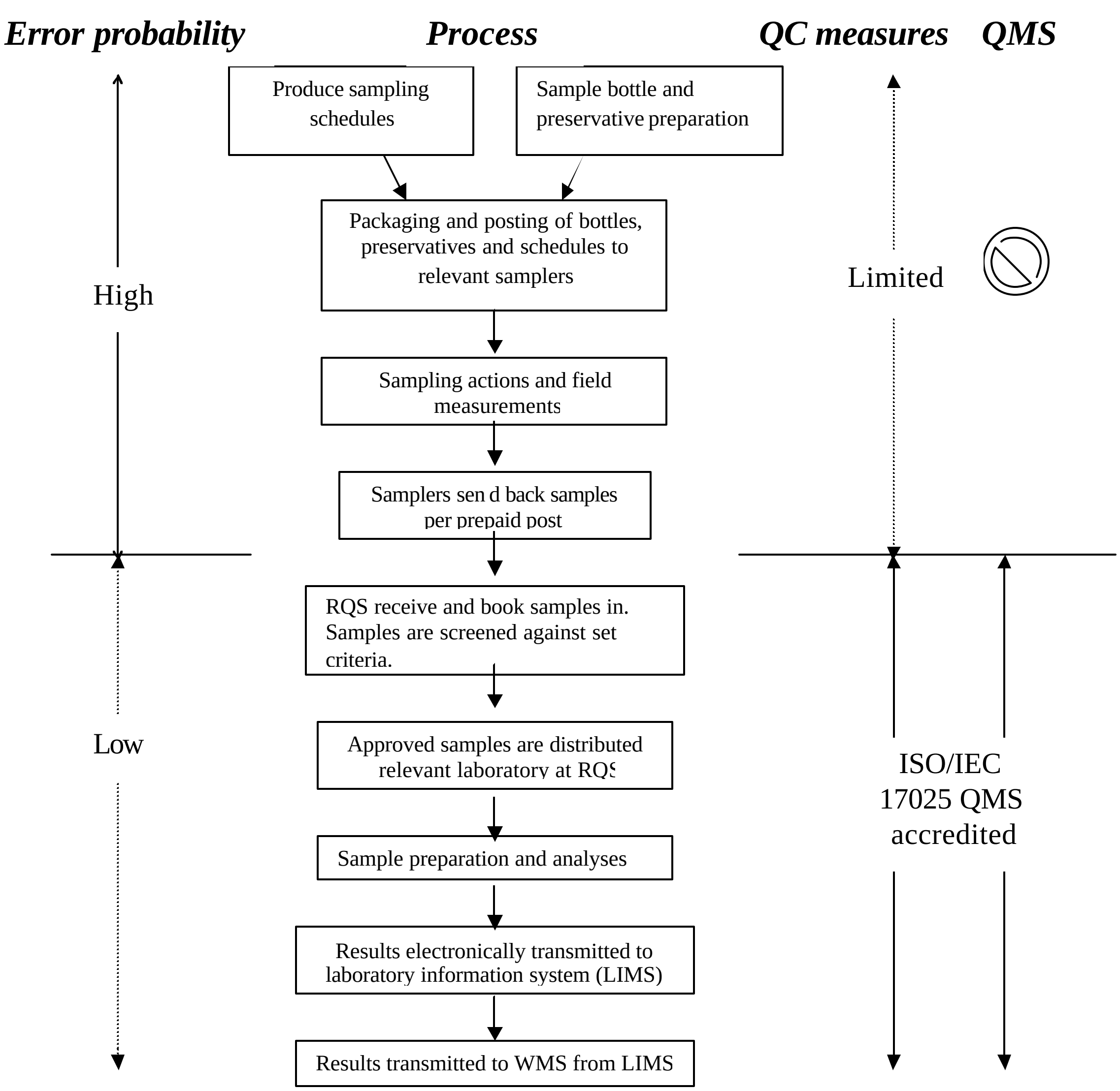


Figure 4.2: Current Quality assurance status in the NCMP

Figure 4.2 shows 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
- 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-receival of post as result of non-payment.
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
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.

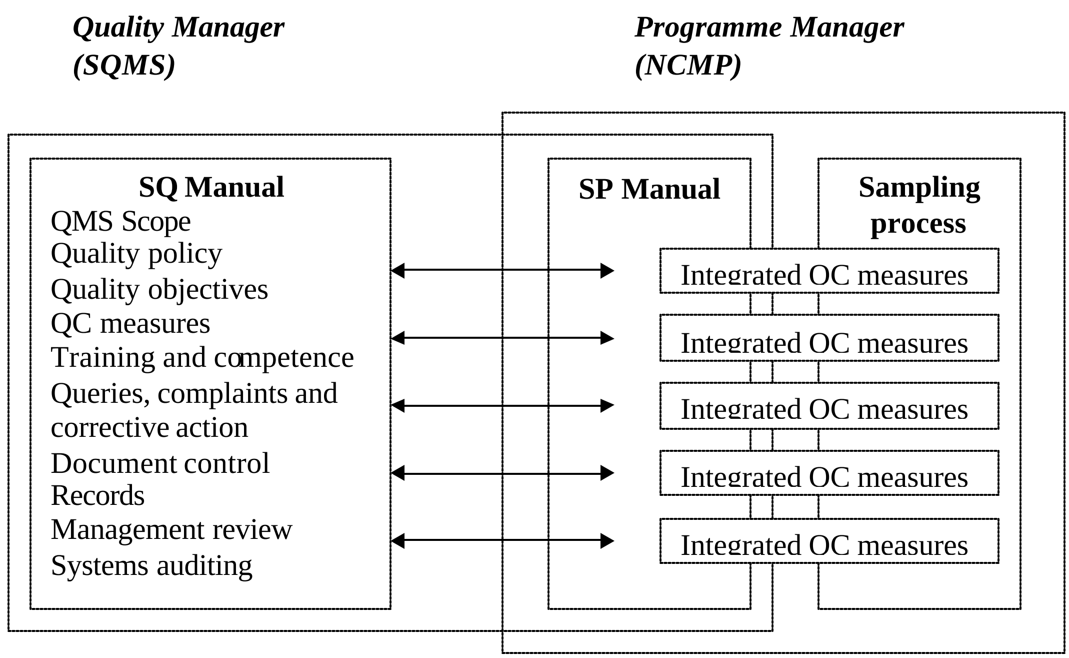


Figure 4.3: Illustration of the main interaction and components of the SQMS

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. See annexure 5.
- 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 topics 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 proagramme operators with the assistance of the SQ manager.

Example Box: Proposed format of QMS procedures.

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

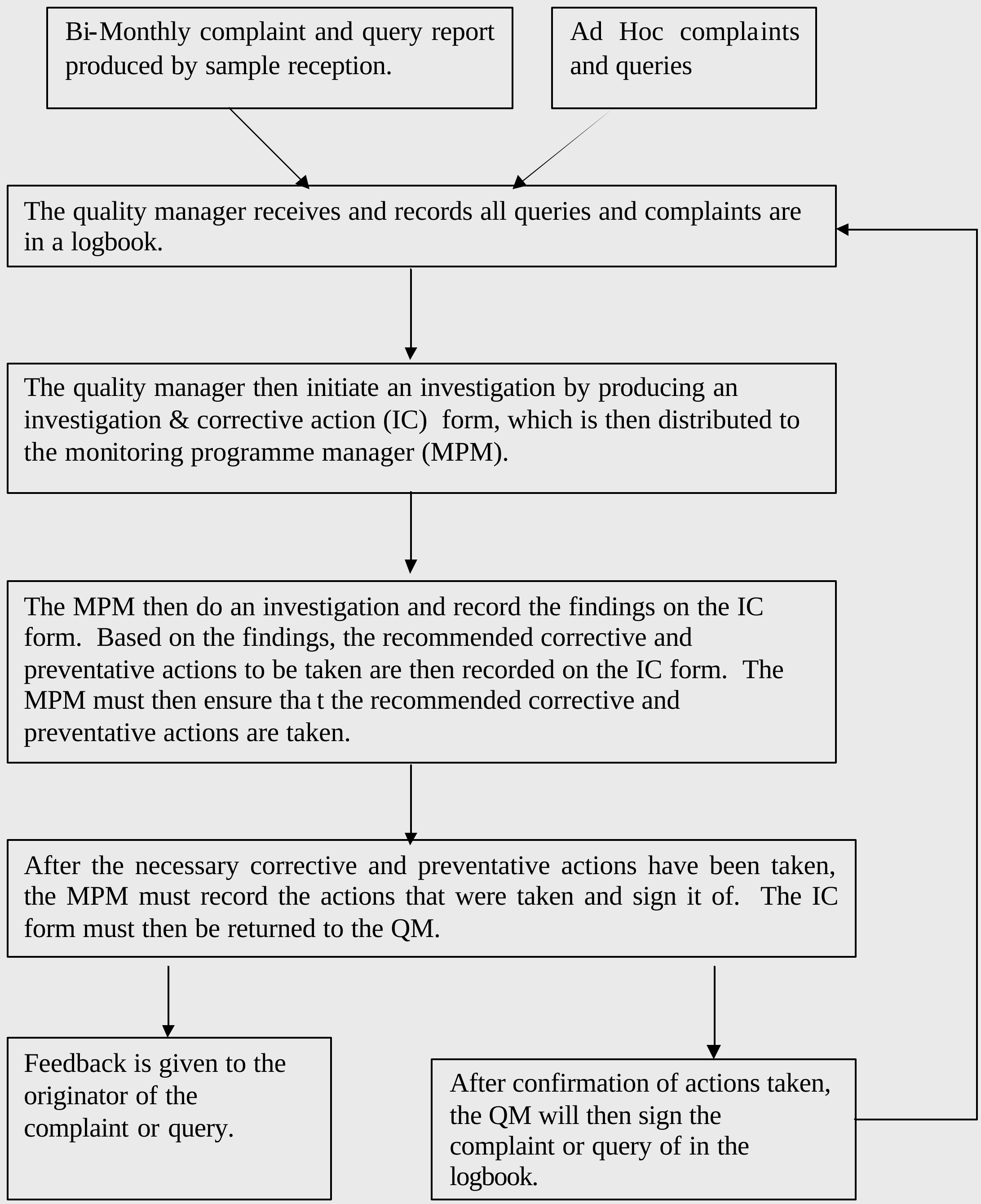
The purpose of this procedure is to describe a system through which all complaints and queries will be logged, investigated and corrective & preventative actions taken. Proper implementation of this system will enhance the effectiveness and efficiency of the SQMS and the sampling process.

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 16 (example) 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. It is recommended that the procedure in annexure 5 be used as a basis for this process.

- 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
  - 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
- 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.

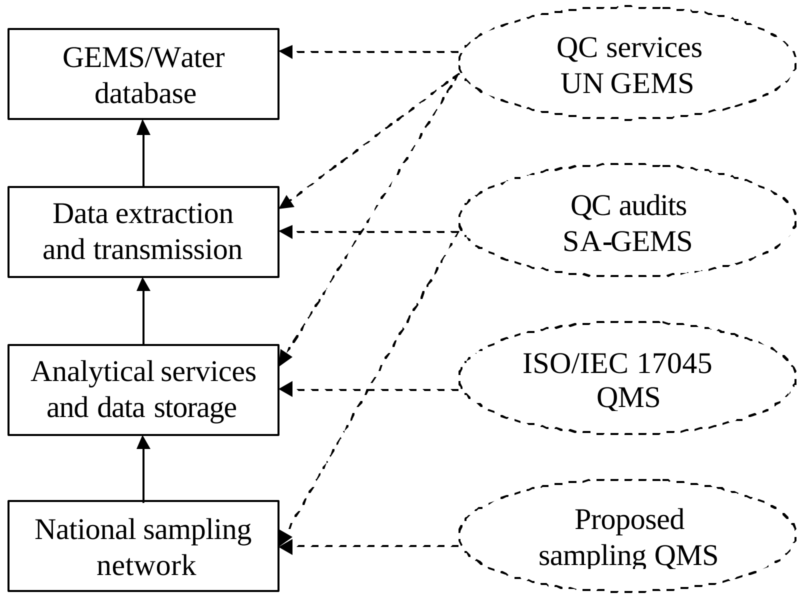


Figure 4.4: Proposed quality assurance structure for SA-GEMS/Water programme

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 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.

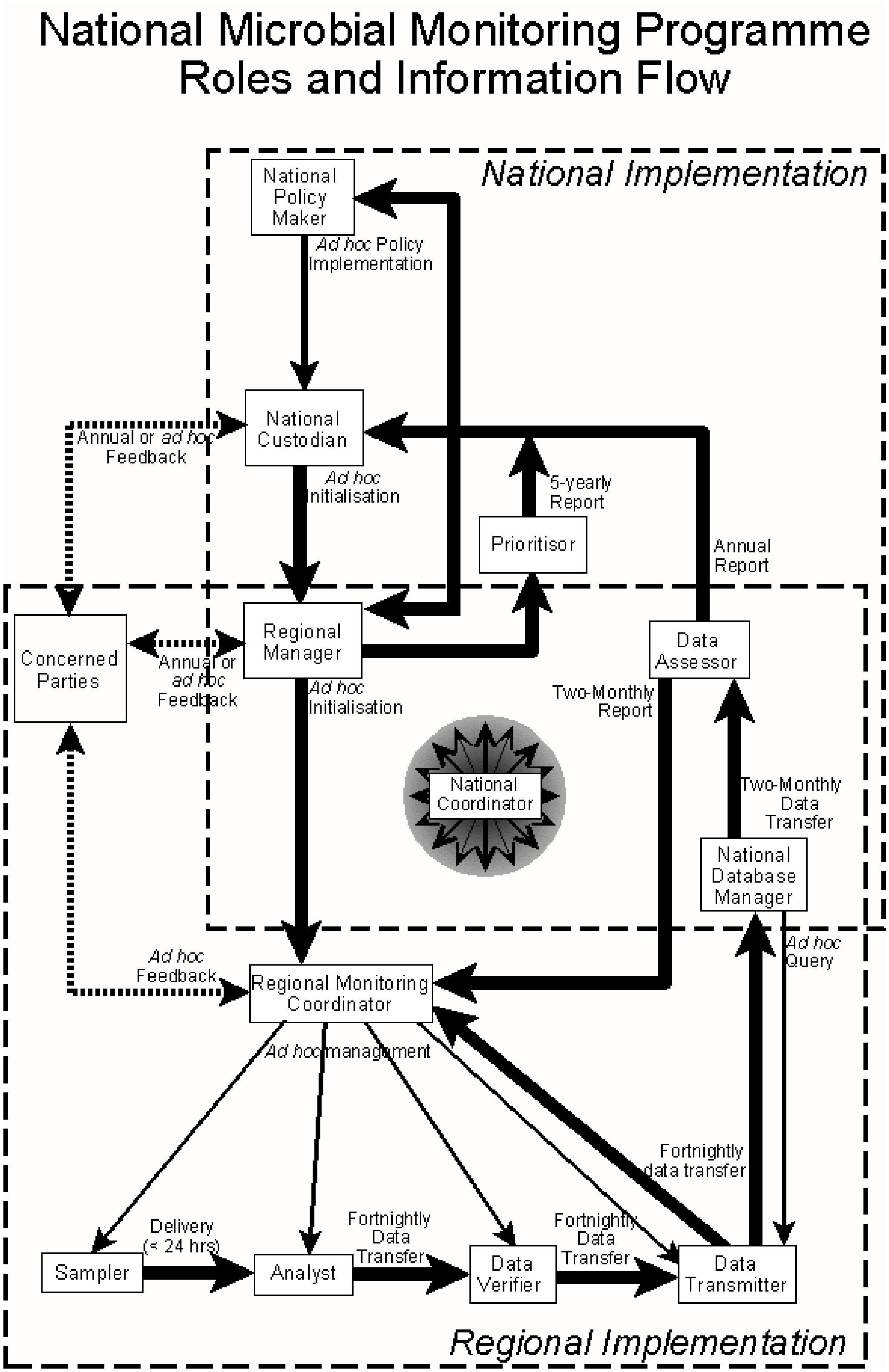


Figure 5.1: Process flow illustration of the National Microbial Monitoring Programme (DWAF, 2002b).

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) Proposedsampling QMS
- (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 represents 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 lone standing monitoring programme, although in reality it will piggy backing 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).

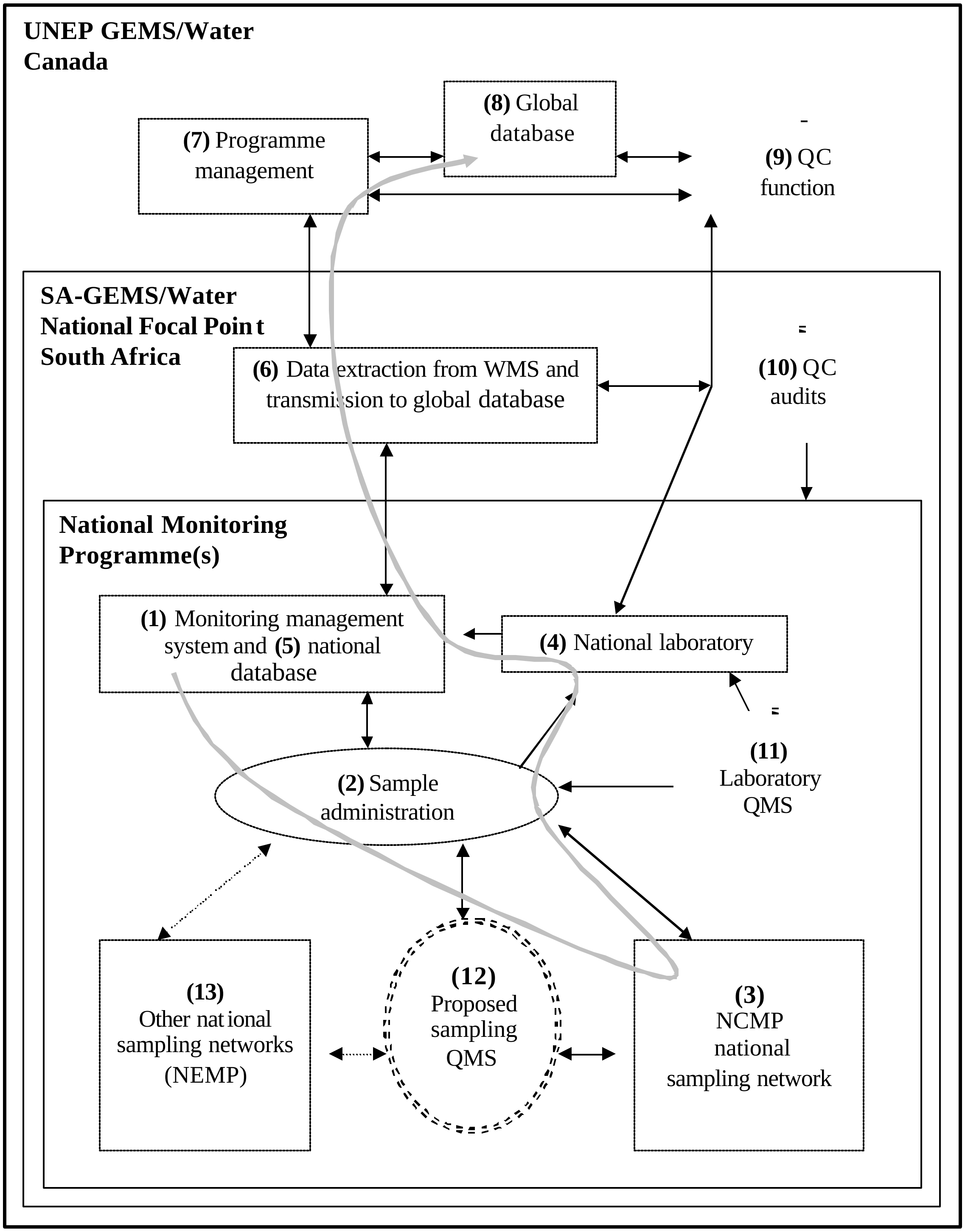


Figure 5.2: Proposed SA-GEMS/Water processes and interactions involved in producing and submitting relevant and credible data to the GEMS/Water global database. The light gray arrow line indicates the main process flow from sample scheduling **(1)** to data entry onto the global database **(8)**. See 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 for mat 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, monitor ing 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 requirements

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.

Chapter Six: Conclusion and Recommendations

The purpose of this chapter is to discuss the study outcomes inline with the study goals, conclude whether the hypothesis stated in section 1.2 can be accepted or rejected and to ultimately make the necessary recommendations to the Department of Water Affairs and Forestry.

6.1 Conclusion

This concluding discussion will firstly focus on the specific project goals as a precursor to the final conclusion, which relates directly to the hypothesis set in section 1.2 of this theses.

6.1.1 Project goal: Formulation of a strategy to link SA to GEMS/Water

The most important and most difficult part of joining the GEMS/Water Global Monitoring Programme is to design the monitoring programme on country leave. It is, however, necessary to have a broader overarching strategy within which such a monitoring programme must function. The proposed strategy is based on four main components that will be required of any country wanting to join the UN GEMS/Water programme. The components are as follows:

- Political initiation and interaction.
- Formal agreement and liaison
- Technical design and alignment
- Implementation, operation and data submission

Figure 6.1 below gives an outline of the strategy and associated interactions required for successful participation in the GEMS/Water programme.

Political Initiation and Interaction

1

1. Initial discussions between senior officials from both parties. Discussions normally during international meetings such as World Water Forum, World Summit on Sustainable Development, UNESCO and UNEP Governing Council meetings, etc.
2. A direct request in writing can also be made the GEMS/Water Director or the GEMS/Water Director can make a direct request to country to join the programme.
3. This initial contact is made for various reasons, such as a countries desire to fulfill it's responsibilities in terms of Agenda 21, to ensure accurate and relevant information on the country's water quality is available for international reporting, etc. or GEMS/Water's mandate to have data available and report on global water quality.

Formal Agreement and Liaison

2

1. Official written agreement by senior officials from both parties both parties (letter of request and letter of acceptance)
2. Appointment of country representative (National Focal Point). The National Focal Point will be responsible for all administrative and technical duties relating to the countries interaction with GEMS/Water.
3. International visits to either party to discuss all administrative and technical requirements of for participation in the GEMS/Water programme.
4. The National Focal Point (NFP) should, as far possible, also engage in international discussions and working groups on global water quality reporting. .

Technical Design and Alignment

3

1. Close interaction, by NFP, with GEMS/Water technical staff to determine the exact requirements for participation.
2. Develop a monitoring programme that will satisfy the GEMS/Water data requirements. This includes all aspects dealt with in this study, namely, monitoring objectives, monitoring network, operational requirements and responsibilities, quality assurance, etc.
3. Ensure alignment with GEMS/Water in terms of terminology, analyses methods, data submission technologies, etc.
4. Make the necessary recommendations to management and other relevant parties regarding requirements for the implementation of the designed monitoring progammes.

Implementation, Operation and Data Submission

4

1. Establish a working group through which discussions, planning and implementation of the recommendations can take place. All parties relevant to the implementation of the programme must be involved.
2. Implementation of the proposed quality management system should be priority as this will ensure that the necessary procedures are available for training and that the appropriate checking and follow-up mechanisms are in place.
3. Data should be submitted to GEMS/Water annuallv in the correct format.

Figure 6.1: Overarching strategy for linking SA to GEMS/Water.

6.1.2 Project goal: Formulating SA-GEMS/Water objectives

Setting objectives for any project, progamme, is of extreme importance to ensure effective operation of the project or programme in a sustainable manner. The setting of objectives for a monitoring programme are normally directly linked to the final information user. In most cases the final information users would be known and, therefore, form part of the team setting the monitoring objectives. The information generation process is also normally seen as an integral part of a monitoring programme. In this case, however, it was found that there is a constant change in international information users and generators, which all make use of the central database hosted by GEMS/Water. This limited the task of setting objectives to the delivery of data that can be used for a broader spectrum of international information generation exercises. After analyses of the most common data, and information requirements, the following monitoring programme objectives were set:

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.*

Although it was possible to set a clear set of monitoring objectives for South Africa it was generally found that some of the methodologies used for generating information from the raw data on an international scale is questionable and this is an important aspect that needs to be taken up by GEMS/Water. International debate around this issue has led to a task team being set by GEMS/Water in 2005 to investigate and make proposals on more effective global reporting methodologies. It should, however, be said that in many cases these reports are not aimed at having a direct impact on countries, but rather to highlight general international sustainability issues and stimulate political debate around those issues. With that being said, it can be concluded that this specific project goal was successfully achieved and served as the basis for the execution of the rest of the project.

6.1.3 Project goal: Designing the monitoring network

The sole purpose of the monitoring network design phase was to propose a network (sampling sites, sampling frequencies, monitoring variables) that would enable DWAF to reach the set objectives. A DWAF requirement that was incorporated into the objectives was that only the existing national networks could be used as a basis for the SA-GEMS/Water network design. This restriction mainly impacted on the variable selection process with limited effect on the sample site selection process. The restriction had no bearing on the frequency determination process as the optimum frequencies that were calculated were generally lower than that of the existing national programmes.

A total of 27 monitoring sites where identified to represent SA's surface water resources on a global scale. Of those sites 16 represent runoff from the major SA catchments, 7 represent large dams of strategic importants and 4 represent un-impacted streams in catchment headwaters. The question of whether such a low number of sample sites could be representative of SA surface water resources were also addressed. It was found that sites in the lower parts of catchments could be used as indicators of general changes in salinity higher up in the catchment and that the specific GEMS sites chosen are representative in terms of the global monitoring programme. The main area of concern was the Eastern Cape with specific emphasis on the T primary catchment area and the Gourits catchment where a suitable existing monitoring site could not be found. Except for the area of concern it can be concluded that the monitoring site selection process was successful.

The determination of optimum sampling frequencies was based on extensive statistical analyses of existing data and the proposed sampling frequencies of monthly for rivers confirmed recommendations made in previous studies. With the proposed frequency it would generally be possible to maintain a high level of confidence for long-term mean calculations. Sampling for suspended solids were, however, set at weekly to accommodate first flush events during the rain season. It was also found that at some stations the current national sampling frequency of weekly is to high for the intended purpose and will result in serial correlation within the data set and wasted resources. Appropriate recommendations are made in this regard in section 6.2.4.

Identification of the appropriate monitoring variables were restricted by the current suite of monitoring variables used in the existing national monitoring programmes. Although the more commonly used monitoring variables such as the macro inorganic salts, pH, EC, nutrients etc. could be accommodated, the non-conservative variables proofed to be a problem. Monitoring variables such as persistent organic pollutants, suspended solids, heavy metals, etc. are not currently being monitoring at a national scale. Although there are plans to implements such national programmes, those programmes will mainly focus on priority areas as a result of the non-conservative behaviour of the variables. It would generally not be representative to test for those variables at the outflow of major catchments as they are generally found close to the pollution source. Although SA have an extensive national microbial monitoring programme, the sample sites are also situated close to pollution sources and not at the outflow of catchments. This issue was raised during discussions with the GEMS/Water office in Canada and it was acknowledged that this is a problem. It is recommended not to include non-conservative variables at this stage, but rather stick to the more general and conservative water quality variables to ensure that only representative data will be submitted from the identified sites. Although data for all the desired monitoring variables cannot be submitted to the global database, it is believed the data that will be submitted is sufficient to ensure proper participation in the global programme without compromising the representative nature of the data.

6.1.4 Project goal: Defining an operational monitoring strategy

Equally as important as having the optimum monitoring network is also having the ability to operationalise and manage the monitoring activities. The monitoring network has been designed to ensure that relevant and representative data can be produced, whereas the optimum operational and management structure were designed to ensure credibility of data and sustainability of data production. Although the current DWAF structures that was used as a basis for a GEMS operational and management structure are well defined, it was found that a large number of samples are not taken as scheduled. It was also found that that a large percentage of samples that reaches the laboratory are rejected because of a number of quality reasons (see chapter 4). In general it was found that data currently produced are suspect as a result of the lack of a formal quality management system (QMS) for sampling on a national basis.

To ensure that SA submits credible data to the UN it was, therefore, necessary to develop an extensive quality management system for the entire national monitoring network. Adoption of this QMS by DWAF is crucial to ensure that the SA-GEMS/Water objectives can be fully met. A number of recommendations in this regard are made (see section 4.4.2). Overall it can be said that this project goal was successfully achieved.

6.1.5 Project goal: Assessing DWAFs capability and recommendations

During the entire project the DWAF water quality monitoring capabilities were assessed against optimum design requirements and discussed where applicable. The main purpose of this assessment was to generate information that would form the basis for the final acceptance or rejection of the project hypotheses and to make the necessary recommendations to DWAF to ensure effective participation in the global monitoring progarmme. The project goal was successfully achieved in that a number gaps were identified as previously discussed and the associated recommendation were made as summarized in section 6.2 below.

6.1.6 Final Conclusion

Based on the above discussion it can be concluded that the all the goals have been achieved successfully and subsequently the aim has been reached. It is clear from the concluding discussions above that although all the project goals have been achieved, a number of potential obstacles have also been identified. This does, however, not mean that South Africa does not have the ability to fulfill its political commitment to actively and effectively participate in this global monitoring programme. During this project (GEMS/Water Technical Advisory Committee meeting in Austria, 2005), discussions with GEMS/Water representatives from Japan, Australia, Belgium, Canada and Iraq indicated that other participating countries generally have the same problems and only submit data that they feel is representative of their surface water systems. None of those countries have, however, gone through such a rigorous design process and it can be said that the data that can be submitted by SA will certainly be representative. Although questions can be raised regarding the current data quality management ability of DWAF, it should be said that by the time this conclusion was written DWAF has already initiated a process of implementation the quality management plan recommended in this study. It will also be advantages to DWAF and GEMS/Water to engage in discussions regarding the problems associated monitoring for non-conservative variables such as POPs and faecal indicators which is highly localized in the area of origin.

It can, therefore, be concluded that South Africa does have the capability of providing the UN GEMS/Water with relevant and credible water quality data for use in global assessments. Adoption and implementation of the recommendations below may even further enhance this ability.

6.2 Recommendations

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

6.2.1 General recommendations

- The recommendations below should be implemented within the context of the overarching strategy discussed in section 6.1.1.
- In order to ensure full recognition of the SA-GEMS/Water programme the relevant data requirement of SA GEMS/Water must be reflected in the objectives of relevant national monitoring programmes.

6.2.2 Sample sites

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

- Only two of the four baseline monitoring sites (Blyde River and Kraai River) are currently active NCMP sites. It is recommended that the other two proposed sites (i.e. Jonkershoek and Mooi River) 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 T primary catchment. 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.

6.2.3 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 water quality 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 has great value in respect of long-term global and regional climate change and should be considered for inclusion a one of the national water resource quality programme.

6.2.4 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 than monthly but that TSS at Vioolsdrift be sampled weekly (see section 3.2.3).

- The most appropriate sampling frequency for SA-GEMS/Water dam sites was determined to be bi 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 proble m be resolved by the NCMP Programme Manager as soon as possible.

6.2.5 Quality assurance

- In general it was found that a large percentage of sample is 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.

6.2.6 Operational requirements

- To aid the transmission of data from 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 DWAF were fragmented in terms of responsibilities for the 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.

References

BARTRAM J and BALANCE R (1996) *Water Quality Monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes*. E & FN Spon, London.

CAVANAGH N, NORDIN RN, POMMEN LW and SWAIN LG (1998) *Guidelines for Designing and Implementing a Water Quality Monitoring Programme in British Columbia*. Resources Inventory Committee, British Columbia.

CHAPMAN D (1996) (2nd ed.) *Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring*. E & FN Spon, London.

CLARK MJR (2000) Quality Assurance in Environmental Analysis. *In Encyclopedia of Analytical Chemistry*. Meyers RA (ed). John Wiley & Sons, Chichester. 3197-3227 pp.

DALLAS HP, DAY JA, MUSIBONO DE and DAY EG (1998) *Water Quality for Aquatic Ecosystems: Tools for Evaluating Regional Guidelines*. Report No. 626/1/98. Water Research Commission, Pretoria, South Africa.

DWAF (1996a) *Design Framework for a National Microbial Monitoring Programme to Assess the Faecal Pollution of SA Surface Water Resources*. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa

DWAF (1996b) *a National Microbial Monitoring Programme to Assess the Faecal Pollution of SA Surface Water Resources: Conceptual Monitoring Programme Design*. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa

DWAF (1997) *National Water Policy*. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (2002a) *National Eutrophication Monitoring Programme for Surface Water: Implementation Manual.* Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (2002b) *National Microbial Monitoring Programme for Surface Water: Implementation Manual.* Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (2003) *Needs Assessment and development Framework for a tested Implementation Plan for the Initiation and Execution of a National Toxicants Monitoring Programme*. Report No. N/0000/00/REQ0303. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (2004). *Strategic Framework for National Water Resource Quality Monitoring Programmes by DC Grobler and M Ntsaba.* Report No. N/0000/REQ0204. ISBN 0-621-35069-9. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

FRASER AS, HODGSON KM and ROB ARTS RD (2001) Integrated Monitoring Strategies for Global and Regional Assessments. *Proceedings MTM-III – Strategies for Global and regional Assessments.*

FUGGLE RF and RABIE MA (1996) *Environmental Management in South Africa.* Juta & Co, Cape Town.

GRDC (1998) *Mean Annual Freshwater Surface Water Fluxes into the World Oceans*. www.bafg.de/grdc.htm , Germany

GRIFFITH LM, WARD RC, MCBRIDEGB and LOFTIS JC (2001) *Data Analyses Considerations in Producing 'Comparable' Information for Water Quality Management Purposes.* USGS Technical Report 01-01.

HARRIS **J,** VAN VEELEN M and GILFILLAN TC (1992) *Conceptual Design report for a National River Water Quality Assessment Programme*. Report No. 204/1/92. Water Research Commission, Pretoria, South Africa.

HARRIS J**,** HOWMAN A, GROBLER D, KUHN A and NTSABA M (2001) Information systems for water resource monitoring and assessment. *Conference on Environmental Responsible Mining*, Johannesburg. Chamber of Mines (September 2001),

HELMER R (1994) Water quality monitoring: national and international approaches. *Hydrological, Chemical and Biological Processes of Transformation and Transport of Contaminants in Aquatic Environments (proceedings of the Rostov -on-Don Symposium, May 1993)* IAHS Publ. No. 219

HELSEL DR and HIRSCH RM (1992) *Statistical Methods in Water Resources*. Elsevier, Amsterdam.

HOHLS BC, SILBERBAUER MJ, KUHN AL, KEMPSTER PL and VAN GINKEL CE (2002) *National Water Resource Quality Status Report: Inorganic Chemical Water Quality of Surface Water Resources in SA - The Big Picture*. Report No. N/0000/REQ080I. ISBN No. 0-621-32935-5. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

HOHLS DR (1996) *National Biomonitoring for Riverine Ecosystems: Framework document for the programme*. NBP Report Series No. I. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

KEURIS H (2003) Data Storage and Management: The experience from Hydrology. Paper: *Water Quality Monitoring Programme Design Course*. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

LOOSER JU (2004) Personal communication. DWAF, Resource Quality Services. Pretoria, South Africa.

MACDONALD LH and SMART A (1993) Beyond the guidelines: Practical lessons for monitoring. *Environmental Monitoring and Assessment* 26 143-155.

MANGOLD S (2001) *National Aquatic Ecosystem Biomonitoring Programme: An Implementation Manual for the River Health Programme - a hitch hiker's guide to putting the RHP into action*. NAEBP Report Series No 15. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

MIDGLEY DC, PITMAN WV and MIDDLETON BJ (1994) *Surface water Resources of South Africa*. Volumes I-VI. WRC Report Series, Pretoria

MOON BP and DARDIS GF (1988) *The Geomorphology of South Africa*. Southern Book Publishers, Johannesburg.

MURRAY K (1999) *National Microbial Monitoring Programme Implementation Manual: Final report*. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

SANDERS TG, WARD RC, LOFTIS JC, STEELE TD, ADRIAN DD and YEVJEVICH V (2000) *Design of Networks for Monitoirng Water Quality*. Water Resources Publications, LLC, Colorado.

SHAMPINE WJ (1993) Quality assurance and quality control in monitoring programs. *Environmental Monitoring and Assessment* **26** 143-151

UNEP (2002a) *Minutes of the first meeting of the advisory group to the global network for the monitoring of chemicals in the environment*, UNEP Chemicals, Geneva.

UNEP (2002b) *UNEPIDEWA Water Assessment Strategy: Contributing to the overall implementation of the UNEP Water Policy and Strategy*. Division of Early Warning and Assessment, UNEP.

UNEP (2004) *GEMS/Water Annual Report 2003*. www.gemswater.org

UNESCO (2003) *The United Nations World Water Development Report*. World Water Assessment Programme. Paris.

VAN NIEKERK H, KÜHN A and KEMPSTER P (2001) Implementation of a Catchment Based National Microbial Water Quality Monitoring Programme in Prioritized High Health Risk Areas. *River Basin Management.* WITPRESS, Southampton.

VAN NIEKERK H, HARRIS J and KÜHN A (2002) Practical Considerations for the development and Operation of and Effective Water Quality Monitoring Programme. *Water Institute of South Africa Bi-annual Conference Proceedings*. Durban, South Africa.

VENTER, S. N., KÜHN, A. L. and HARRIS, J (1998) A method for the prioritization of areas experiencing microbial pollution of surface water. *Water, Science and Technology,* 38(12) 23-27 pp.

VOS P, MEELIS E and TER KEURS WJ (2000) A framework for the design of ecological monitoring programs as a tool for environmental and nature management. *Environmental Monitoring and Assessment* 61, 317-344.

WARD CW (2003) Design of Water Quality Monitoring Networks. *Short course notes*. Colorado State University.

WARD RC, LOFTIS JC and MCBRIDE GB (1990) *Design of Water Quality Monitoring Systems*. Van Nostrand Reinhold, New York.

WHO (1991) *GEMS/Water 1990-2000: The Challenge Ahead*. Geneva.

WHO (1992) *GEMS/Water Operational Guide. Burlington,* Canada. 211 pp.

ANNEXURE 1

Spatial and Temporal Monitoring Site Information

Location, basic site information and barcodes of sites data are summarized in this annexure. The barcode system is used to give a snapshot view of the quantitative and qualitative nature of historical flow and water quality data at that particular site.

Global River Flux Site (1)

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Global Trend Monitoring Sites (23)

.

Global Baseline Monitoring Sites (4)

Monitoring Site Name: Orange River at Vioolsdrift

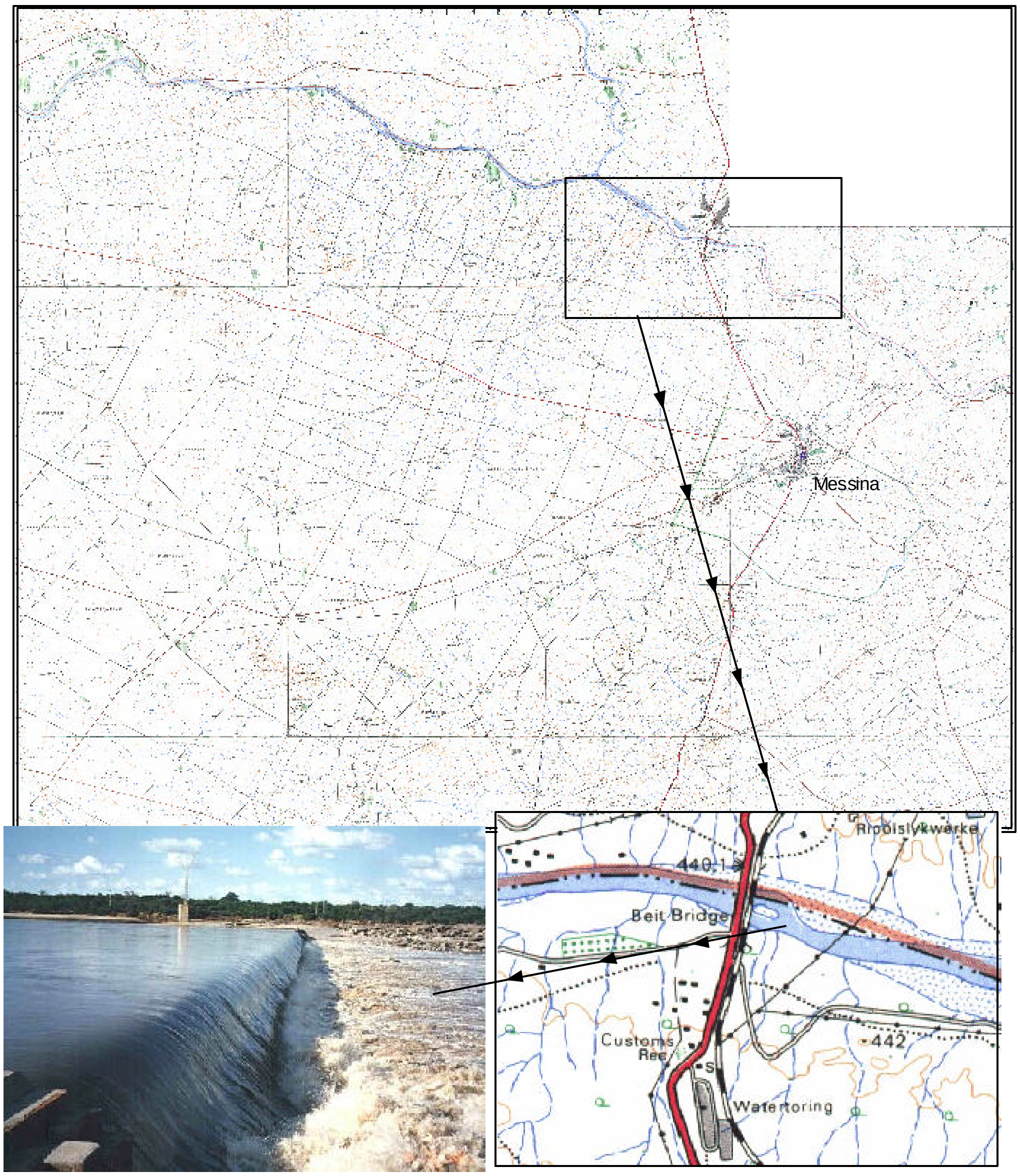
1. SA WMS site ID No.: 101888
2. SA Hydro site ID No.: D8H003Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global River Flux and Global Water Quality Trends
5. Resource Type: River
6. Resource name: Orange River
7. Position (co-ordinates): S -28^0 45" 39'
   E 17^0 43" 49'
8. Upstream catchment area: 850 530 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS & GRDC)
10. Description of resource and upstream catchment:

For a detailed physical description of the Orange River Catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.,* 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The hydrometric gauging station at Vioolsdrift receives runoff from 87% of the Orange River Catchment. The remaining 13% drains a dry area between Vioolsdrift and the Orange River mouth. Vioolsdrift gauging station is the closest SADC-HYCOS station to the ocean. This is as a result of the high sediment loads downstream of Vioolsdrift that prevents consistent hydrometric measurements. An audit of current water quality sampling consistency at all potential sites also revealed that sampling at Vioolsdrift was the most consistent of all the potential sites. This site is, therefore, the most appropriate site for inclusion in the Global River Flux monitoring network. As this site has already been identified as the most appropriate site for monitoring loads of water quality constituents from the Orange River catchement. It is therefore also the ideal site for trend monitoring of runoff from the interior of South Africa

SA-GEMS/Water Monitoring Site 90375 - Downstream of Beitbridge on Limpopo River



Monitoring Site Name: Markdrift on Orange River

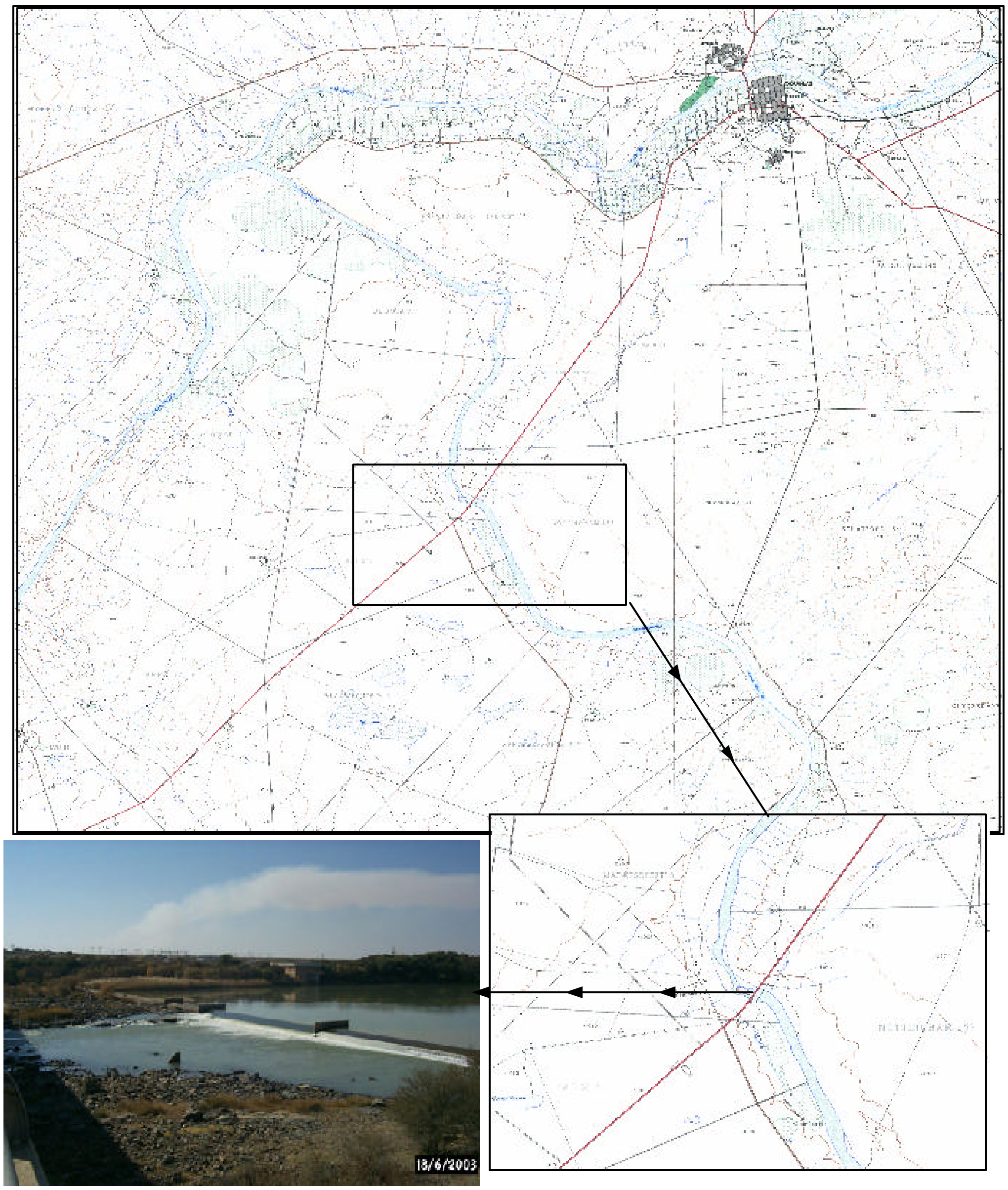
1. SA WMS site ID No.: 101824
2. SA Hydro site ID No.: D3H008Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River:
6. Resource name: Orange River
7. Position (co-ordinates): S -29^0 09" 42'
   E 23^0 41" 47'
8. Upstream catchment area: 99 316 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS)
10. Description of resource and upstream catchment:

For a detailed physical description of the Orange River Catchment refer to volume III, Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.,* 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

This site was included to represent runoff from the Orange river catchment upstream of the Vaal River confluence. The data will represent a mixture of water from the Caledon River, Kraai River and Orange River. Two large dams, namely the Gariep and Vanderkloof Dams are situated upstream of the site below the confluences with the Caledon and Kraai Rivers.

SA-GEMS/Water Monitoring Site
101824 - Marksdrift on Orange River



Monitoring Site Name: Schmidtsdrift on Vaal River

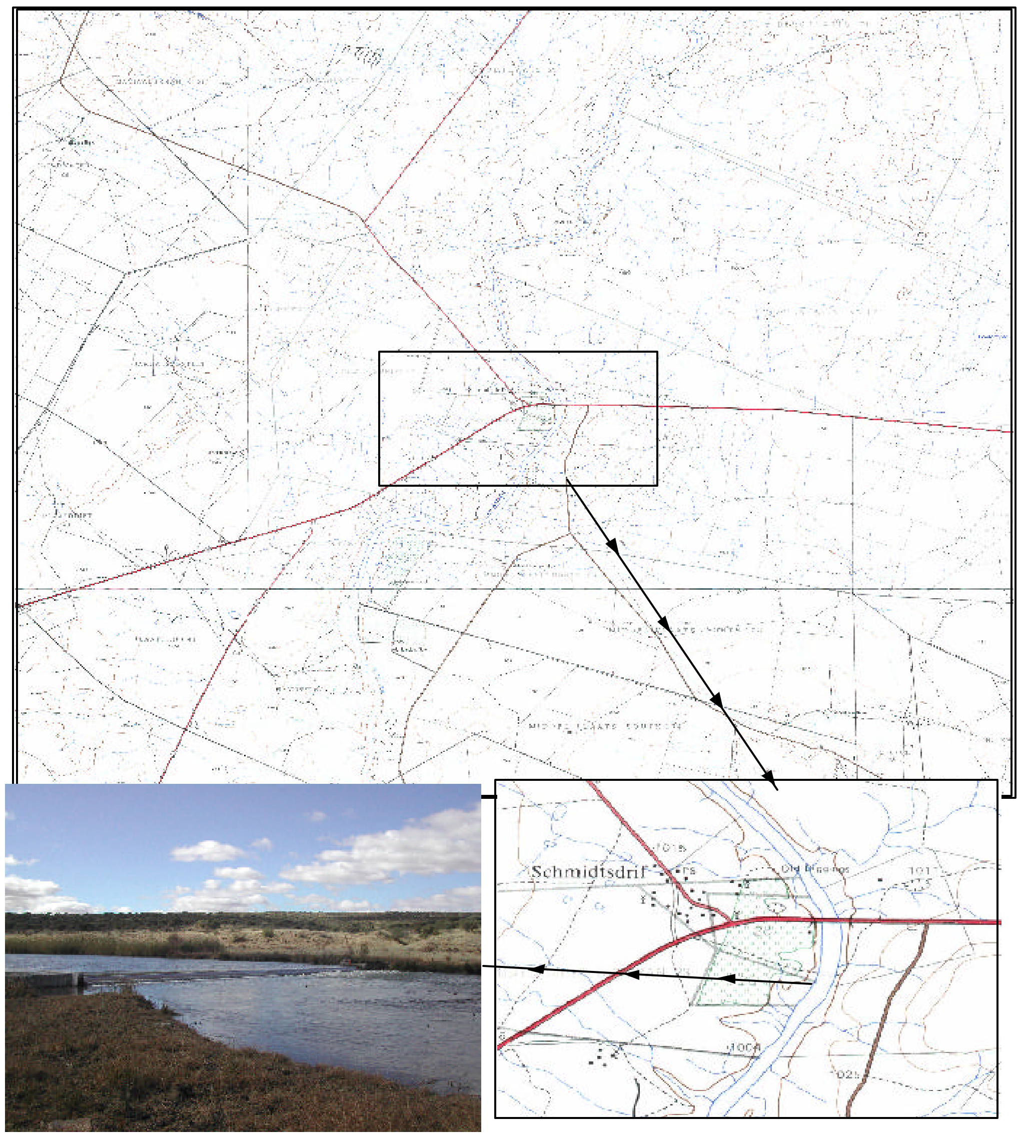
1. SA WMS site ID No.: 101770
2. SA Hydro site ID No.: C9H024Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Vaal River
7. Position (co-ordinates): S -28^0 42" 40'
   E 24^0 04" 24'
8. Upstream catchment area: 193842 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

Except for the Modder/Riet sub-catchment, this site represents whole Vaal River system, which can be said to be the hardest working river in South Africa. The Modder/Riet river system joins below the site upstream of the confluence with the Orange River. No suitable site could be found below the Modder/Riet and the confluence with the Orange. The site represents the impacts of large irrigation schemes such as the Vaal/Harts and upstream industrial and mining activities.

SA-GEMS/Water Monitoring Site
101770 - Schmidtsdrift on Vaal River



Monitoring Site Name: Pilgrims Estate Orkney on Vaal River

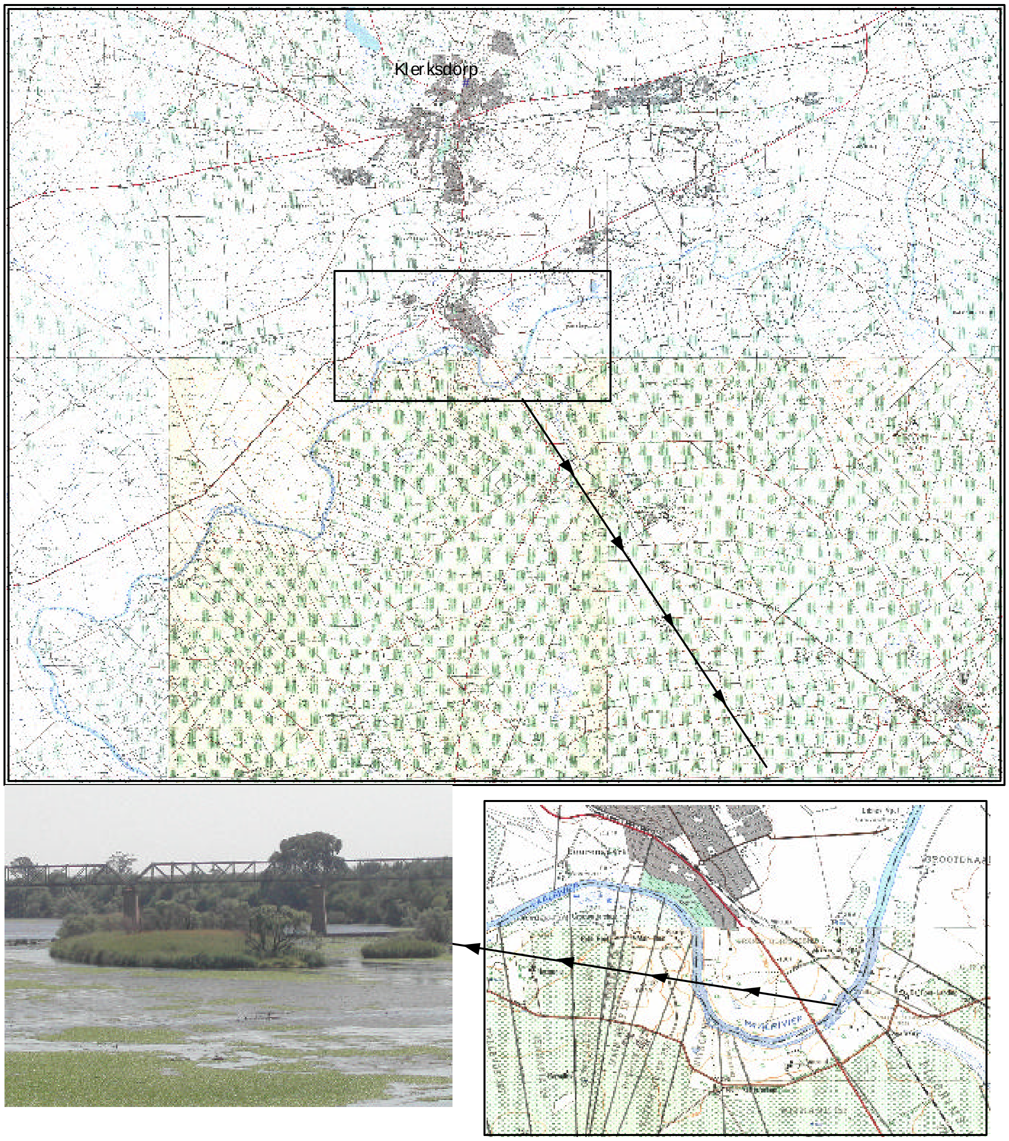
1. SA WMS site ID No.: 90618
2. SA Hydro site ID No.: C2H007Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Vaal River
7. Position (co-ordinates): S -27^{0} 00" 40'
   E 26^{0} 41" 54'
8. Upstream catchment area: 63 437 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The purpose of this site is to reflect the combined impacts of the major industrial complexes and mining activities in the upstream catchment of the Vaal River system.

SA-GEMS/Water Monitoring Site 90618 - Pilgrims Estate Orkney on Vaal River



Monitoring Site Name: Kalkheuwel on Crocodile River

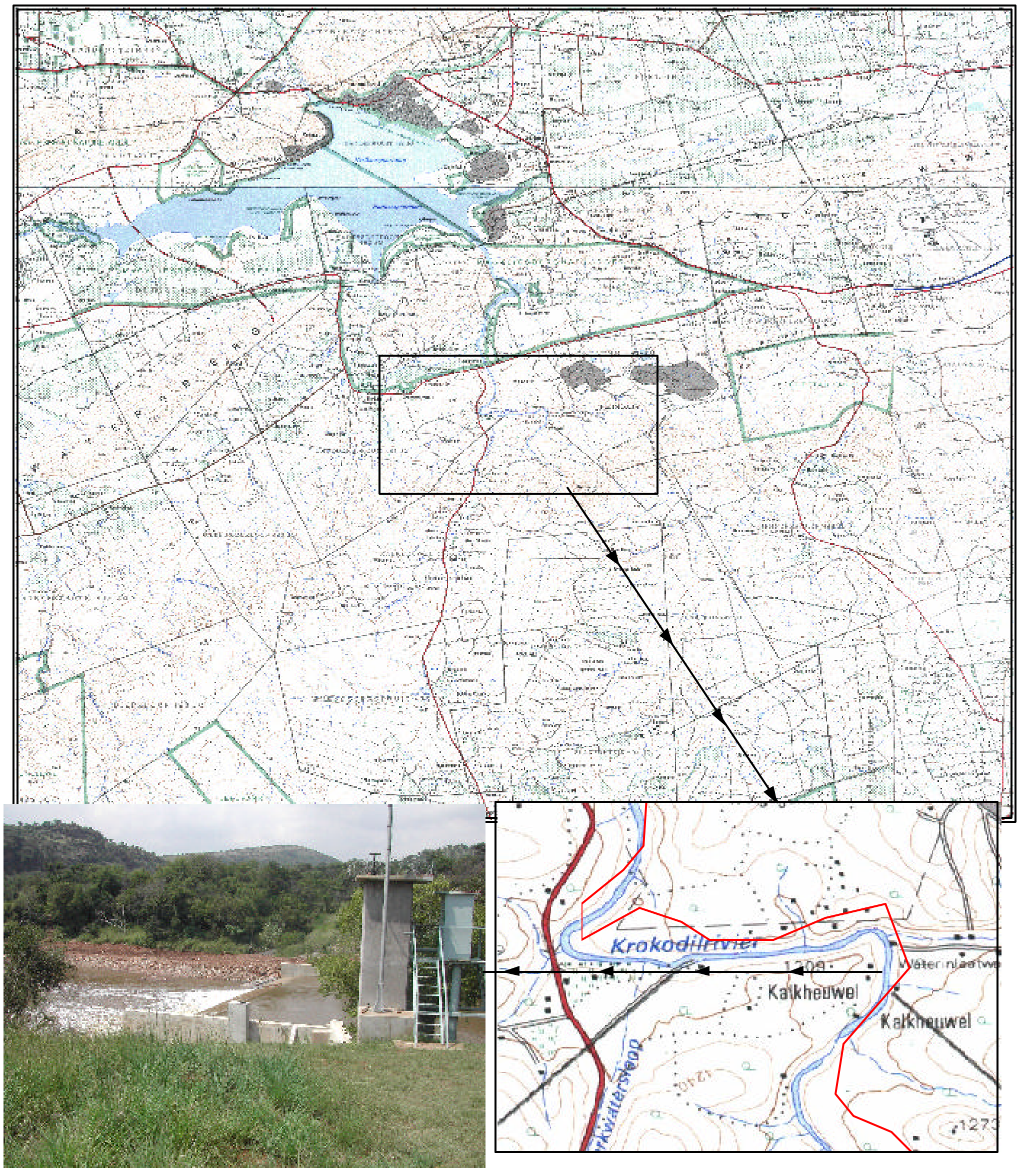
1. SA WMS site ID No.: 90164
2. SA Hydro site ID No.: A2H012Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Crocodile River
7. Position (co-ordinates): S -25^0 48" 26'
   E 27^0 54" 38'
8. Upstream catchment area: 2 551 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to volume III, Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

This site represents the catchments area of the Crocodile River upstream of the Hartebeespoort Dam. This sub-catchment drains the major economical hub, namely the PWV area. Although it represents a small drainage area it reflects on the typical quality of water draining from a large urban and industrial area. Both the Jukskei and Hennops Rivers are included in this drainage area which also represents drainage from large informal settlements. Large volumes of water that are pumped from the Vaal River system by Rand Water for domestic and industrial purposes also end up in this catchment as sewerage and industrial effluent.

SA-GEMS/Water Monitoring Site
10164 - Kalkheuwel on Crocodile River



Monitoring Site Name: Botswana Sterkloop on Limpopo River

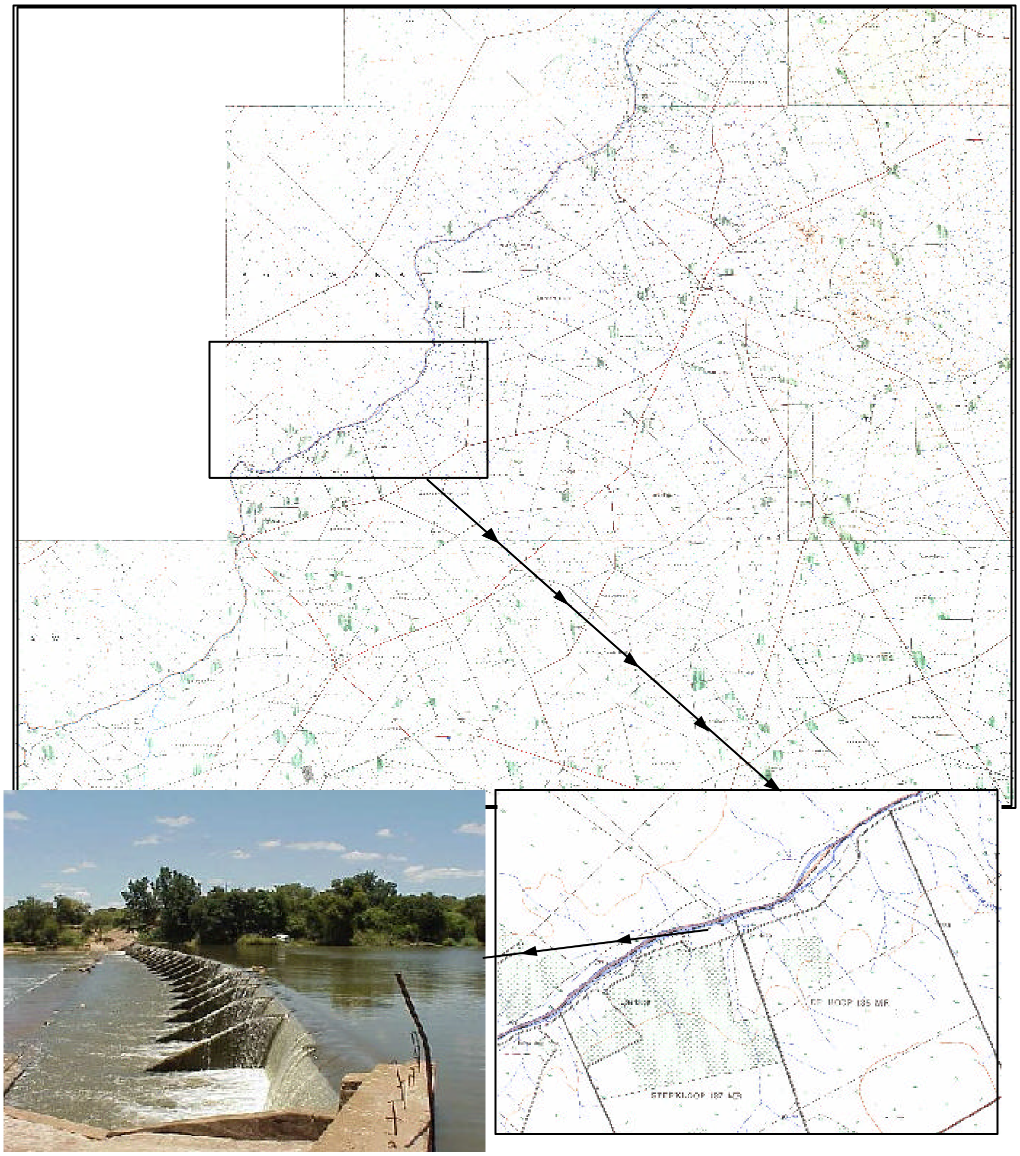
1. SA WMS site ID No.: 90340
2. SA Hydro site ID No.: A5H006Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Limpopo River
7. Position (co-ordinates):   S -22^0 56" 06'
   E 28^0 00" 15'
8. Upstream catchment area: 98 240 km^2
9. Site description: Hydrometric gauging station
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The Sterkloop site represents drainage from the entire Crocodile (West) Marico Water Management Area and Ngotwane River Catchment in Botswana that includes runoff from Gaberone.

SA-GEMS/Water Monitoring Site
90340 - Botswana Sterkloop
on Limpopo River



Monitoring Site Name: Downstrean of Beitbridge on Limpopo River

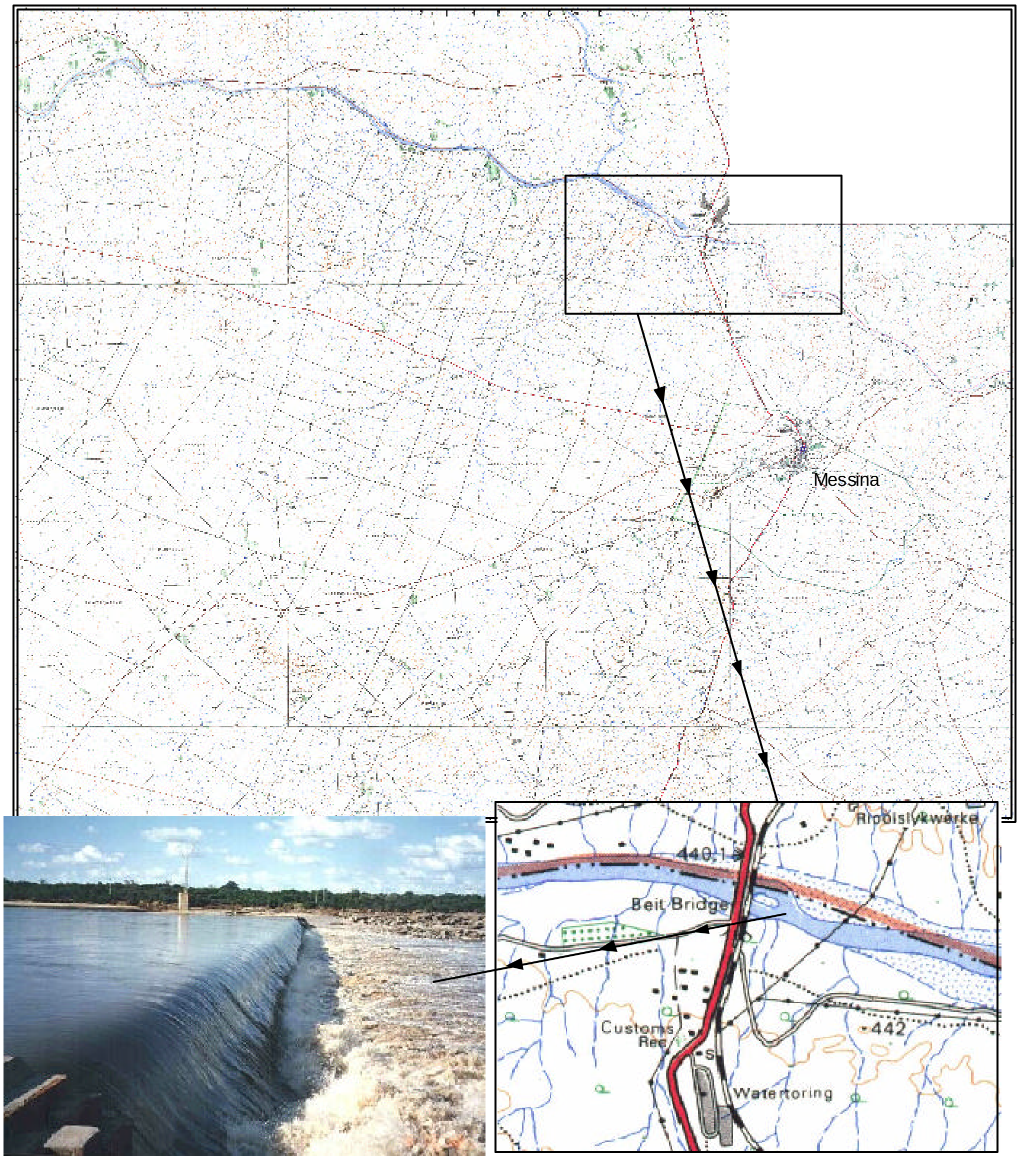
1. SA WMS site ID No.: 90375
2. SA Hydro site ID No.: A7H008Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Limpopo River
7. Position (co-ordinates): S -22^0 13" 32'
   E 29^0 59" 26'
8. Upstream catchment area: 201000 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS & GRDC)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

This site represents drainage from South Africa and Botswana's capital cities together with large agricultural and limited forest areas in the Limpopo catchment. Downstream of this site the Limpopo River flows into Mozambique from where it flows into the Indian Ocean.

SA-GEMS/Water Monitoring Site 90375 - Downstream of Beitbridge on Limpopo River



Monitoring Site Name: Oxford on Olifants River

1. SA WMS site ID No.: 90503
2. SA Hydro site ID No.: B7H007Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Olifants River
7. Position (co-ordinates): S -24^0 11" 02'

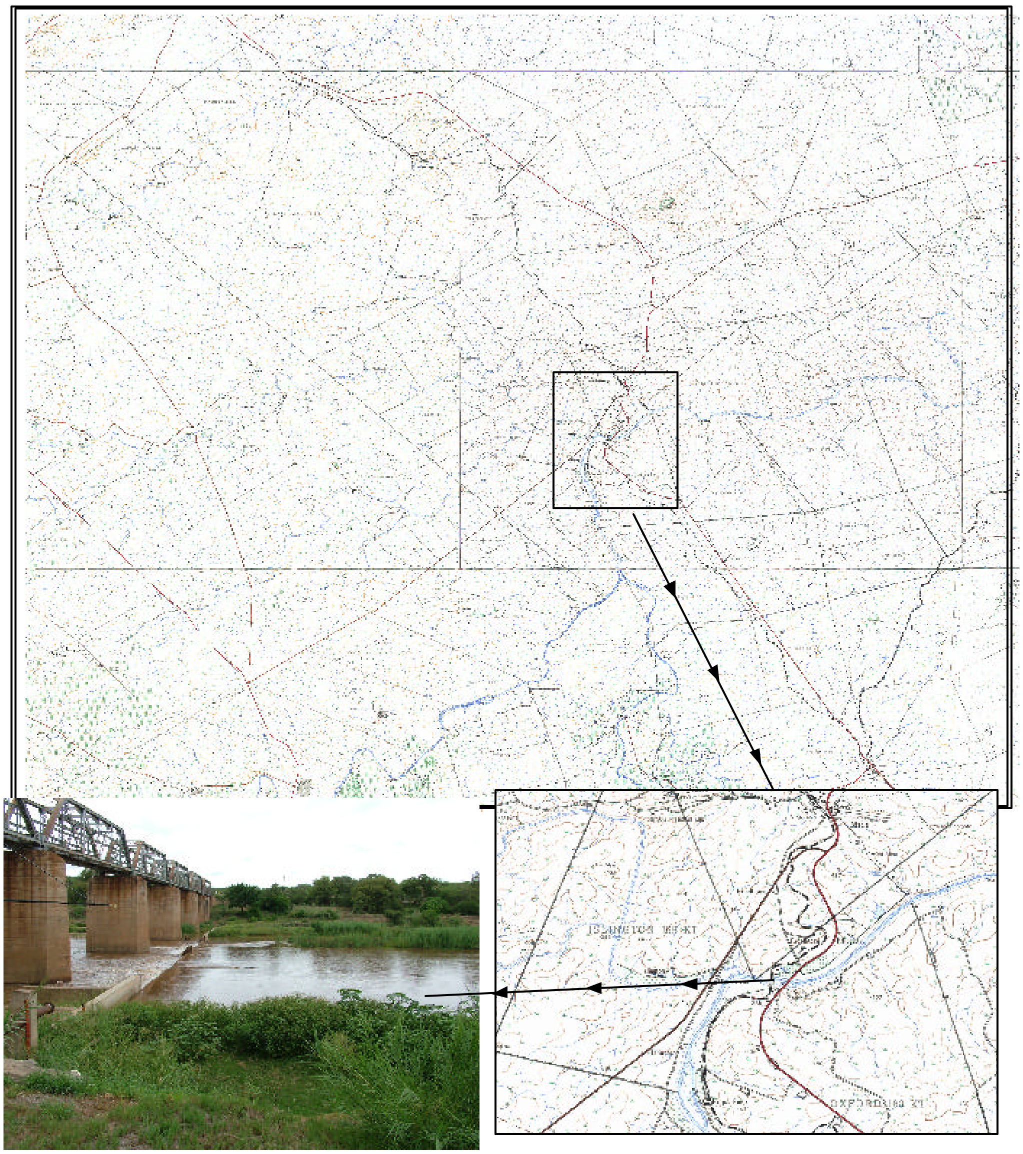
   E 30^0 49" 26'
8. Upstream catchment area: 46 583 km^2
9. Site description: Hydrometric gauging station
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The Olifants River catchments drains extremely mineral rich area which are also characterized by large coal deposits and forest areas. The site therefore represents a drainage area dominated by mining and forestation. The site is situated upstream of the Kruger National Park as no suitable sites could be identified in the National Park.

SA-GEMS/Water Monitoring Site
90503 - Oxford on Olifants River



Monitoring Site Name: Komatipoort Kruger National Park on Komati River

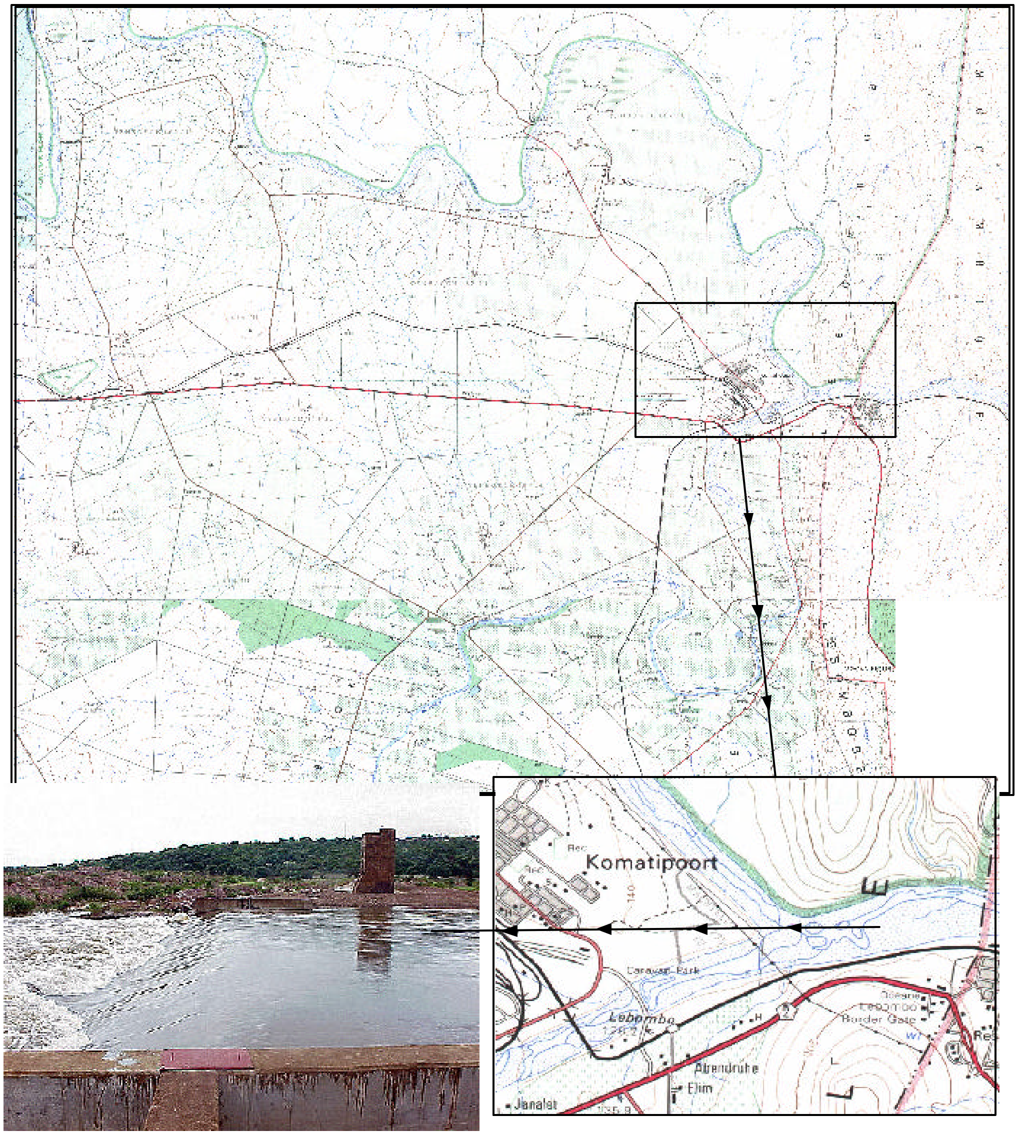
1. SA WMS site ID No.: 102979
2. SA Hydro site ID No.: X2H036Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Komati River
7. Position (co-ordinates): S -25^{0} 26" 10'
   E 31^{0} 58" 56'
8. Upstream catchment area: 21 481 km^{2}
9. Site description: Hydrometric gauging station.
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

This site is situated immediately downstream of the confluence of the Crocodile with the Komati River before it flows through Mozambique into the Indian ocean. Forestation and protected nature areas largely dominate both Catchments, although some mining activities do occur.

SA-GEMS/Water Monitoring Site 102979 - Komatipoort Kruger National Park on Komati River



Monitoring Site Name: Mandini on Tugela River

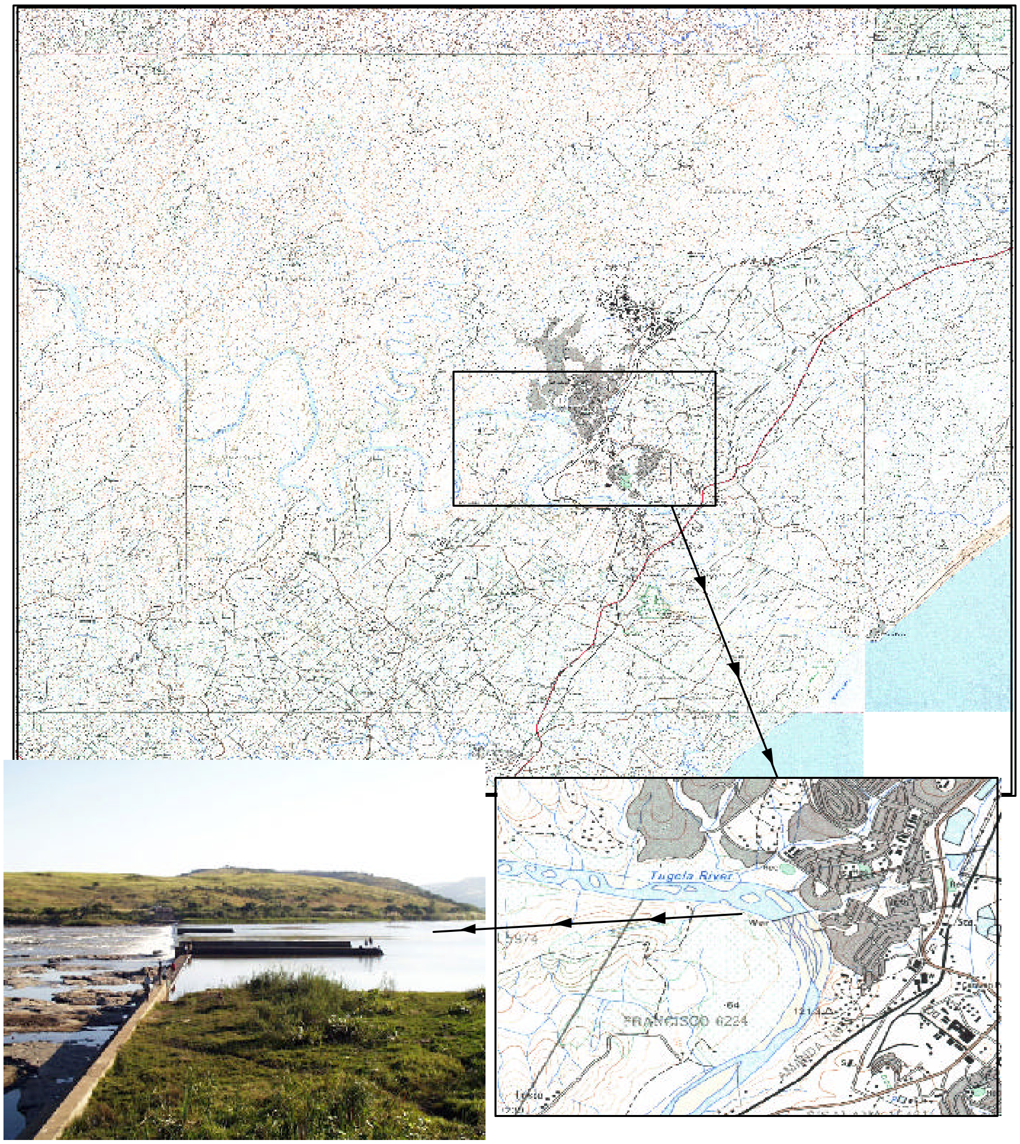
1. SA WMS site ID No.: 102779
2. SA Hydro site ID No.: V5H002Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Tugela River
7. Position (co-ordinates):   S -29^0 08" 26'
   E 31^0 23" 31'
8. Upstream catchment area: 28 920 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The Tugela catchment forms part of the group of Kwazulu/Natal catchments that is responsible for the highest Mean Annual Runoff in the country. It originates in the Drakensburg and is characterized by high sediment runoff. The monitoring site is close to where the Tugela enters the ocean.

SA-GEMS/Water Monitoring Site
102779 - Mandini on Tugela River



Monitoring Site Name: Inanda Location Egugwini on Mgeni

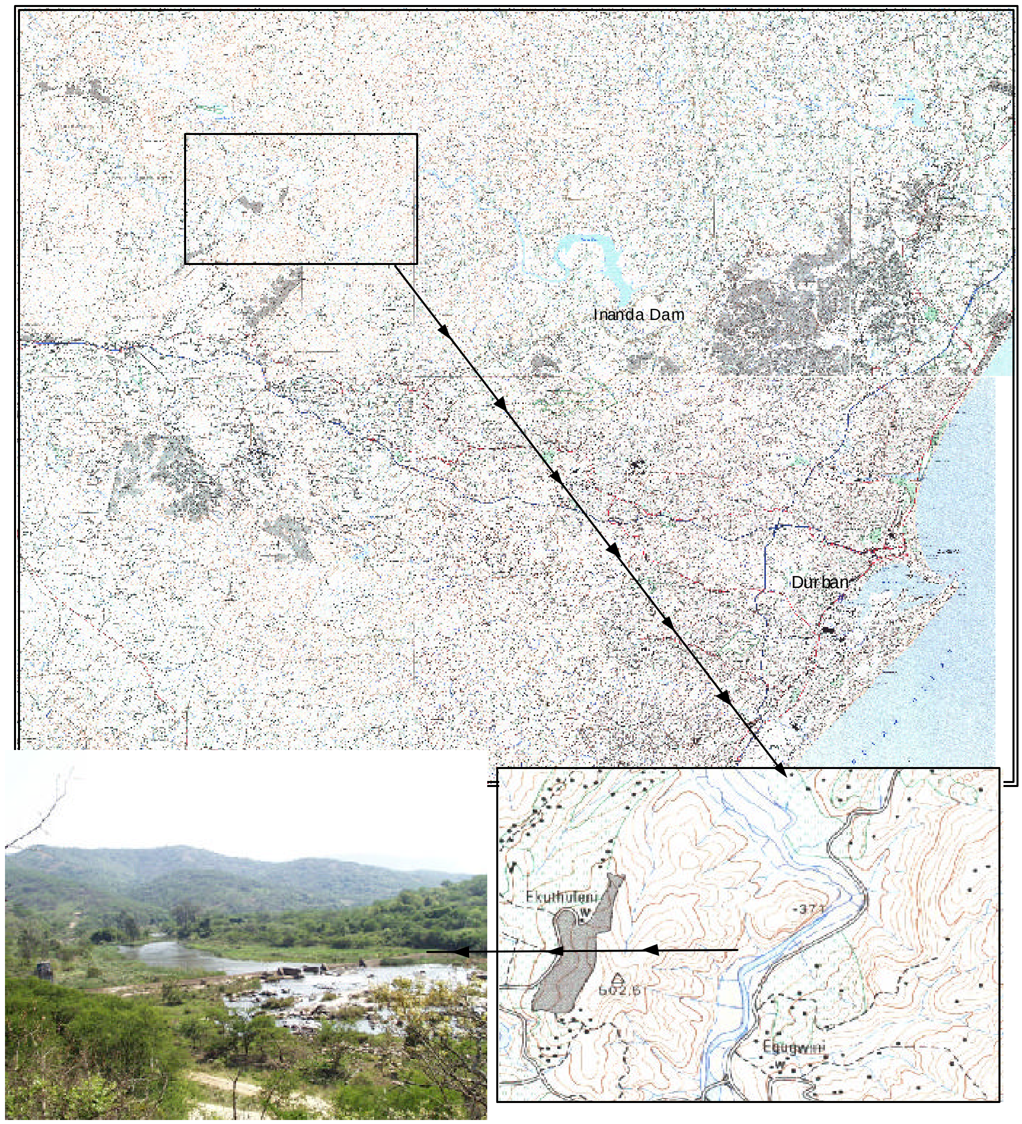
1. SA WMS site ID No.: 87822
2. SA Hydro site ID No.: U2H055Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Mgeni River
7. Position (co-ordinates):   S -29^0 38" 31'
   E 30^0 41" 15'
8. Upstream catchment area: 2 624 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The Mgeni catchment is a hard working catchment characterized by large rural and urban settlements, a high level of industrial development and number of impoundments. Although it is a relatively small catchement compared to the Tugela it was felt that as a result of the high level of development this site should be included.

SA-GEMS/Water Monitoring Site 87822 - Inanda Location Egugwini on Mgeni River



Monitoring Site Name: Area 8 Springs B on Groot-Keirivier

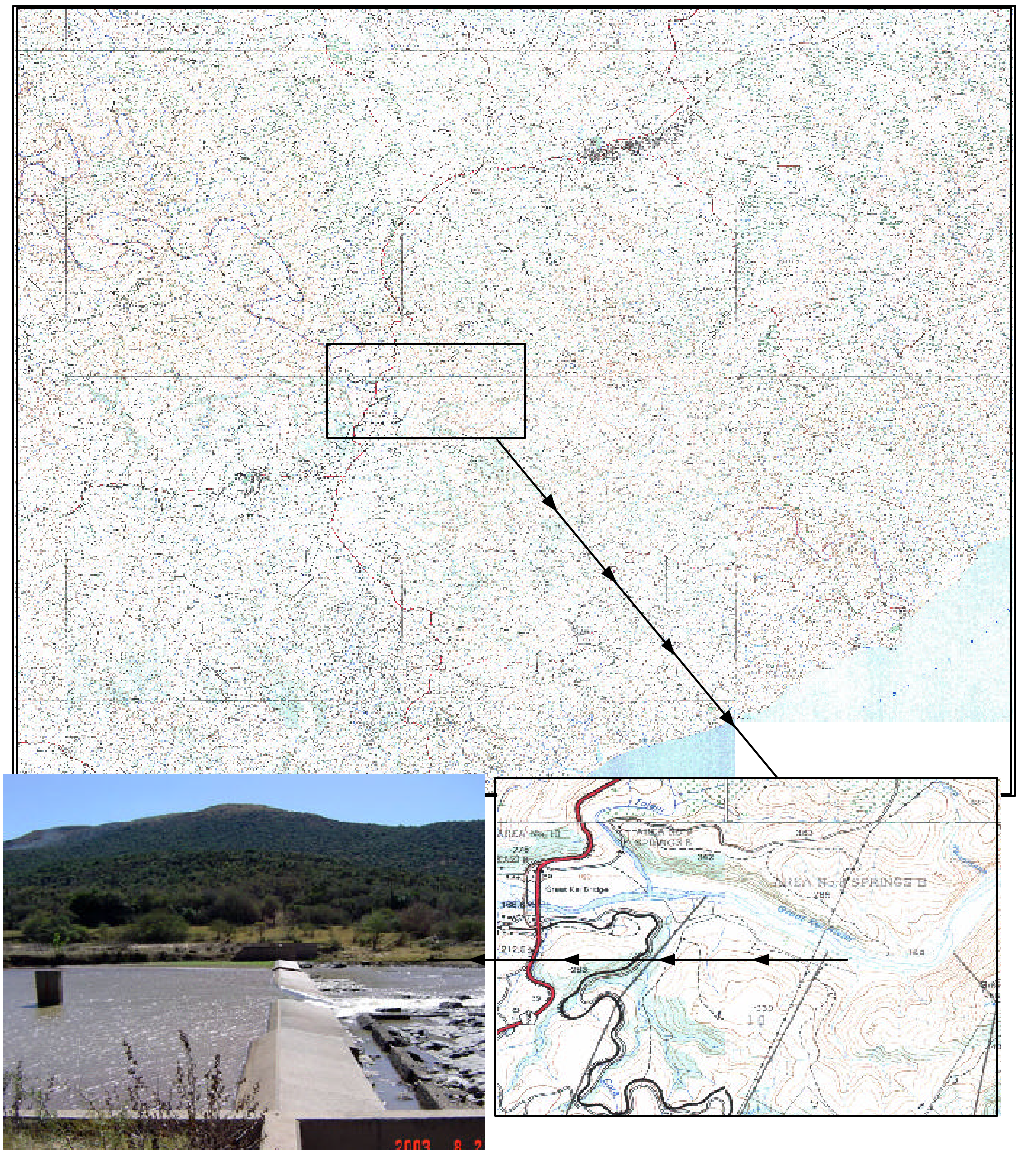
1. SA WMS site ID No.: 102568
2. SA Hydro site ID No.: S7H004Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Great Kei River
7. Position (co-ordinates):   S -32^{0} 30" 55'
   E 28^{0} 00" 56'
8. Upstream catchment area: 20 485 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The site represents runoff from the S primary catchment. It reflects the area of interchange between the high rainfall catchments to the north and the low rainfall area to the south. The catchment is characterised by a low level of development. High sediment yield are common in this area.

SA-GEMS/Water Monitoring Site
102568 - Area 8 Springs B
on Great-Kei River



Monitoring Site Name: Matomela's Reserve Outspan on Groot-Visrivier

1. SA WMS site ID No.: 102487
2. SA Hydro site ID No.: Q9H018Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Great Fish River
7. Position (co-ordinates): S -33^{0} 14" 16'

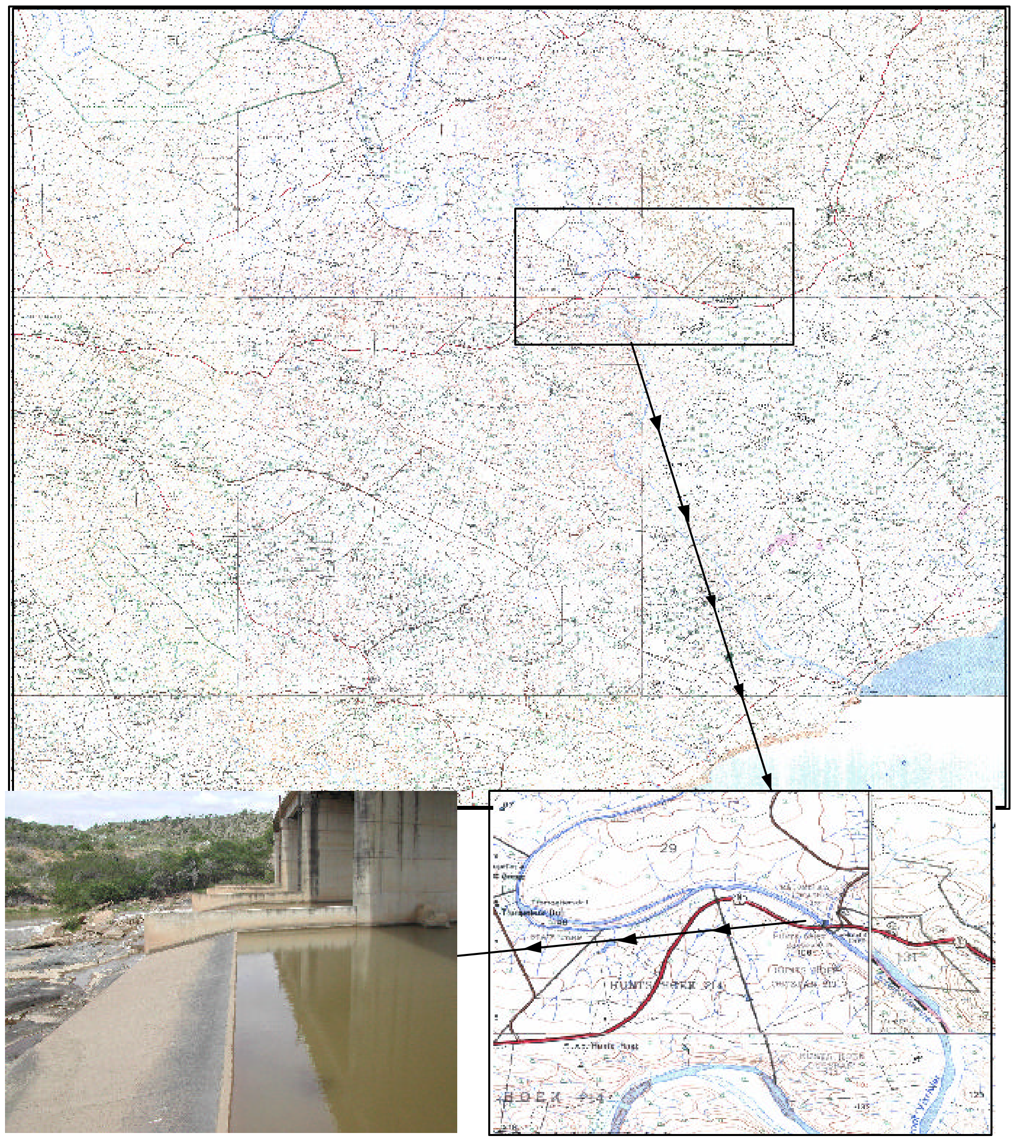
   E 26^{0} 59" 25'
8. Upstream catchment area: 29 745 km^2
9. Site description: Hydrometric gauging station (GRDC)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The largest proportion (inland) of the Fish River Catchement has a very low occurrence of rainfall. The catchment does however receive large quantities of water from the Gariep Dam in the Orange River system via pipelines. This is mainly for irrigation purposes and further distribution to the Sundays River to the South. Natural saline conditions poses a major problem for irrigation schemes. Except for the lower part of the catchment in the Port Elizabeth area where there are generally a low level of industrial development in the catchmenet.

SA-GEMS/Water Monitoring Site 102487 - Matomela's Reserve Outspan on Great-Fish River



Monitoring Site Name: Swellendam on Bree River

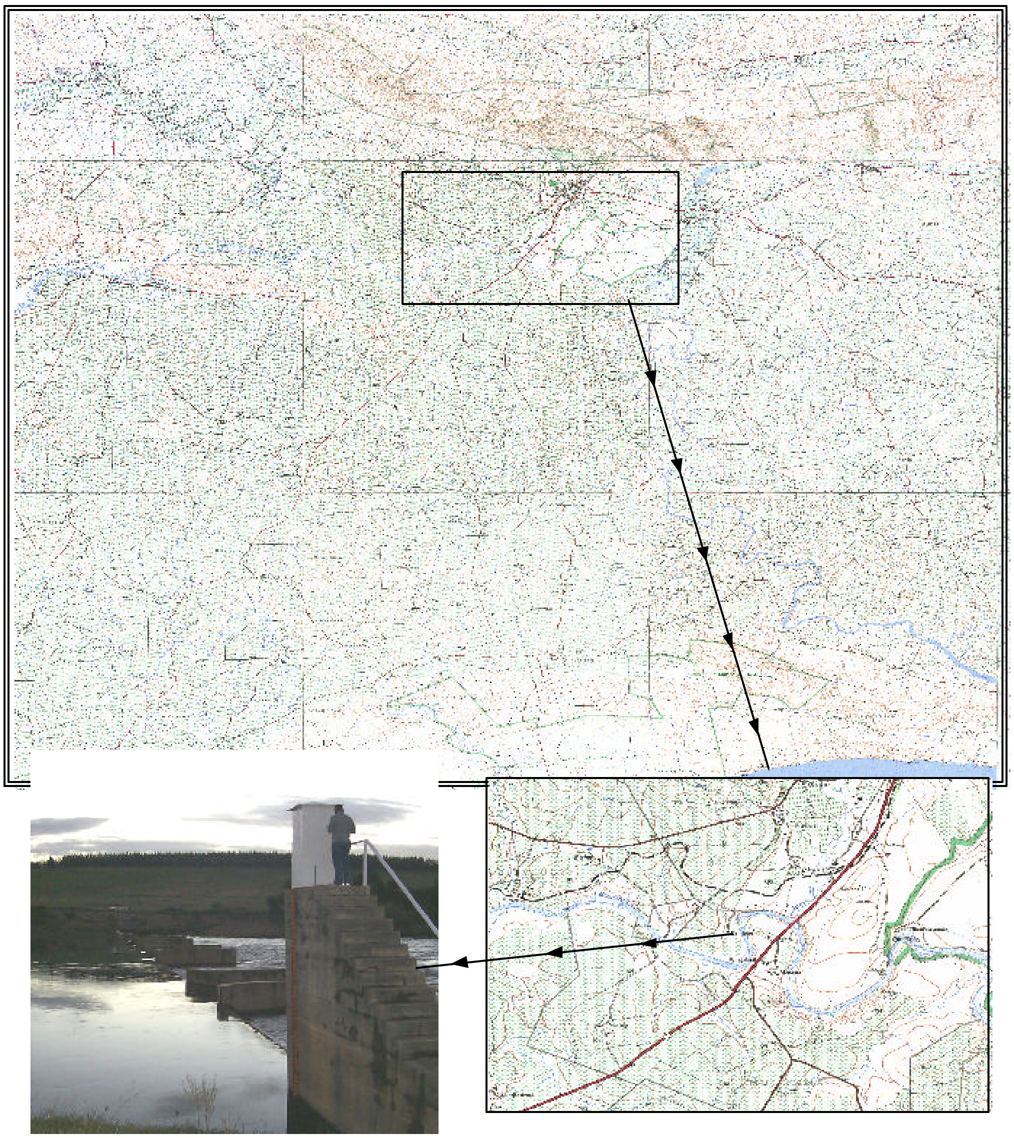
1. SA WMS site ID No.: 102119
2. SA Hydro site ID No.: H7H006Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Bree River
7. Position (co-ordinates):   S -34^0 03" 57'
   E 20^0 24" 15'
8. Upstream catchment area: 9 842 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The Bree River catchment is the most Western catchment draining to the Indian ocean. Although it has by far the smallest catchment area, it has the highest mean annual precipitation, runoff, and reservoir storage capacity and irrigated land area in the Western Cape. Grape farming and the wine industry are dominant in the catchment. The site represents drainage from one of the most intensively irrigated areas in the country

SA-GEMS/Water Monitoring Site
102119 - Swellendam on Bree River



Monitoring Site Name: Vleesbank Hermon Bridge on Bergrivier

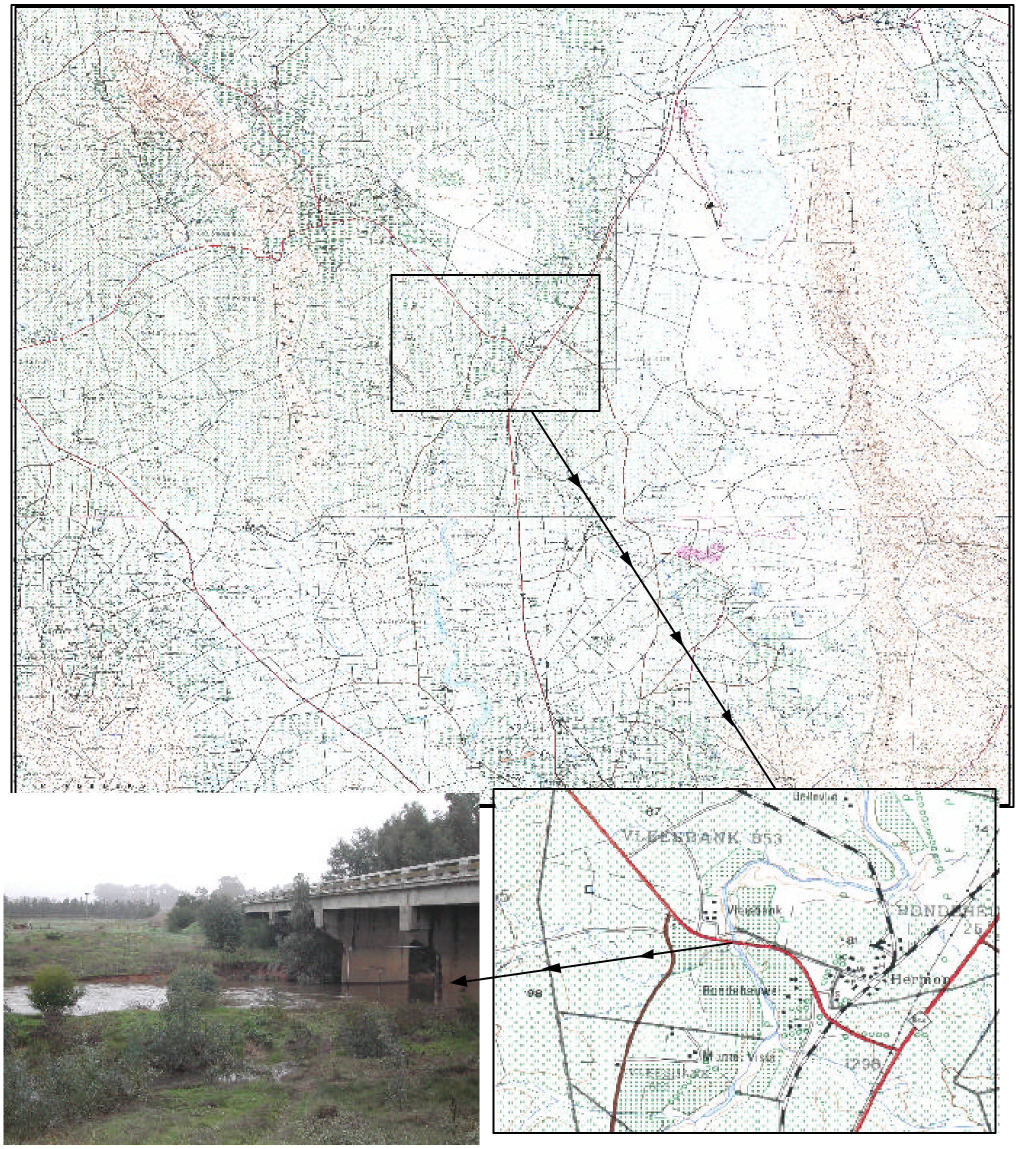
1. SA WMS site ID No.: 101939
2. SA Hydro site ID No.: G1H036Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Burg River
7. Position (co-ordinates): S -33^0 26" 06'
   E 18^0 57" 25'
8. Upstream catchment area: 1 312 km^2
9. Site description: Hydrometric gauging station (SADC-HYCOS & GRDC)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The Berg River catchment is the most Southern catchment draining into the Atlantic Ocean. It is also the catchment with the highest rainfall on the South African West Coast. It is also highly developed in terms grape farming and the wine industry with some degree of forestation. Selecting the ideal site was problematic as limited sites were available to choose from. The lower part of the catchmnet is known for high salinity values with salt mines impacting on sites in the outflow of the catchmnet The site that was selected does however reflect the general water quality in the catchment.

SA-GEMS/Water Monitoring Site 101939 - Vleesbank Hermon bridge on Berg River



Monitoring Site Name: Melkboom on Doringrivier

1. SA WMS site ID No.: 101903
2. SA Hydro site ID No.: E2H003Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: River
6. Resource name: Doring River
7. Position (co-ordinates):   S -31^0 51" 37'

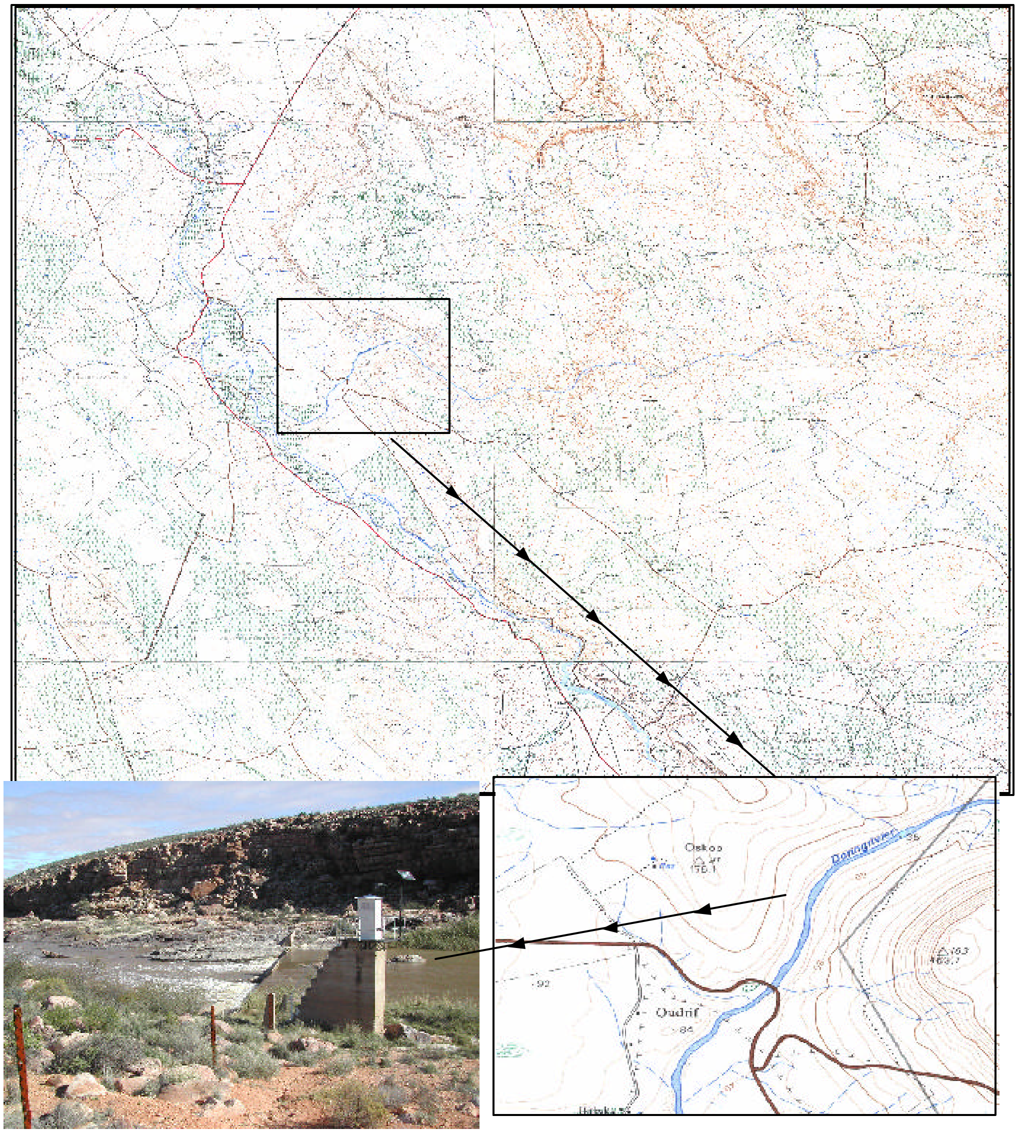
   E 18^0 41" 15'
8. Upstream catchment area: 24 044 km^2
9. Site description: Hydrometric gauging station.
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

This site represents only the Doring River sub-catchment in the greater Olifants/Doring catchment.The is a direct result of a lack of operational guiging stations that form part of the national water quality monitoring network. This was however not seen as a problem as the main areas of concern relating to water quality lies within this sub-catchment.

SA-GEMS/Water Monitoring Site
101903 - Melkboom on Doring River



Monitoring Site Name: Hartebeespoort Dam on Crocodile River

1. SA WMS site ID No.: 90240
2. SA Hydro site ID No.: A2R001Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: Dam/reservoir
6. Resource name: Hartebeespoort Dam
7. Position (co-ordinates): S -25^0 43" 29'
   E 27^0 51" 00'
8. Upstream catchment area: 4 112 km^2
9. Site description: Open water close to dam wall.
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

Although the Hartebeespoort 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 eutrophic dams in the world and is currently being investigated for potential rehabilitation options. The dam also acts as a sump for organic and inorganic pollutants from the highly developed Crocodile catchment.

SA-GEMS/Water Monitoring Site 90240 - Hartbeespoort Dam on Crocodile River

Monitoring Site Name: Vaal Dam on Vaal River: Near Dam Wall

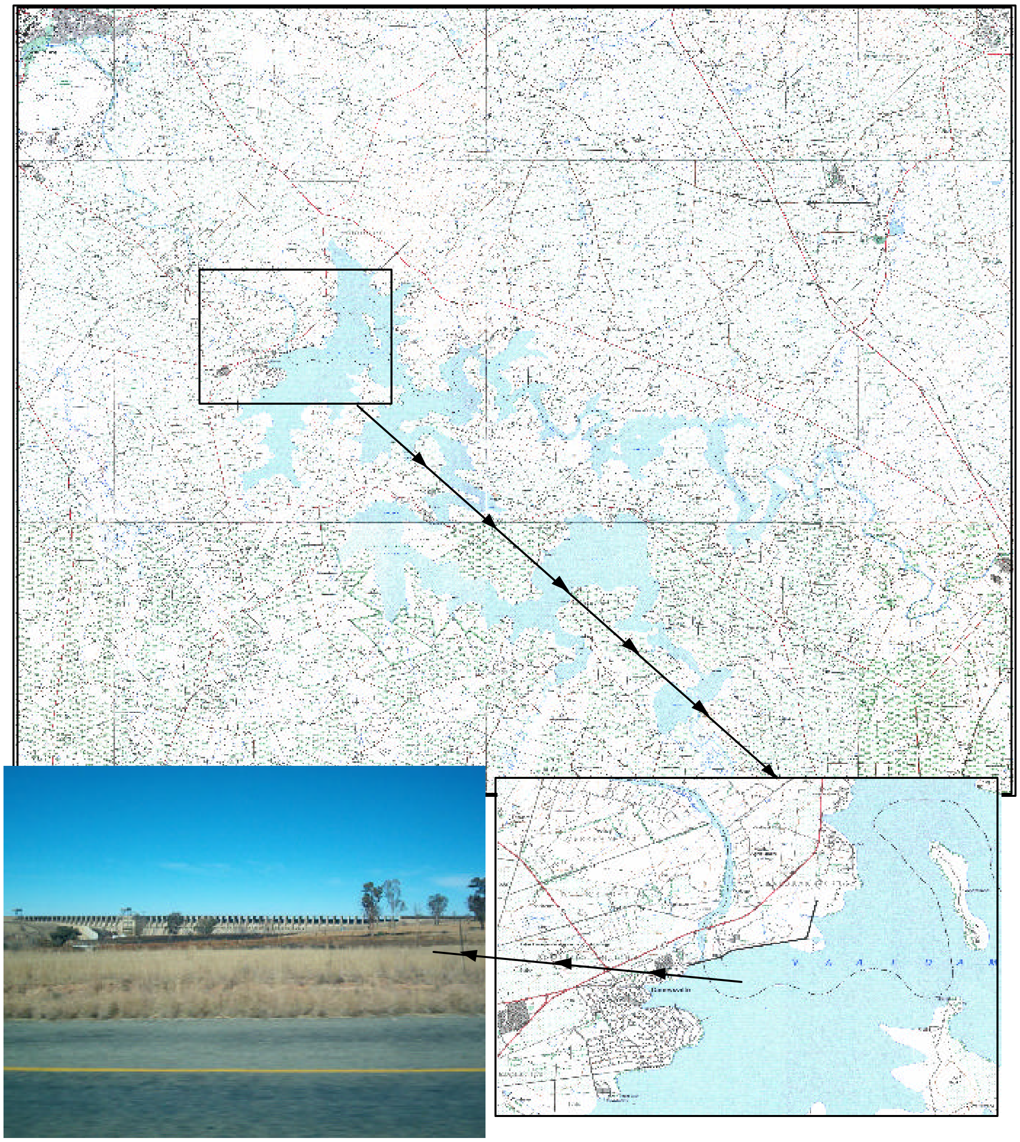
1. SA WMS site ID No.: 90604
2. SA Hydro site ID No.: C1R001Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: Dam/reservoir
6. Resource name: Vaal Dam
7. Position (co-ordinates):   S -26^0 52" 46'
   E 28^0 07" 23'
8. Upstream catchment area: 38 505 km^2
9. Site description: (SADC-HYCOS)
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

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 extensive utilized by Rand Water for domestic and industrial water supply purposes to area that form the economical hub of South Africa.

SA-GEMS/Water Monitoring Site
101774 - Vaal Dam on Vaal River



Monitoring Site Name: Bloemhof Dam on Vaal River: Near dam Wall

1. SA WMS site ID No.: 101774
2. SA Hydro site ID No.: C9R002Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: Dam/reservoir
6. Resource name: Bloemhof Dam
7. Position (co-ordinates): S -27^{0} 40" 09'

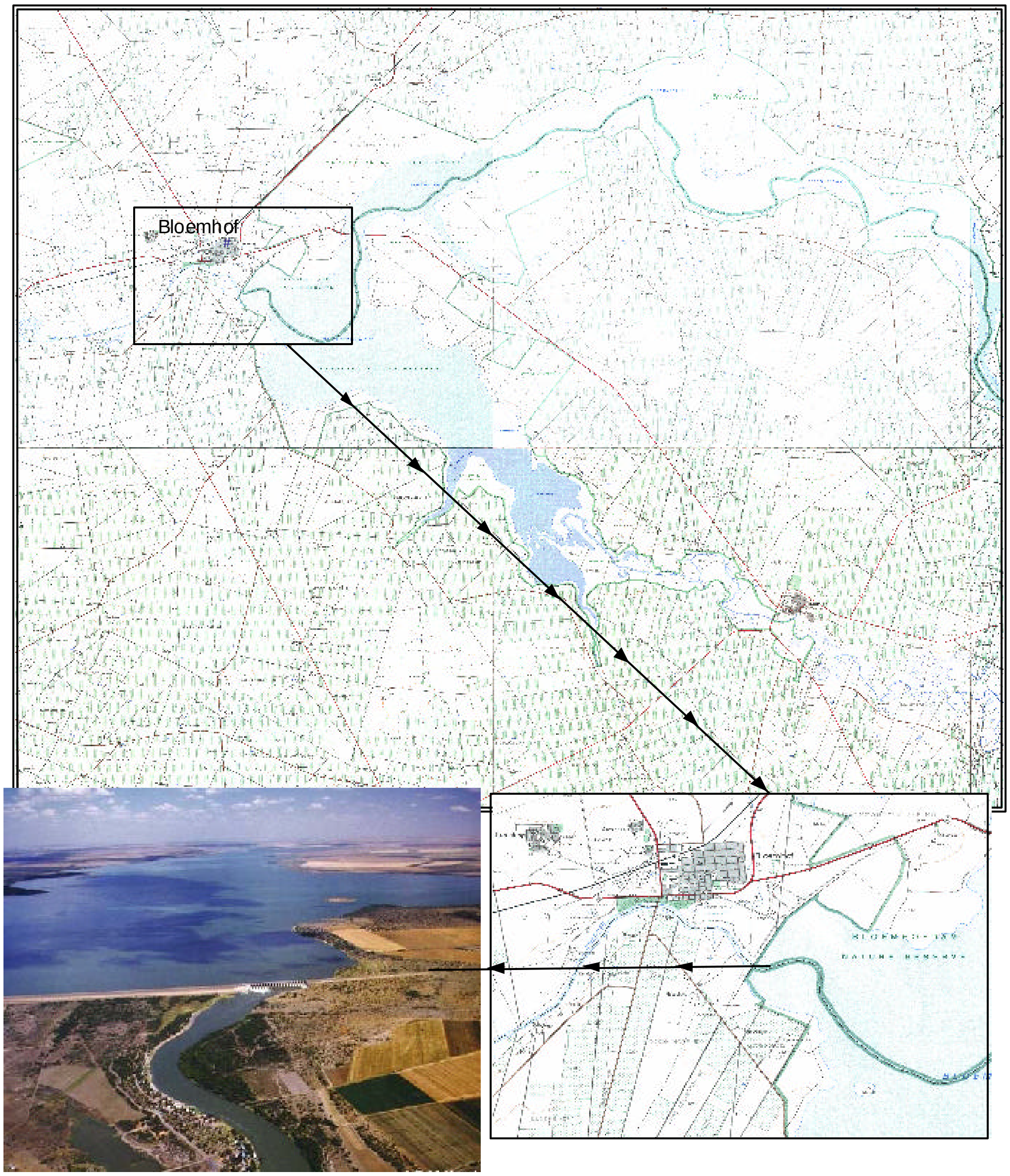
   E 25^{0} 37" 05'
8. Upstream catchment area: 107 911 km^{2}
9. Site description: (HYCOS) Open water close to dam wall
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to volume III, Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

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.

SA-GEMS/Water Monitoring Site
101774- Bloemhof Dam on Vaal River



Monitoring Site Name: Inanda dam on Mgeni River: Near Dam Wall

1. SA WMS site ID No.: 102669
2. SA Hydro site ID No.: U2R004Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: Dam/reservoir
6. Resource name: Inanda Dam
7. Position (co-ordinates):   S -29^{0} 42" 29'

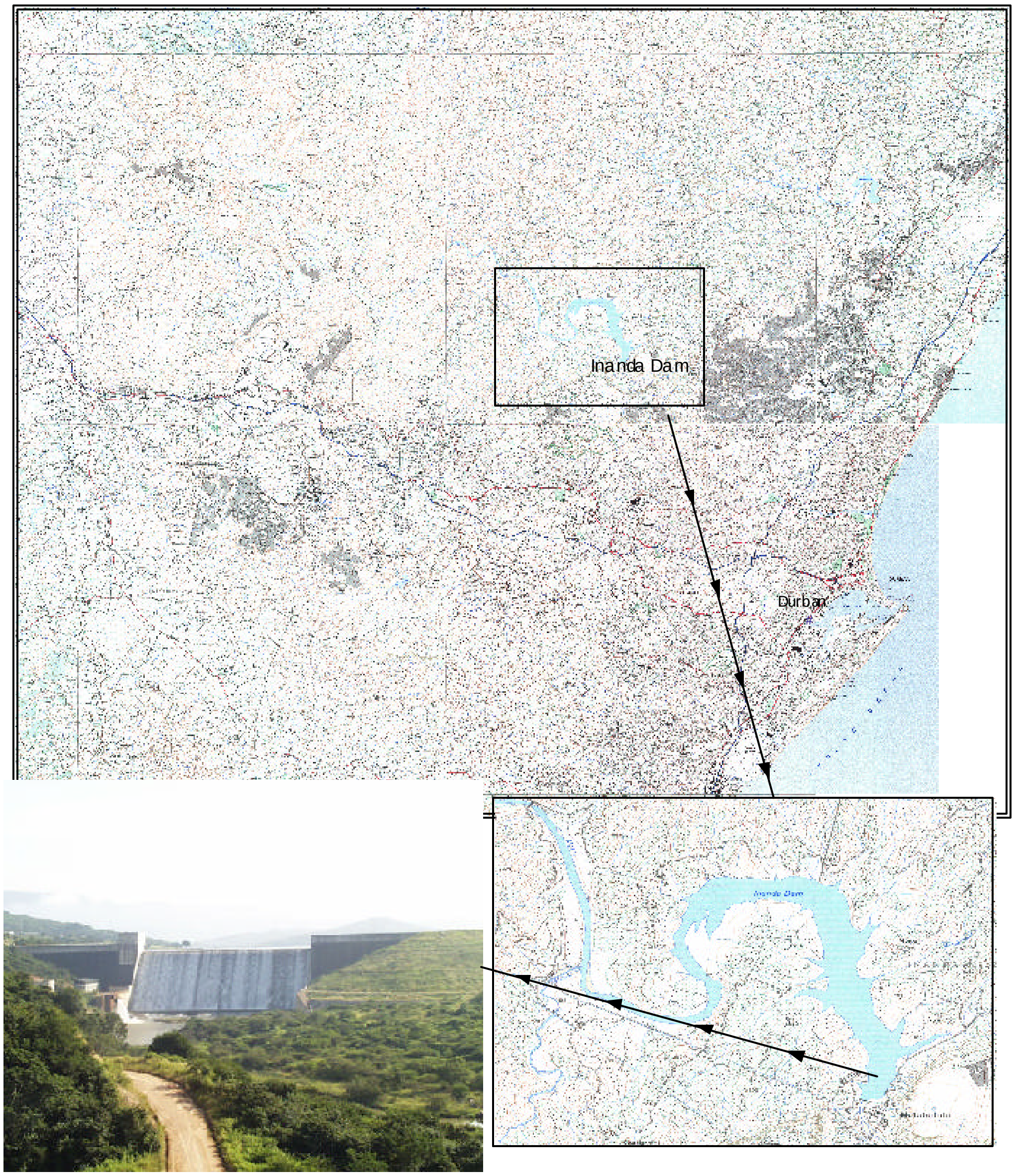
   E 30^{0} 52" 04'
8. Upstream catchment area: 4 082km^{2}
9. Site description: (SADC-HYCOS) Open water close to dam wall.
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

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 for domestic and industrial purposes economically important area.

SA-GEMS/Water Monitoring Site
102669 - Inanda Dam on on Mgeni River



Monitoring Site Name: Gariep Dam on Orange River: Near Dam Wall

1. SA WMS site ID No.: 101834
2. SA Hydro site ID No.: D3R002Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: Dam/reservoir
6. Resource name: Gariep Dam
7. Position (co-ordinates): S -30^0 37" 23'

   E 25^0 30" 26'
8. Upstream catchment area: 70 749 km^2
9. Site description: (SADC-HYCOS) Open water close to dam wall.
10. Description of resource and upstream catchment:

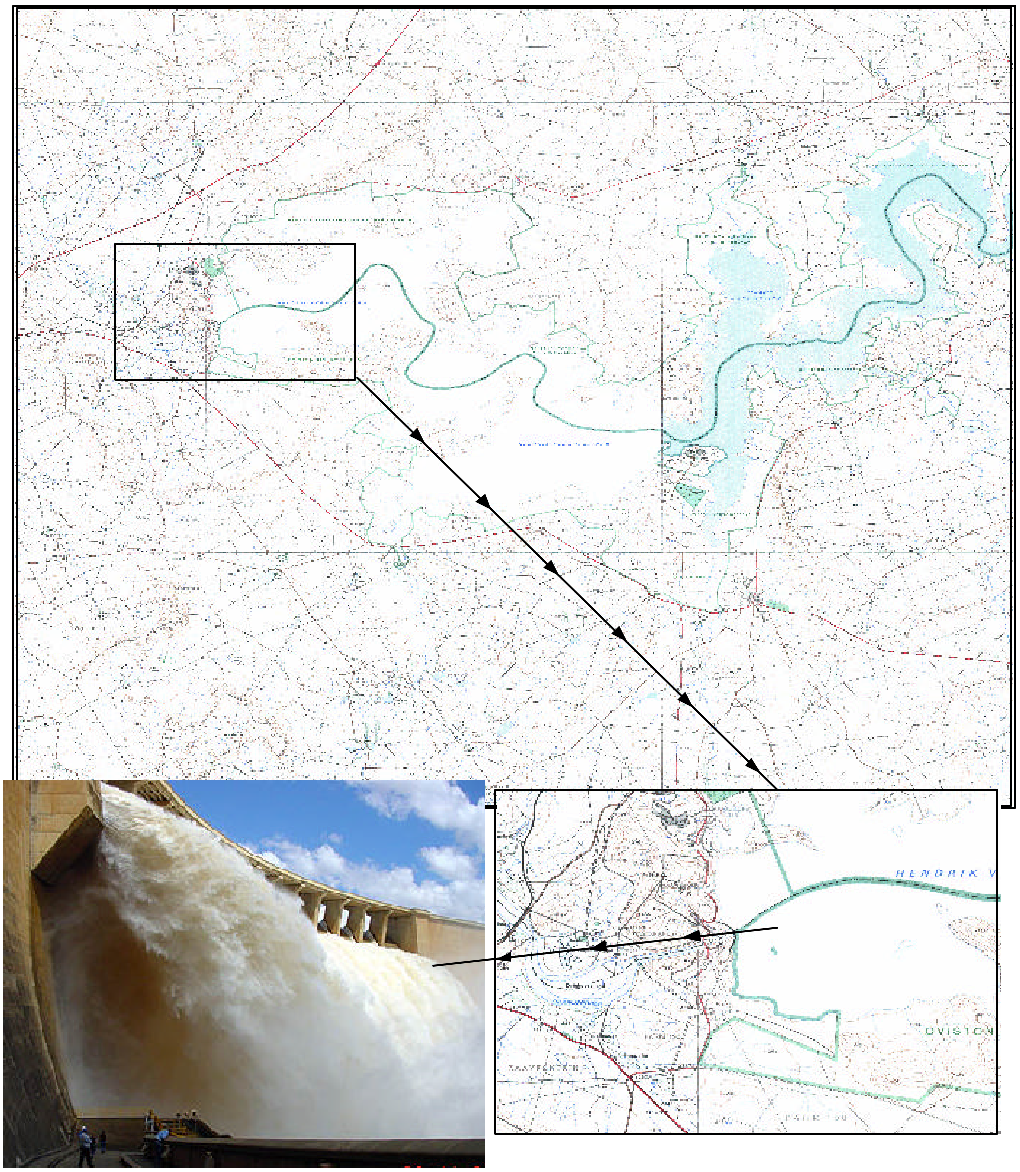
For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The Gariep Dam (previously Verwoerd Dam as indicated on map) is the largest dam in the country. Large volumes of water are pumped from the dam to the Fish/Sunday river systems for irrigation purposes. The dam plays a major role in storage and regulation of irrigation water for downstream use in the Orange River.

Note: The 1:50 000 map on the next page uses white and blue to indicate dam water. The open white space is therefore also part of the dam.

SA-GEMS/Water Monitoring Site
101834 - Gariep Dam on Orange River



Monitoring Site Name: Theewaterskloof Dam onRiviersonderend

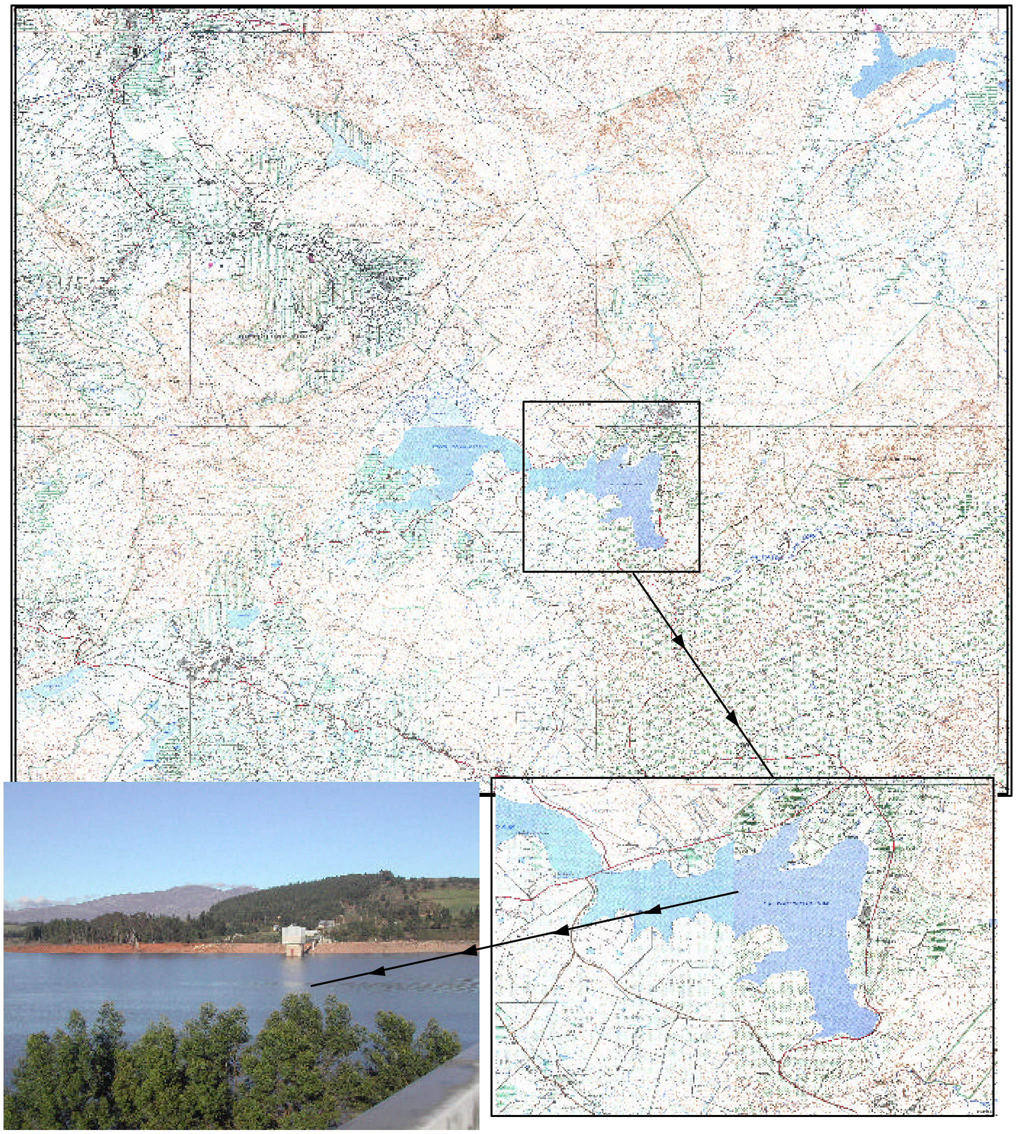
1. SA WMS site ID No.: 102112
2. SA Hydro site ID No.: H6R001Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: Dam/reservoir
6. Resource name: Theewaterskloof Dam
7. Position (co-ordinates): S -34^0 03" 29'
   E 19^0 16" 36'
8. Upstream catchment area: 496 km^2
9. Site description: (SADC-HYCOS) At water abstraction point.
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The Theewaterkloof Dam is most strategic water storage facility in the Western Cape. Water from the dam gravitates through 35km of tunnels to supply the Cape Metropolitan Area (including Cape Town) with water.

SA-GEMS/Water Monitoring Site
102112 - Theewaterskloof Dam
on Riviersonderend.



Monitoring Site Name: Loskop Dam on Olifants River: Near Dam Wall

1. SA WMS site ID No.: 90462
2. SA Hydro site ID No.: B3R002Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Water Quality Trends
5. Resource Type: Dam/Reservoir
6. Resource name: Loskop Dam
7. Position (co-ordinates): S -25^0 25" 00'

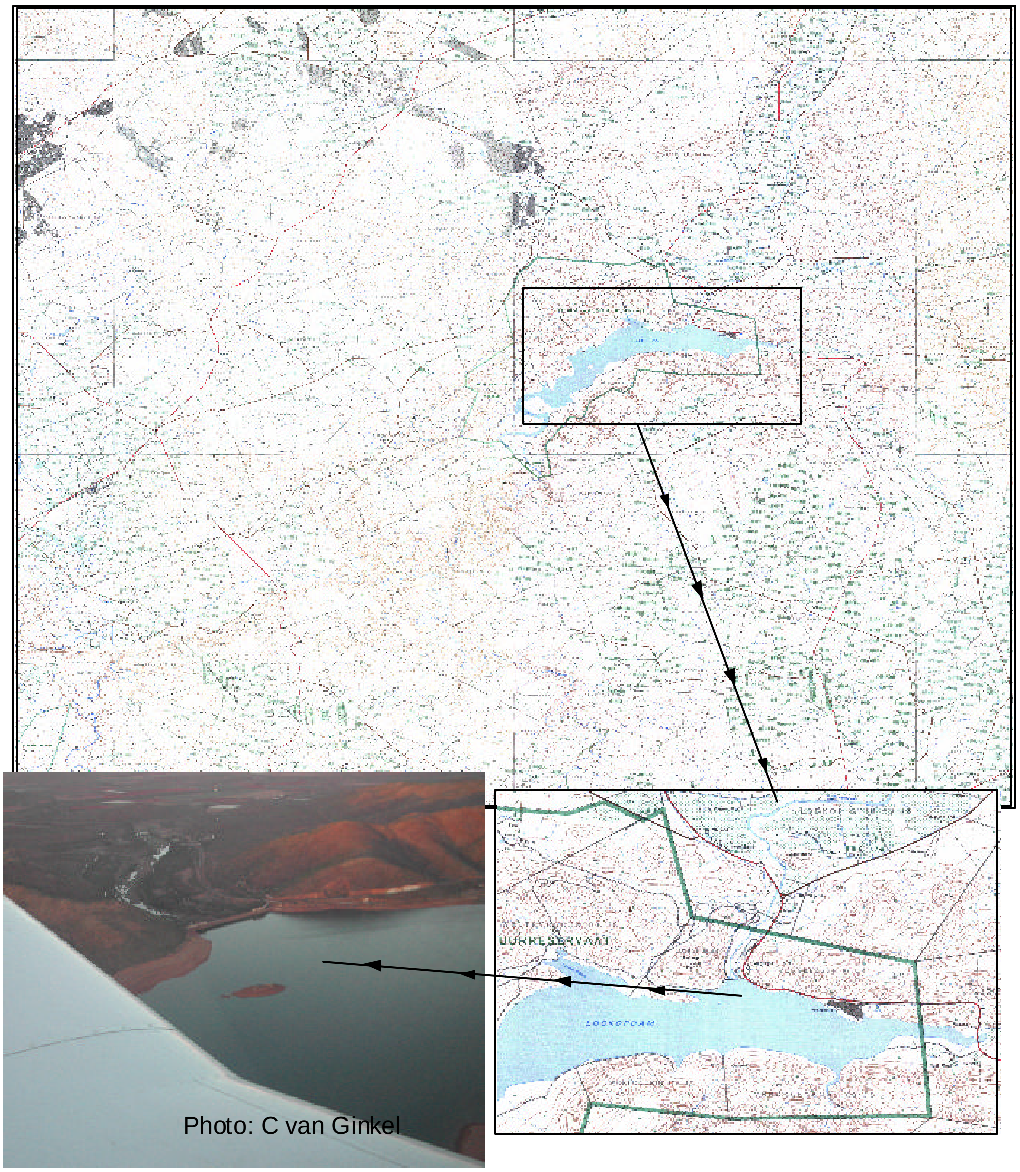
   E 29^0 21" 30'
8. Upstream catchment area: 12 285 km^2
9. Site description: Open water close to dam wall.
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

Loskop Dam was mainly identified as important as a result of it's use for irrigation (export market), recreation, and domestic purposes. Potential future developments also played a role.

SA-GEMS/Water Monitoring Site
90462 - Loskop Dam on Olifants River



Monitoring Site Name: Mooi River at Kamberg Nature Reserve

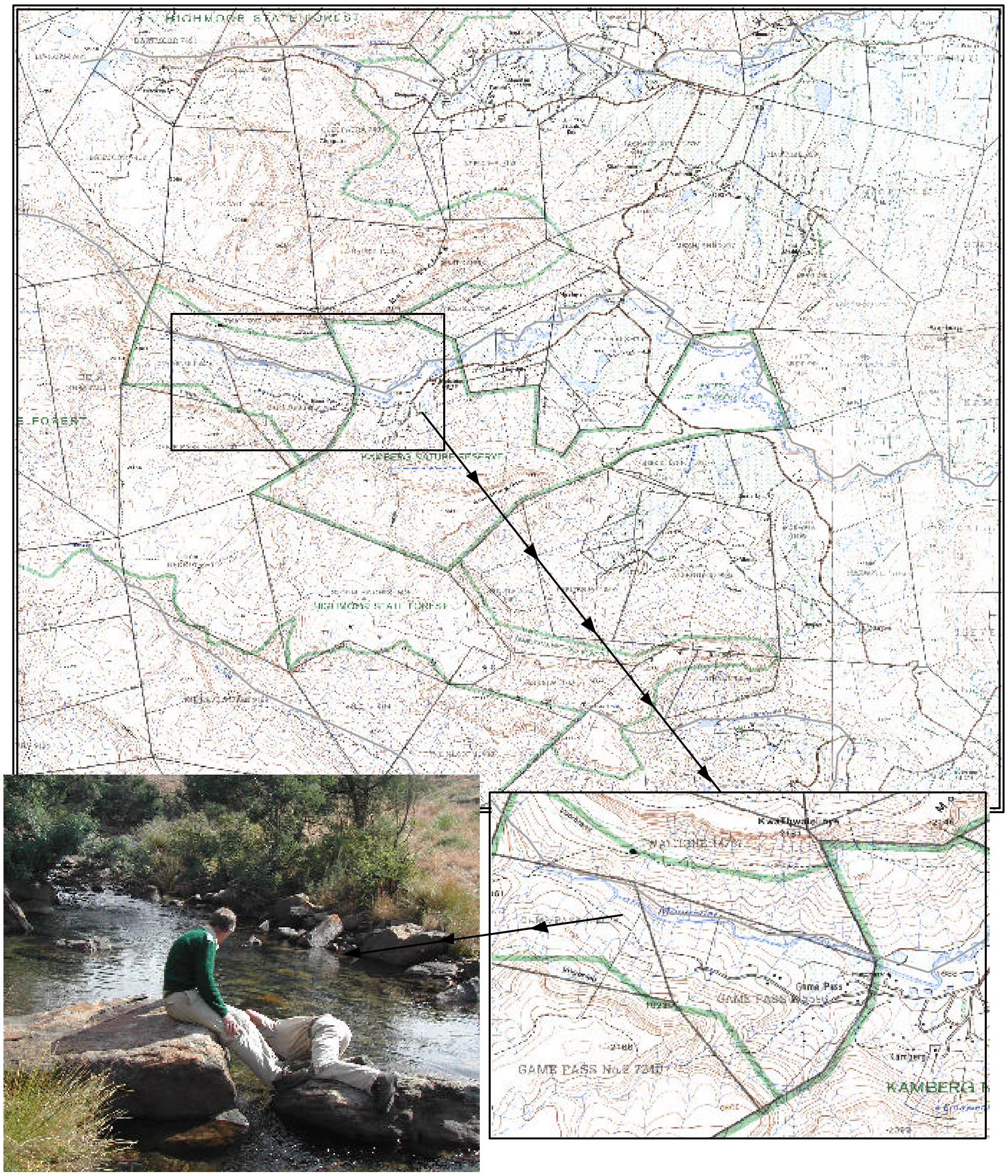
1. SA WMS site ID No.: Not assigned yet.
2. SA Hydro site ID No.: No Hydro number
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Baseline Water Quality Trends
5. Resource Type: River
6. Resource name: Mooi River (KZN)
7. Position (co-ordinates): S -29^0 22" 32'
   E 29^0 38" 22.7'
8. Upstream catchment area: Not available
9. Site description: Open stream above hatchery.
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

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.

SA-GEMS/Water Monitoring Site
Mooi River at Kamberg Nature Reserve



Monitoring Site Name: Blyde River upstream of the Truer River confluence.

1. SA WMS site ID No.: 90489
2. SA Hydro site ID No.: B6H001Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Baseline Water Quality Trends
5. Resource Type: River
6. Resource name: Blyde River
7. Position (co-ordinates):   S -24^0 40" 45'

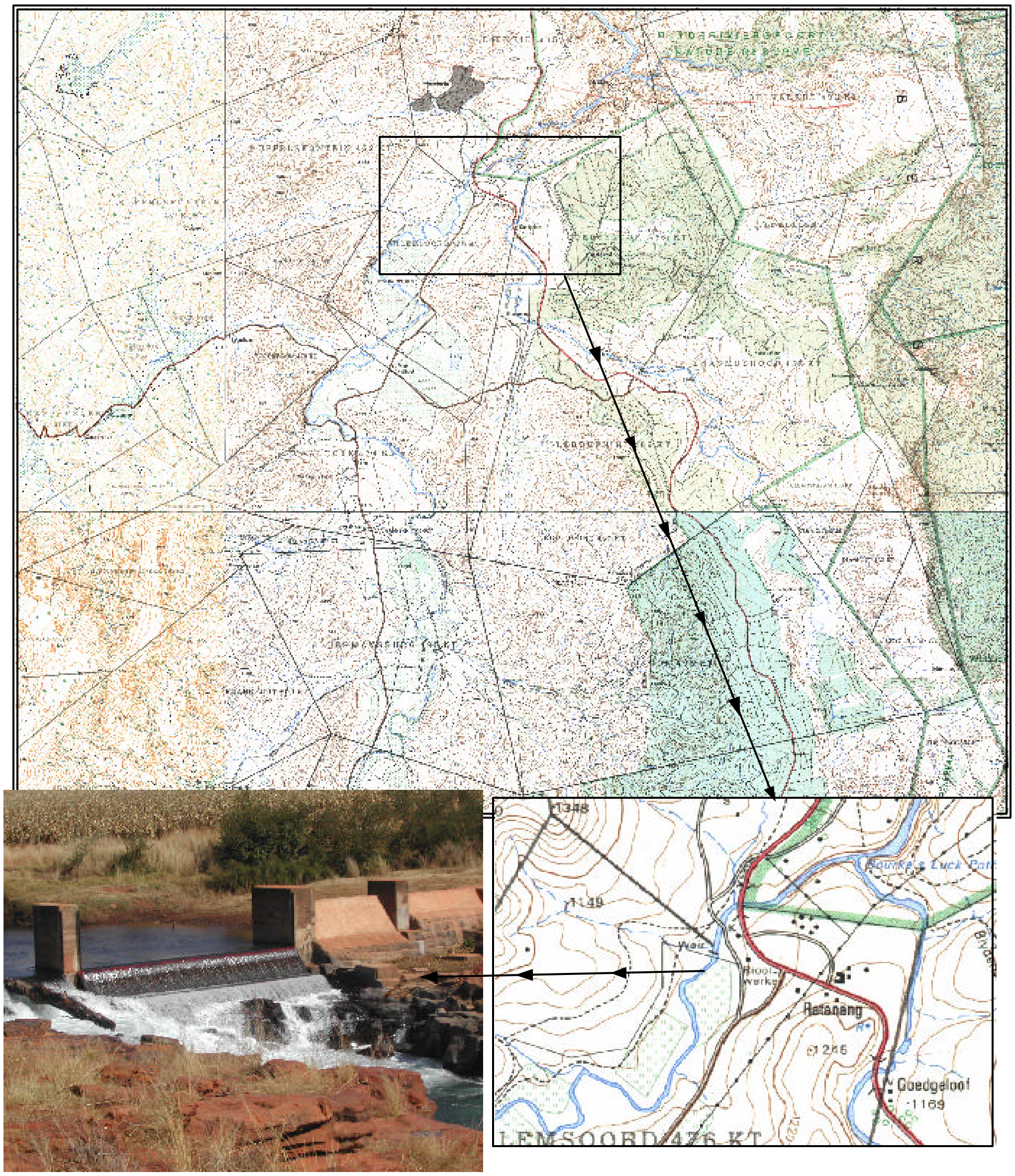
   E 30^0 48" 09'
8. Upstream catchment area: 518 km^2
9. Site description: At gauging station above old water works.
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

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.

SA-GEMS/Water Monitoring Site 90489 - Blyde River upstream of Treur River confluence



Monitoring Site Name: Kraai River at Roodewal

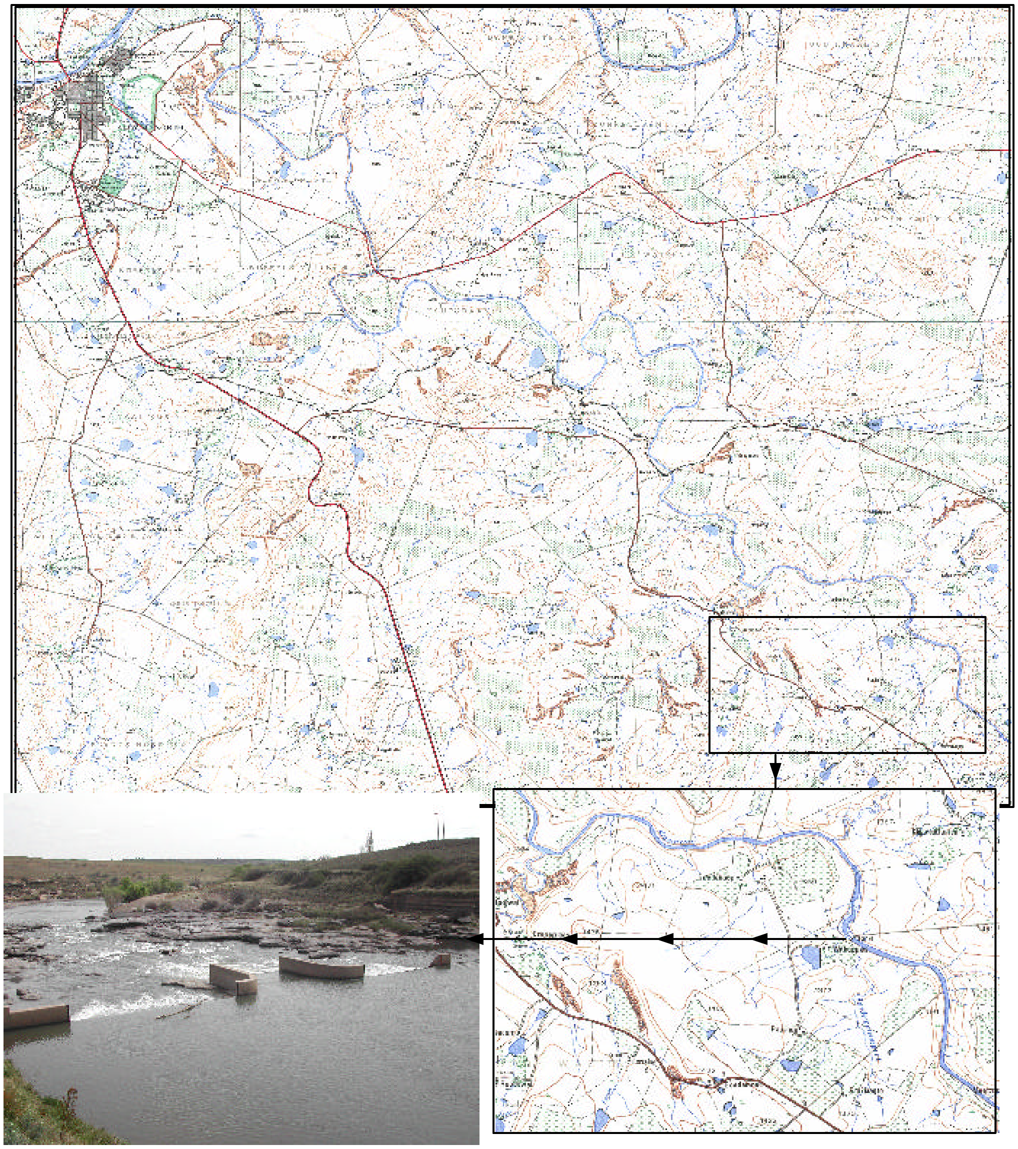
1. SA WMS site ID No.: 101795
2. SA Hydro site ID No.: D1H011Q01
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Baseline Water Quality Trends
5. Resource Type: River
6. Resource name: Kraai River
7. Position (co-ordinates):   S -30^0 49" 50'
   E 26^0 55" 17'
8. Upstream catchment area: 8 688 km^2
9. Site description: At flow gauging station.
10. Description of resource and upstream catchment:

For a detailed physical description of this catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.*, 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The Kraai River drains the Drakensburg D13 catchment towards the Orange River. There are very little potential for human impact although some farming activities does occur in the catchment. Twenty years of historical flow and water quality data are available.

SA-GEMS/Water Monitoring Site
101795 - Kraai River at Roodewal



Monitoring Site Name: Jonkershoek River at Witbrug

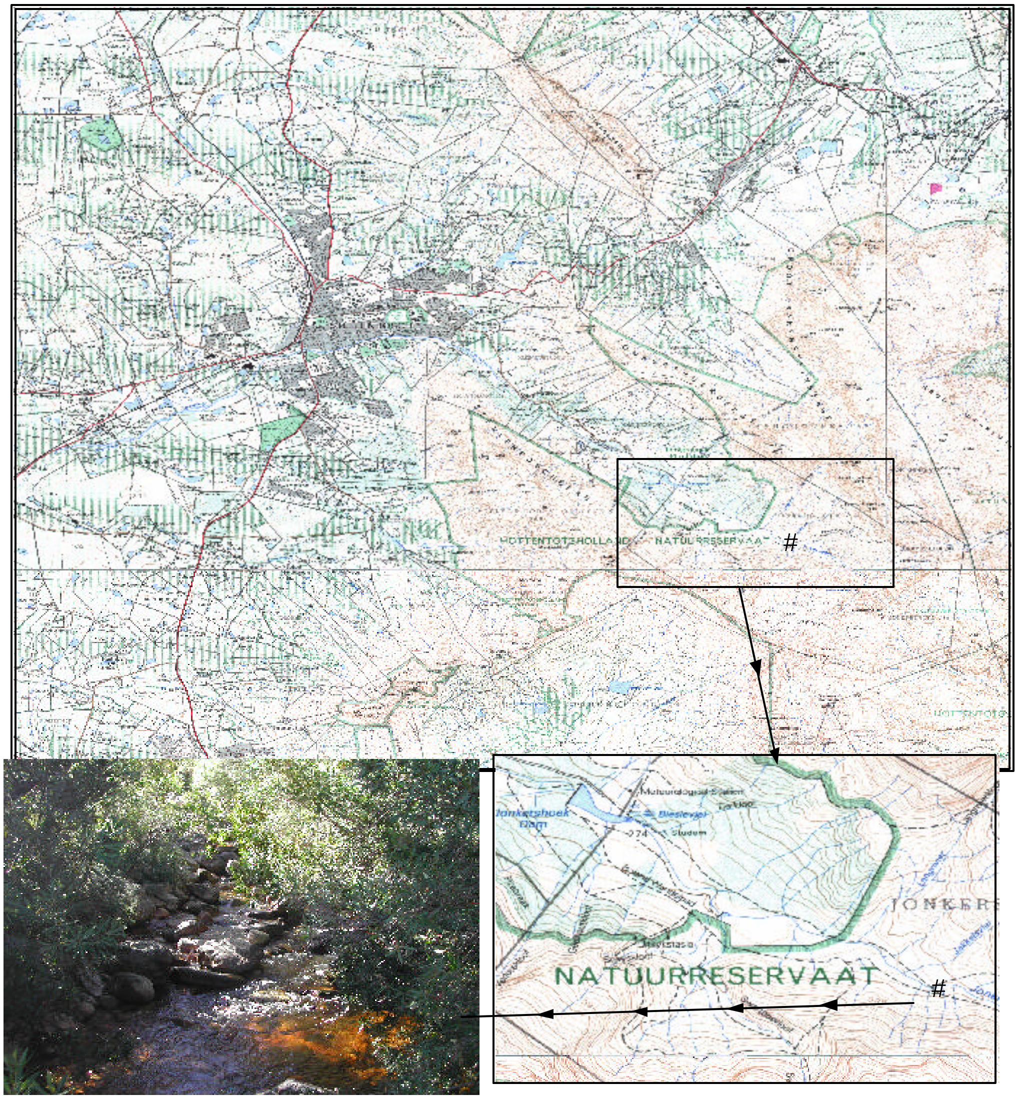
1. SA WMS site ID No.: Not assigned yet
2. SA Hydro site ID No.: No Hydro number
3. GEMS/Water site ID.No.:
4. GEMS/Water site type: Global Baseline Water Quality Trends
5. Resource Type: River
6. Resource name: Jonkershoek River
7. Position (co-ordinates): S -33^0 59" 37.9'
   E 18^0 58" 31.3'
8. Upstream catchment area: Not available
9. Site description: Stream upstream of road.
10. Description of resource and upstream catchment:

For a detailed physical description of the Orange River Catchment refer to the Appendices and Book of Maps, of Surface Water Resources of South Africa (Midgley *et al.,* 1990).

11. Reasons for site inclusion in SA-Gems/Water monitoring network

The site represents the water quality 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.

SA-GEMS/Water Monitoring Site
Jonkershoek River upstream of road



ANNEXURE 2

Site Identification Workshop

SA-GEMS/WATER WORKSHOP

PROCEEDING

17 FEBRUARY 2004

Selection of trend and baseline water quality monitoring sites

as part of the SA-GEMS/Water monitoring programme design process.

Held at
Resource Quality Services
Roodeplaat Dam

Workshop Agenda

08:00 – 9:00:	Purpose of workshop GEMS/Water overview Design process to date
9:00 – 12:30:	Presentation and discussion of criteria for trend monitoring site selection Selection of trend monitoring sites
13:00 – 15:45:	Presentation and discussion of criteria for selection of baseline monitoring sites Selection of baseline monitoring sites

Proceeding

1. Purpose of workshop

Mr van Niekerk welcomed all and explained the purpose of the workshop. The main purpose of the workshop is to identify appropriate monitoring sites in South Africa for the GEMS/Water global water quality monitoring network. The workshop outcome will feed into the draft monitoring programme design. The identification of the sites will be based on pre-determined draft criteria that will be discussed and finalized at the workshop. Sites will be identified for global trend and baseline monitoring. Various resources such as maps, historical data, reports and, most important, water monitoring specialists with a large number of years experience will be utilized for the site identification process. A small group of water scientists with extensive experience and knowledge on South Africa's river, dam and associated monitoring networks will forms the working group at the workshop.

The group consisted of the following specialists from within DWAF, namely:

- U Looser, Assistant Director: Resource Quality Information.
- M Silberbauer, Senior Specialist Scientist.
- P Kempster, Chief Specialist Scientist
- N Kleynhans, Chief Specialist Scientist (not able to attend, but will review the outcome of the workshop and gave inputs before the workshop)
- B Hohls. Principal Scientist.
- B Madikizela, Deputy Director: Resource Monitoring and Assessment.
- J Myburgh, Control Industrial Technician.
- A Gerber, Chief Limnological Technician
- P van Deventer, Chief Limnological Technician
- C van Cinkel, Specialist Scientist
- H van Niekerk, Specialist Scientist

2. GEMS/Water overview

Mr van Niekerk gave the following overview:

For over twenty years the Fresh Water Component of the Global Environmental Monitoring Programme (GEMS/Water) has being operating as the 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, lakes and groundwater. Since 1998 the number of participating countries has increased to 101.

Monitoring programmes in participating countries contribute 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 operationilize 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 good quality data to GLOWDAT.

Global water quality assessments have in the past given extremely subjective views of the general freshwater quality in various countries, including South Africa. This has mainly been as a result of a lack of good quality representative data. This is, therefore, an opportunity to make data available 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 in 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 gives 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.

3. Design process up to date

Mr van Niekerk explained that the design of the SA-GEMS/Water monitoring programme consists of three main phases, namely:

- Preparation of conceptual design
- Implementation and testing of design
- Generation of an operational manual

The preparation of the conceptual design is currently underway and the workshop recommendations will feed into the section on sample site selection in the design document. Below is an indication of the envisaged design document layout with an indication of the progress to date.

Conceptual design document layout

Chapter One
- Introduction *Completed*
- Purpose of document *Completed*
- Water quality monitoring and its application in South Africa. *Completed*
    - Water Quality Monitoring *Completed*
    - SA National Water Quality Monitoring Programmes *Completed*

Chapter Two: Information Requirements and Monitoring Objectives
- Introduction *Completed*
- Evaluation of information and data needs *Completed*
    - Information needs *Completed*
    - Data requirements *Completed*
- Monitoring programme objectives *Completed*

Chapter Three: Monitoring Network Design
- Introduction *Completed*

Global river flux to the oceans *Completed*

Samples site selection *Completed*

Variable selection *Completed*

Sampling frequency determination *Completed*

Global trend monitoring

Samples site selection

Rivers ***Workshop outcome***

Dams ***Workshop outcome***

Variable selection *To be addressed*

Rivers *To be addressed*

Dams *To be addressed*

Sampling frequency determination *To be addressed*

Rivers *To be addressed*

Dams ***To be addressed***

Global baseline monitoring

Samples site selection ***Workshop outcome***

Variable selection *To be addressed*

Sampling frequency determination *To be addressed*

Chapter Four: Data storage, management and transmission *To be addressed*

Chapter Five: Quality assurance programme *To be addressed*

Chapter Six: Operational structure, roles and responsibilities *To be addressed*

Annexures

References

4. Presentation and discussion of criteria for trend monitoring site selection

The following background to setting criteria was given by Mr van Niekerk.

The GEMS/Water definition for trend stations is as follows:

"Trend Stations are typically located in major river basins and lakes. They will be used to follow long-term changes in water quality related to a variety of pollution sources and land use; to provide a basis for the identification of causes or influences on measured conditions or identified trends"

One of the implications of the SA-GEMS 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 800 distributed over 100 countries. This is an average of 8 sites per country. In reality some countries have 20-30 sites where others only have 1 site. It mainly depends the country's drainage regime and available financial and human resources.

The challenge, therefore, is to identify a small number of sites, compared to the 800 sites in the national monitoring network, that would be sufficient for tracking long term trends in the following global water quality issues (GEMS/Water), namely

- 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.

After a lengthy discussion by the specialists there was consensus that the following criteria for rivers will be used as guidelines for selecting trend monitoring sites for dams and rivers, namely;

River Sites

- Sites must represent the drainage from medium sized catchments (GEMS, 1992). For trend monitoring, GEMS/Water typically view 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 < 100000 km and > 10000 km^2. In the South African catchment hierarchy the highest level of catchments, namely the primary catchments, fall 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.

- 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 guaging 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 a catchment the site should 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 do not have to be placed in all primary catchments. This specifically applies to smaller coastal catchments with little economic and social importance.

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

- 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).

- All sites must, as a minimum, be an existing national salinity monitoring programme sample site. If a specific site is identified as strategically important and it is not part of the national monitoring network, then a recommendation must be made to include the site in the national network.

- Other considerations are future developments and inter-basin transfers.

> All identified sites will be discussed with the DWAF regional offices of concern to ensure objectivity of the site selection process.

Dam Sites

During the workshop it was decided that approximately five dams that are of strategic importance to the SA economy and social welfare would be identified. Mr van Niekerk indicated that dams listed below have already been identified by the regional DWAF offices, water boards and the DWAF Directorate: Water Resource Planning as being of strategic importance to the SA economy and social welfare, namely:

- Vaal Dam
- Gariep Dam
- Theewaterskloof Dam
- Bloemhof Dam
- Midmar Dam

- Inanda Dam

The exact monitoring positions will depend on the placement of the national monitoring network sites.

5. Selection of trend monitoring sites

A total of 23 trend monitoring stations (16 river and 6 dam) were selected during the workshop. Those sites are listed in table 1 together with the reasons for inclusion.. Map1 indicates the placement of the monitoring sites. The selection team was satisfied that the selected sites would be able to give a fair reflection of the general water quality in South Africa on a very strategic level.

Table 1. Selected monitoring stations.

Station name on WMS	HYCOS GRDC	Water quality data	Site purpose
Trend stations for drainage of the interior of South Africa (Orange and Vaal river systems).			
D8H003Q01 AT VIOOLSDRIFT ON ORANGE	Yes	Yes	This site has already been identified as the most appropriate site for monitoring loads of water quality constituents from the Orange River catchement. It is therefore also the ideal site trend monitoring of runoff from the interior of South Africa
D3H008Q01 AT MARKSDRIFT ON ORANGE RIVER	Yes	Yes	This site was included to represent runoff from the Orangr river catchment upstream of the Vaal River confluence.

Station name on WMS	HYCOS GRDC	Water quality data	Site purpose
C9H024Q01 AT SCHMIDTSDRIFT (WEIR) ON VAAL RIVER	Yes	Limited	Except for the Modder/Riet sub-catchment, this site represents whole Vaal river system, which can be said to be the hardest working river in South Africa. The Modder/Riet river system joins below the site upstream of the confluence with the Orange River. No suitable site could be found below the Modder/Riet and the confluence with the Orange. The site represents the impacts of large irrigation schemes such as the Vaal/Harts and upstream industrial and mining activities.
C2H007Q01 AT PILGRIMS ESTATE ORKNEY ON VAAL RIVER	Yes	Yes	The purpose of this site is to reflect the impact of the major industrial complexes and mining activities in the upstream catchment of the Vaal River system.
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	Yes	Yes	This site represents the catchments area of the Crocodile River upstream of the Hartebeespoort Dam. This sub-catchment drains the major economical hub, namely the PWV area. Although it represents a small drainage area it reflects on the typical quality of water draining from a large urban and industrial area. Both the Jukskei and Hennops Rivers are included in this drainage area which also represents drainage from large informal settlements. Large volumes of water that are pumped from the Vaal River system by Rand Water for domestic and industriel purposes also end up in this catchment as sewerage and industrial effluent.
A5H006Q01 AT BOTSWANA STERKLOOP ON LIMPOPO RIVER	No	Yes	The Sterkloop site represents drainage from the entire Crocodile (West) Marico Water Management Area and Ngotwane River Catchment in Botswana that includes runoff from Gaberone.

Station name on WMS	HYCOS GRDC	Water quality data	Site purpose
A7H008Q01 DOWN STREAM OF BEIT BRIDGE ON LIMPOPO RIVER	Yes	Yes	This site represents drainage from South Africa and Botswana's capital cities together with large agricultural and limited forest areas in the Limpopo catchment. Downstream of this site the Limpopo River flows into Mozambique from where it flows into the ocean.
B7H009Q01 AT OXFORD ON OLIFANTS RIVER	No	Yes	The Olifants River catchments drains extremely miniral rich area which are also characterized by large coal deposits and forest areas. The site therefore represents a drainage area dominated by mining and forestation. The site is situated upstream of the Kruger National Park as no suitable sites could be identified in the National Park.
X2H036Q01 @ KOMATIPOORT KRUGER NATIONAL PARK ON KOMATI RIVER	No	Yes	This site place immediatly downstream of the confluence of the Crocodile with the Komati River before it flows through Mozambique into the Indian ocean. Both Catchments are largely dominated by forestation and protected nature areas, although some mining activities do occur.
Trend stations for catchments in the coastal regions of South Africa			
V5H002Q01 AT MANDINI ON TUGELA RIVER	Yes	Yes	The Tugela catchment is forms part of the group of Kwazulu/Natal catchments that is responsible for for the highest Mean Annual Runoff in the country. It originates in the Drakensburg with and are characterized by high sediment runoff. The monitoring site is close to where the Tugela enters the ocean.
U2H055Q01 AT INANDA LOCATION EGUGWINI ON MGENI	Yes	Yes	The Mgeni catchment is a hard working catchment characterized by large rural and urban settlements, a high level of industrial development and number of impoundments. Although it is a relatively small catchement compared to the Tugela it was felt that as a result of the high level of development this site should be included.

Station name on WMS	HYCOS GRDC	Water quality data	Site purpose
S7H004Q01 AT AREA 8 SPRINGS B ON GROOT-KEIRIVIER	Yes	Yes	The site represents the S primary catchment with a drainage area of 20 485 km^2. It reflects the area of interchange between the high rainfall catchments to the north and the low rainfall area to the south. The characterized by a low level of development. High sediment yield are common in this area.
R2H027Q01 AT MHLABATI NEEDS CAMP ON BUFFALO RIVER	No	Yes	Compared to the Groot Kei River the Buffalo River has a small catchment area, although Bufalo system are charactirised by high level of industrial development.
Q9H018Q01 AT MATOMELA'S RESERVE OUTSPAN ON GROOT-VISRIVIER	Yes	Yes	The largest proportion (inland) of the Fish River Catchement has a very low occurrence of rainfall. The catchment does however receive large quantities of water from the Gariep Dam in the Orange River system via pipelines. This is mainly for irrigation purposes and further distribution to the Sundays River to the South. Natural saline conditions poses a major problem for irrigation schemes. Except for the lower part of the catchment in the Port Elizabeth area there are genery a low level of industrial development in the catchmenet.
Knysna			
H7H006Q01 AT SWELLENDAM ON BREE RIVER	Yes	Yes	The Bree River catchment is the most Western catchment draining to the Indian ocean. Although it has by far the smallest catchment area, it has the highest mean annual precipitation, runoff, and reservoir storage capacity and irrigated land area in the Western Cape. Grape farming and the wine industry are dominant in the catchment. The site represents drainage from one of the most intensively irrigated areas in the country

Station name on WMS	HYCOS GRDC	Water quality data	Site purpose
G1H036Q01 AT VLEESBANK HERMON BRIDGE ON BERGRIVIER	Yes	Yes	The Berg River catchment are the most Southern catchment draing into the Atlantic Ocean. It is also the catchment with the highest rainfall on the South African West Coast. It is also highly developed in terms grape farming and the wine industry with some degree of forestation. Selecting the ideal site was problematic as limited sites were available to choose from. The site that was selected does however reflect the general water quality in the catchment.
E2H003Q01 AT MELKBOOM ON DORINGRIVIER	No	Yes	This site represents only the Doring River sub-catchment in the greater Olifants/Doring catchment. This is a direct result of a lack of operational gauging stations that form part of the national water quality monitoring network. This was however not seen as a problem as the main areas of concern relating to water quality lies within this sub-catchment.
Trend/reservoirs			
A2R001Q01 HARTBEESPOORT DAM ON CROCODILE RIVER	No	Yes	Although the Hartebeespoort 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 eutrophic dams in the world and is currently being investigated for potential rehabilitation options.

Station name on WMS	HYCOS GRDC	Water quality data	Site purpose
C1R001Q01 VAAL DAM ON VAAL RIVER: NEAR DAM WALL	Yes	Yes	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 extensive utilized by Rand Water for domestic and industrial water supply purposes to area that form the economical hub of South Africa.
C9R002Q01 BLOEMHOF DAM ON VAAL RIVER: NEAR DAM WALL	Yes	Yes	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	Yes	Yes	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 for domestic and industrial purposes economically important area.
D3R002Q01 GARIEP DAM ON ORANGE RIVER: NEAR DAM WALL	Yes	Yes	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 purposes. 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: NR DAM WAL	Yes	Yes	The Theewaterkloof Dam is most strategic water storage facility in the Western Cape. Water from the dam gravitates through 35km of tunnels to supply the Cape Metropolitan Area (including Cape Town) with water.
B3R002Q01 LOSKOP DAM ON OLIFANTS RIVER: NEAR DAM WALL	No	Yes	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.

6. Presentation and discussion of criteria for baseline monitoring site selection

The following background to setting criteria was given by Mr van Niekerk.

The GEMS/Water definition for baseline stations is as follows:

"Baseline stations are typically located in headwater lakes or undisturbed upstream river stretches where no direct diffuse or point sources of pollutants 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 (i.e. trend and global river flux stations); to determine, through trend analyses, the influence of long range transport of contaminants and of climatic changes."

GEMS/Water envisage having at least 50 baselines monitoring station distributed over all continents. The implication is that the number of sites required in South Africa is fairly low. The sites will also be limited to upstream river stretches as a result of the absence of headwater lakes. Dams cannot be considered as undisturbed upstream lakes.

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 (19?) of ecoregions. This is an approach that should be considered by the national monitoring network during the redesign phase.

There was consensus that the following guidelines would be used, 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 be fairly distributed over the country…

All identified sites will be discussed with the DWAF regional offices of concern to ensure objectivity of the site selection process.

7. Selection of baseline monitoring sites

During the workshop four potential areas were identified for placement of baseline sites. Mr van Niekerk were to visit these areas together with the regional water managers to help identify the most appropriate sample sites in those areas. The areas that were identified were:

- Jonkershoek in the Western Cape.
- Upper reaches of the Groot Vis river in the Eastern Cape or Kraai river.
- Royal Natal National Park
- Upper reaches of the Treur/Blyde river catchment in Mpumalanga.

8. Resources used

The following resources were available to assist with the site selection process, namely;

- Surface Water resources of South Africa, all six volumes of the annexure and book of maps.
- SADC-HYCOS and GRDC station inventory.
- 1:2000 000 Drainage Regions Map of South Africa.
- Water Management System (WMS) online for site and data queries of national water quality monitoring network.
- National Water Quality Status Report: Inorganic Chemical Water Quality of Surface Water Resources in SA – The Big Picture (DWAF, 2002)
- Conceptual Design Report for a National River Water Quality Assessment Programme, (Harris *et all.*, 1992).
- A map indicating the current hydrological monitoring network stations.

- DWAF, List of Hydrological Gauging Stations (1990)
- National Water Resource Strategy

ANNEXURE 3

Summary of laboratory analyses methods currently used for the National Chemical Monitoring Programme by the DWAF National laboratory at Roodeplaat Dam

Method 0001101 Automated Determination of pH

Scope

This method is applicable to the determination of pH for all types of water samples.

Measurement range: 2,0 to 12 pH units.

Principle of method

pH measurements give an indication of the acidic or basic character of a solution by measuring the hydrogen ion concentration.

The Inorganic Chemistry Laboratory uses an automated instrument for the determination of pH.

Method 0006101 Automated Determination of Dissolved Organic Carbon by UV Oxidation

Scope

This method is applicable to the determination of dissolved organic carbon in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 1,3 to 20,0 mg carbon/L.

Principle of Method

The sample stream is segmented with CO_2 free air, acidified, heated and sparged with nitrogen gas to remove the inorganic carbon.

After re-sampling and air segmentation, persulphate and mercury(II) nitrate solutions are added and the mixed liquid stream is pumped through a quartz coil where it is exposed to a low intensity ultraviolet light, used as a source of energy.

This process oxidizes the dissolved organic carbon to CO_2 which by means of a gas permeable silicon membrane is dissolved in a weakly buffered thymol blue indicator solution.

The colour change of the acid-base indicator is measured at 590 nm and is proportional to the concentration of dissolved organic carbon in a water sample

Method 0007003 Automated Determination of Dissolved Nitrogen (Kjeldahl)

Scope

This method is applicable to the determination of Kjeldahl nitrogen (KN) in clear surface, ground, waste and drinking water samples.

Optimum concentration range: 0,30 to 4,00 mg nitrogen/L.

Principle of Method

In the Kjeldahl method, the organic compounds are digested with concentrated sulphuric acid, which convert organic nitrogen into ammonium sulphate.

Inorganic nitrogen compounds, which include amongst others, nitrate and nitrite are not reduced.

For most surface waters, it is accepted that the method determines the sum of the ammonium originally present and the organic nitrogen.

The digestion is accelerated in two ways, by the addition of mercury(II) as a catalyst and potassium sulphate to raise the boiling point of the digestion mixture.

After digestion of the sample, the ammonium ions are determined using the indophenol-blue method. Measurements are done colorimetrically at 630 nm.

Method 0007106 Automated Determination of Dissolved Ammonium with Indophenol Blue

Scope

This method is applicable to the determination of ammonium in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 0,03 to 2,00 mg ammonium/L.

Principle of Method

Ammonium reacts in a mildly alkaline medium with hypochlorite to form monochloramine, which forms indophenol-blue in the presence of phenol, catalytic quantities of nitroprusside and an excess of hypochlorite.

Monochloramine formation requires a pH between 8 and 11,5. At higher pH values incomplete oxidation of ammonium to nitrite occurs.

Precipitates of calcium and magnesium hydroxide are formed at pH values higher than 9,6 and a complexing agent (citrate) is added to prevent precipitation.

The complex is read colorimetrically at 630 nm.

Mercury chloride, used as a preservative, gives a negative interference by complexing with the ammonia. This can be overcome by adding the same quantity of Hg(II) to the standard used for the calibration curves and the samples.

Method 0007107 Automated Determination of Dissolved Nitrate by Cadmium Reduction

Scope

This method is applicable to the determination of nitrate in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 0,11 to 4,0 mg nitrogen/L.

Principle of Method

This method is based on the reduction of nitrate to nitrite and the subsequent colorimetric determination of nitrite.

The reduction takes place in a cadmium tube.

The conditions for the reduction process are set up such that nitrate can be quantitatively reduced to nitrite.

The effectiveness of the reduction of nitrate is dependent on the metal of the reductor, the pH of the solution and the activity of the metal surfaces.

A copper coil in the buffer line, together with cadmium is suitable for this heterogeneous reduction. In a neutral medium the cadmium ions, which are produced in the reduction process, form a precipitate with hydroxide ions.

In addition, the reduction potential is a function of the hydroxide ion concentration, with the result that the pH, especially on the surface of the metal, changes if the solution is not buffered. Since the buffering capacity of the surface water is not sufficient, ammonium chloride is added, which serves both as a complexing agent and as a buffer.

The colorimetric determination of the formed nitrite is based on the reaction of nitrite with an aromatic amine (sulphanyl-amide-hydrochloride) which results in the formation of a diazonium compound that is coupled to a second aromatic amine (n-1-naphthylethylene-diamine-dihydrochloride).

The reaction results in the formation of an azo-dye. The absorbance of the dye is measured colorimetrically at 520 nm.

Separate nitrate and nitrite values can be obtained through analysis without the cadmium reduction step.

Interferences

The concentrations of oxidation and reduction agents and potential interfering metal ions are usually low in the surface water.

Metal ions, which are present at high concentration, can lead to positive errors.

Method 0007109 Automated Determination of Dissolved Nitrite

Scope

This method is applicable to the determination of nitrite in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 0,11 to 4,0 mg nitrogen/L.

Principle of Method

The colorimetric determination of nitrite is based on the reaction of nitrite with an aromatic amine (sulphanyl-amide-hydrochloride) which results in the formation of a diazonium compound that is coupled to a second aromatic amine (n-1-naphtylethylene-diamine-dihydrochloride).

The reaction results in the formation of an azo-dye, which is measured colorimetrically at 520 nm.

Method 0009101 Automated Determination of Dissolved Fluoride with an Ion-Selective Electrode

Scope

This method is applicable to the determination of fluorides in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 0,2 to 5,0 mg fluoride/L.

Principle of Method

The fluoride electrode consists of a single lanthanum fluoride crystal, which internally is in contact with a constant fluoride ion concentration and an internal reference electrode.

When the external electrode surface comes in contact with a solution (standard or unknown sample) a potential difference is established over the crystal, which is dependent on the different fluoride concentrations in contact with the crystal surface.

An external reference electrode (calomel), which allows the measurement of the membrane or crystal potential, completes the circuit.

Interferences

Polyvalent cations such as for example, Al(III), Fe(III), Si(IV) will remove free fluoride ions out of solution through the formation of soluble complexes.

Similarly, the pH must be greater than 5, to prevent the formation of the molecular hydrogen fluoride thus lowering the free fluoride ion concentration.

In this method the cyclohexylene-diamine-tetraacetic acid (CDTA) is used as a complexing agent.

The pH of the sample solution is critical. Thus the role of the CDTA buffer solution is important to also maintain a stable pH.

Variations in the ionic strength between samples and standards must be prevented. An excess of sodium chloride is added to ensure a constant ionic strength.

The automated procedure is designed to reduce these problems (Technicon Auto Analyzer methodology).

Method 0010101 Automated Determination of Alkalinity using Bromophenol Blue

Scope

The method is applicable to the determination of alkalinity in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 8 to 400 mg alkalinity/L as calcium carbonate.

Principle of Method

Bromophenol blue is used in the method as the acid-base indicator and it has a definite colour change (green to purple) which can be measured colorimetrically at 600 nm.

The presence of alkalinity causes a differential change in the pH resulting in a proportional change in the colour of the indicator.

Interferences

Colour and turbidity interfere in this method. High turbidity is removed during the filtration process.

Coloured samples should preferably be analysed using the titrimetric method.

Method 0011103 Automated Determination of Sodium with Flame Emission Spectroscopy

Scope

This method is applicable to the determination of sodium in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 2 to 200 mg sodium/L.

Principle Of Method

Sodium is determined by means of flame emission spectroscopy.

Samples are nebulised into a gas flame under carefully controlled, reproducible excitation conditions.

Some of the atoms will be excited to a higher energy level and when these atoms return to the ground state they emit radiation, which lies mainly in the visible region of the spectrum. Each element will emit radiation at a wavelength specific to that element.

The light emitted by an element at the characteristic wavelength is isolated by an optical filter and the intensity of that light measured by a photo detector. An electrical signal can be obtained proportional to the sample concentration.

Method 0012101 Automated Determination of Dissolved Magnesium by Atomic Absorption

Scope

This method is applicable to the determination of magnesium in clear surface, ground, drinking water and waste water samples.

Optimum concentration range: 1 to 75 mg magnesium/L.

Principle of Method

Magnesium is determined by atomic absorption spectrometry.

Samples are aspirated into a flame and atomised. A light beam is directed through the flame into a monochromator and onto a detector that measures the amount of light absorbed by the atomised element in the flame.

Because each element has its own characteristic absorption wavelength, a source lamp composed of that element is use.

The amount of energy at the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample over a limited concetration range.

Lanthanum is used to prevent the interference of phosphate, while the addition of potassium serves as an ionization buffer.

Hydrochloric acid added to the method prevents precipitation in the flow system.

Method 0014105 Automated Determination of Dissolved Silicon with Molybdate Blue

Scope

This method is applicable to the determination of silicon in clear surface, ground, drinking water and waste water samples.

Optimum concentration range: 0,6 to 40,0 mg/L silicon.

Principle of Method

The automated determination of silicon in the orthosilicomolybdate form in natural water is based on the formation of β-1:12 molybdosilicic acid and the partial reduction of that to a blue heteropoly acid.

The β-isomer of the 1:12 molybdosilicic acid is unstable and is spontaneously converted to the α-isomer. This isomerization is dependent on temperature, pH and the dissolved salt concentration and requires a relatively long period for completion. By setting the pH at 2, conditions for the formation of the β-complex are optimized (Truesdale, Smith and Smith, 1979).

The addition of oxalic acid prevents the formation of phosphorus complexes, which cause interference, by reacting with the excess molybdate.

The reduction of the β-isomer with ascorbic acid produces a heteropoly acid which is measured colorimetrically at 660 nm.

Method 0015003 Automated Determination of Total Phosphorus as Phosphomolybdate

Scope

This method is applicable to the determination of total phosphorus in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 0,030 to 0,5 mg phosphorus/L.

Principle of Method

Acid-oxidation of polyphosphates to orthophosphates takes place prior to analysis when the samples are digested under pressure in closed containers with the digestion mixture (peroxydisulphate).

During analysis ammonium molybdate and antimony potassium tartrate react in an acid medium with phosphorus to form an antimony-phospho-molybdate complex.

This complex is reduced to an intensely blue coloured complex by ascorbic acid.

The colour is proportional to the phosphorous concentration and read colorimetrically at 660 nm.

Mercury chloride used as a preservative interferes when the chloride levels of the samples are low (< 50 mg/L). This interference is overcome by spiking the samples with sodium chloride.

Commercial washing agents must not be used, under any circumstances, to avoid possible phosphate contamination.

Method 0015104 Automated Determination of Dissolved Orthophosphate as Phosphomolybdate

Scope

This method is applicable to the determination of orthophosphate in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 0,023 to 0,500 mg phosphorus/L.

Principle of Method

During analysis ammonium molybdate and antimony potassium tartrate react in an acid medium with phosphorus to form an antimony-phospho-molybdate complex.

This complex is reduced to an intensely blue coloured complex by ascorbic acid.

The colour is proportional to the phosphorous concentration and read colorimetrically at 660 nm.

Mercury chloride used as a preservative interferes when the chloride levels of the samples are low (<50 mg/L). This interference is overcome by spiking the samples with NaCl.

Method 0016104 Automated Turbidimetric Determination of Dissolved Sulphate

Scope

This method is applicable to the determination of sulphate in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 6 to 240 mg sulphate/L.

Principle Of Method

The method is based on the formation of a low solubility barium sulphate ($BaSO_4$) suspension (K_{sp} of $BaSO_4 = 9,2 \times 10^{-11}$) in a gelatine medium.

The degree of suspension of the $BaSO_4$ is dependent on the reaction conditions and it is necessary to ensure that the conditions and requirements with regard to the reagents must be strictly followed.

The addition of hydrochloric acid prevents the forming of precipitates of sulphite, carbonate, chromate and phosphate with barium.

The turbidity of the $BaSO_4$ suspension is determined colorimetrically at 420 nm.

Method 0017104 Automated Determination of Dissolved Chloride using Ferric Thiocyanate

Scope

This method is applicable to the determination of chloride in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 5 to 300 mg Cl/L.

Principle of Method

This automated method for the analysis of chloride in water is based on the reaction between mercury(II)thiocyanate and chloride ions to form low solubility mercury(II)chloride.

In the presence of iron(III) the liberated thiocyanate forms an intensely coloured complex, which is colorimetrically measured at 480 nm.

Method 0019103 Automated Determination of Dissolved Potassium by Flame Emission Spectroscopy

Scope

This method is applicable to the determination of potassium in clear surface, ground, drinking and waste water samples.

Optimum concentration range: 0,3 to 25 mg potassium/L.

Principle Of Method

Potassium is determined by flame emission spectroscopy.

Samples are nebulised into a gas flame under carefully controlled, reproducible excitation conditions.

Some of the atoms will be excited to a higher energy level and when these atoms return to the ground state they emit radiation, which lies mainly in the visible region of the spectrum. Each element will emit radiation at a wavelength specific to that element.
The light emitted by an element at the characteristic wavelength is isolated by an optical filter and the intensity of that light measured by a photo detector. An electrical signal can be obtained proportional to the sample concentration.

Method 0020101 Automated Determination of Dissolved Calcium by Atomic Absorption

Scope
This method is applicable to the determination of calcium in of clear surface, ground, drinking and waste water samples.
Optimum concentration range: 1 to 100 mg/L calcium.

Principle of Method
$CaCO_3$ solubility is controlled by pH and dissolved CO_2. The CO_2, HCO_3^- and CO_3^{2-} equilibrium is the major buffering mechanism in fresh water.
Calcium is determined by atomic absorption spectrometry.
Samples are aspirated into a flame and atomised. A light beam is directed through the flame into a monochromator and onto a detector that measures the amount of light absorbed by the atomised element in the flame.
Because each element has its own characteristic absorption wavelength, a source lamp composed of that element is use.
The amount of energy at the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample over a limited concetration range.
Lanthanum is used to prevent interference by phosphate while the addition of potassium serves as an ionization buffer.
Hydrochloric acid added to the method prevents precipitation in the flow system.

Method 0101101 Automated Determination of Electrical Conductivity

Scope

This method is applicable to the determination of electrical conductivity of all types of water samples.

Measurement range: 0,1 to 130 000 mS/m

Principle of Method

Conductivity is the measure of the ability of an aqueos solution to carry an electric current. This ability depends on the presence of ions, their concentration, mobility, and valence and on the temperature of the measured solution.

Temperature variation has a great influence on the conductivity. It is therefore necessary to compensate for the temperature influence. Therefore electrical conductivity measurements carried out are temperature compensated to 25°C.

In the Inorganic Chemistry Laboratory, conductivity is used as a guide in preparing dilutions prior to the analysis of calcium, magnesium, potassium, sodium, sulphate and chloride.

These dilutions are made to ensure as far as possible that the concentration of these determinands are within the calibration range of the respective automated analytical methods.

The relevant dilution factors are as follows:

Conductivity (mS/m)	Dilution factor
less than 260	no dilution
from 260 to 459	5x
from 460 to 899	10x
from 900 to 4 999	40x
5000 and greater	100x

Method 0105001   Nephelometric Turbidity Measurement

Scope

This method is applicable to the determination of turbidity in surface, ground, waste and drinking water samples.

Optimum measuring range: 1 NTU – 10 000 NTU (Nephelometric Turbidity Units)

Principle of Method

Turbidity, an indication of the cloudiness of the water, is measured when light is scattered by suspended particles in water. Turbidity is expressed in NTU in this method.

The optical system of the Turbidimeter is comprised of a tungsten-filament lamp, lenses and apertures to focus the light, a 90° detector to monitor scattered light, a forward-scatter light detector, a transmitted-light detector and a back-scatter light detector.

The Turbidimeter measures turbidity at less than 40 NTU using only the 90° scatter-light detector. This is the case when the RATIO mode is off.

If the Turbidimeter is operated in the RATIO mode, the complete set of detectors is in use and the Turbidimeter's microprocessor uses a mathematical calculation to ratio signals from each detector.

The benefits of using the RATIO mode for measurement include excellent linearity, calibration stability, wide measurement range and the ability to measure turbidity in the presence of color.

Method 5010   Hardness and Total Dissolved Salts by calculation

Scope

This method is applicable to the calculation of the water hardness (as $CaCO_3$, mg/l) and the Total Dissolved Salts (TDS, mg/l) from results obtained by accredited methodology for the determination of dissolved ions in water.

The determinand code for Water Hardness is 0102101 and the calculation is accredited.

The determinand code for TDS is 0103101 and the calculation is not accredited.

Principle of Method

Water hardness

Water hardness refers to the soap-neutralising power of water.

Water hardness is determined from the concentration of magnesium (Mg) and calcium (Ca) ions in water, which will form an insoluble scum with soap before the water will form lather with the soap.

Water hardness can therefore be defined as the sum of Mg and Ca concentrations expressed as equivalent to calcium carbonate ($CaCO_3$) in mg/l.

The molar masses of $CaCO_3$ raised to Ca and Mg respectively are used to convert concentration into $CaCO_3$ equivalents.

Total Dissolved Salts (TDS)

TDS is defined as the sum of a number of fundamental variables, with all concentrations in mg/l (see 3.2).

The concentrations of orthophosphate (PO_4), nitrate-nitrite (NO_3+NO_2), ammonium (NH_4) and alkalinity are converted before calculation of TDS.

The TDS value for PO_4 is derived from the molar ratio of PO_4 to P; the TDS values of NO_3 and NH_4 are derived from the molar ratio of NO_3 to N and NH_4 to N. The TDS value for alkalinity is derived from the ratio of the molar mass of HCO_3^- divided by $CaCO_3$ equivalent mass.

SOP 2001 Dissolved Metals in Water - Sample Preparation

Scope

This operating procedure is applicable to water samples.

Principle

"Dissolved metals" refers to the concentration of elements determined in a sample after it has been filtered through a 0,45 micron filter. The determination of dissolved metals is directed at only those particles, molecules and elementary forms of the metal that are able to pass through a 0,45 micron filter.
During sample preparation 100 mL of the sample is filtered and preserved with 1 mL of concentrated nitric acid. This procedure is intended to change the sample into a form suitable for ICP aspiration.

SOP 2002 Metals Extractable by Acid at Boiling Point

Scope
This operating procedure is applicable to water samples.

Principle
By 'metals extractable' is meant the concentration of elements in solution after treatment of an unfiltered and unpreserved sample with hot dilute mineral acids. When unfiltered samples are acidified, metals absorbed onto suspended particle matter will be brought into solution. The analytical result will then present dissolved metals plus the extracted metals, with the latter often contributing the major portion to the analytical result.

Method 2003002 Total Suspended Solids

Scope
Total suspended solids include dead and live phytoplankton, zooplankton and detritus.
The amount of suspended solids present influences the optical properties and ecology of the aquatic environment.
The method is applicable to the determination of total suspended solids in homogeneous water and wastewater samples.

Summary of Method

A well-mixed sample of known volume is filtered through a prepared pre-weighed glass-fibre filter and the retained matter on the filter is dried to a constant weight at 104°C ± 1°C. The increase in mass of the filter, upon re-weighing, is a measure of the total suspended solids.

Interferences

Very small particles such as nanoplankton may be lost during vacuum filtration. This can be minimised by using the minimum of suction pressure.

High suction pressures can also cause cell disruption with consequent loss of cell contents from some fragile organisms.

The drying temperature of 104°C ± 1°C may result in the loss of some volatile cell components with the consequent underestimation of the total suspended solids. Drying time of 2 h must not be exceeded.

Method 2002005 Chlorophyll *a* - Spectrophotometric Method

Scope

This method is suitable for the determination of the chlorophyll *a* content of water samples, using spectrophotometry.

Summary of Method

The photosynthetic pigments are extracted from the algae, which have been entrapped on a glass microfibre filter, using boiling 90% (v/v) ethanol.

The concentrations of chlorophyll *a* and phaeopigments are determined by measuring the absorbance, before and after acidification of the extract, at 665,5 nm and 750 nm against a 90% (v/v) ethanol blank.

The resulting absorbance measurements are then applied to a standard equation.

Interferences

Extracts must be centrifuged prior to spectrophotometry, as suspended particles interfere with absorbance measurements.

Overestimation of phytoplankton chlorophyll will occur if large populations of photosynthetic bacteria are present.

ANNEXURE 4

Statistical Procedures Used

All statistical calculations were done with WQStat Plus software. Descriptions of statistical procedures used or referred to (below) has been taken from the WQStat Plus User Guide with permission from NIC (copyright holders)

Statistical Outlier Test

Description:

A statistical outlier is a value that is extremely different from the other values in the data set. The "Dixon's outlier test identifies" data points that do not appear to fit the distribution of the rest of the data set and determines if they differ significantly from the rest of the data.

Assumptions:

The outlier test assumes that all data values, except for the suspect observation, are normally or log normally distributed. A minimum of three observations is required; however, a minimum of eight observations is recommended.

Outlier Procedure:

First, the data are log-transformed, then ordered from lowest to highest. The mean and standard deviation are then calculated. Next, calculate the outlier test statistic, $\mathbf{T_n}$, as:

$$\mathbf{T_n = \frac{(X_n - \overline{X})}{S}}$$

Where:

X_n = The suspect observation;

$\overline{\mathbf{X}}$ = The sample mean; and

S = The sample standard deviation.

Then compare T_n, the outlier test statistic, with the critical value, $T_{n(0.05)}$, for the given sample size, **n**, at a five percent significance level (Table 8, Appendix B, EPA, April 1989). If T_n exceeds the tabulated value, there is statistical evidence that X_n is a statistical outlier.

Rank Von Neumann

Description:

This statistical procedure is a test for serial correlation at a given station. The test will also reflect the presence of trends or cycles, such as seasonality. Therefore, to test for serial correlation only, one must first remove any seasonality or trends that are present.

Rank Von Neumann Procedure:

The null hypothesis to be tested is :

H_O**:** There is no serial correlation present in the data.

The alternative hypothesis is:

H_A**:** There is serial correlation present in the data.

The data are first ordered from lowest to highest, assigning the rank of 1 to the smallest observation, the rank of 2 to the next smallest,…, and the rank of n to the largest. Let R_1 be the rank of x_1, R_2 be the rank of x_2, and R_n the rank of x_n.

Compute the Rank Von Neumann statistic as:

$$\mathbf{Rv} = \frac{12}{n(n^2-1)}\sum_{i=1}^{n-1}(R_i - R_{i+1})^2$$

Where:

R_i = The rank of the ith observation in the sequence; and

R_{i+1} = The rank of the (i+1)st observation in the sequence (the following observation).

If the sample size n is greater than or equal to ten or less than or equal to 100, the calculated value R_v is compared to the tabulated $R_{v\alpha}$ (Table A5, Gilbert). The null hypothesis is rejected if the computed value R_v is less than the tabulated critical value.

If the sample size n, is greater than 100, compute:

$$\mathbf{Z_R = \frac{\sqrt{n}(R_v - 2)}{2}}$$

Reject the null hypothesis if Z_R is negative and the absolute value of Z_R is greater than the tabulated $Z_{1-\alpha}$ value (Table A1, Gilbert).

Seasonality Plot

Description:

Seasonality plots are constructed as Time Series plots for both observed values and values deseasonalized according to the method described by the EPA (U. S. EPA, April 1989). In addition to the Time Series plots, box plots are presented for the original and deseasonalized data. The presence of seasonality is tested with the Kruskal-Wallis, **H**, and statistic with correction for ties.

Seasonality Procedure:

The significance of data seasonality is evaluated using the nonparametric Kruskal-Wallis test (U.S. EPA, April 1989) at the a = 0.05 significance level. The null hypothesis to be tested is:

H_O: The populations consisting of the data for each season have the same median.

The alternative hypothesis is:

H_A: At least one population has a median larger or smaller than at least one other population's median.

Where there are no ties, the Kruskal-Wallis statistic, **H**, is calculated:

$$\mathbf{H} = \left[\frac{\mathbf{12}}{\mathbf{N(N+1)}}\sum_{\mathbf{i=1}}^{\mathbf{k}}\frac{\mathbf{R_i}^{\mathbf{2}}}{\mathbf{N_i}}\right] - \mathbf{3(N+1)}$$

Where:

R_i = The sum of the ranks of the *i*th group;

N_i = The number of observations in the *i*th group (station);

N = The total number of observations; and

k = The number of groups (seasons).

If there are tied values (more than one data point having the same value) present in the data, the Kruskal-Wallis **H**' statistic is calculated:

$$\mathbf{H'} = \frac{\mathbf{H}}{\mathbf{1} - \left(\dfrac{\sum_{\mathbf{i=1}}^{\mathbf{g}}\mathbf{T_i}}{\left(\mathbf{N^3 - N}\right)}\right)}$$

Where:

g = The number of groups of distinct tied observations; and

N = The total number of observations

$\mathbf{T_i}$ is computed as:

$$\mathbf{T_i} = \left(\mathbf{t_i}^{\mathbf{3}} - \mathbf{t_i}\right)$$

Where:

$\mathbf{t_i}$ = The number of observations in tie group i.

The calculated value **H** (or **H'** if ties are present) is compared to the tabulated chi-squared value with (**K**-1) degrees of freedom, (Table A-1, Appendix B; U.S. EPA, April 1989) where **K** is the number of seasons. The null hypothesis is rejected if the computed value exceeds the tabulated critical value.

Application of the Kruskal-Wallis test for seasonality requires a minimum sample size of four data points in each season. WQStat Plus currently tests seasonality for up to twelve seasons. The default seasonal start dates are February 1, May 1, August 1, and November 1. These seasonal start dates may be altered in the Configure WQStat Plus… Window.

Correcting for Seasonality Procedure:

When seasonality is known to exist in a Time Series of concentrations, then the data can be deseasonalized prior to running further statistical analyses.

Using the method described by the EPA (U.S. EPA, April 1989), the average concentration for season ***i*** over the sampling period, $\mathbf{X_i}$**,** is calculated as follows:

$$\overline{\mathbf{X}}_{\mathbf{i}} = \frac{(\mathbf{X}_{\mathbf{ij}} + ... + \mathbf{X}_{\mathbf{iN}})}{\mathbf{N}}$$

Where:

X_{ij} = The unadjusted observation for the *i*th season during the *j*th year;

and

N = The number of years of sampling.

The grand mean, $\overline{\mathbf{X}}$, of all the observations is then calculated as:

$$\overline{\mathbf{X}} = \sum_{i=1}^{n} \sum_{j=1}^{N} \frac{\overline{\mathbf{X}}_{\mathbf{ij}}}{\mathbf{Nn}} = \sum_{i=1}^{n} \frac{\overline{\mathbf{X}}_{\mathbf{i}}}{\mathbf{n}}$$

Where:

n = The number of seasons per year.

The adjusted concentrations, Z_{ij}, are then computed as:

$$Z_{ij} = X_{ij} - \overline{X}_i + \overline{X}$$

Normality Statistics

Shapiro-Wilk/Shapiro-Francia Description:

The distribution of the data can be evaluated by applying the Shapiro-Wilk or Shapiro-Francia test for normality to the raw data or, when applicable, to the transformed data. The null hypothesis, $\mathbf{H_O}$, to be tested is:

H_O: The population has a normal (or transformed-normal) distribution.

The alternative hypothesis, $\mathbf{H_A}$, is:

H_A: The population does not have a normal (or transformed normal) distribution.

Shapiro-Wilk Procedure:

Calculation of the Shapiro-Wilk W-statistic to test the null hypothesis is presented in detail on page 158 of *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987).

The denominator, ***d***, of the W test statistic, using n data is computed as follows:

$$d = \sum_{i=1}^{n} \left(X_i - \overline{X}\right)^2 = \sum_{i=1}^{n} X_i^{\,2} - \frac{1}{n}\left[\sum_{i=1}^{n} X_i\right]^2$$

Where:

X_i = The value for the *i* th observation;

$\overline{X}$ = The mean of the n observations; and

n = The number of observations.

Order the n data from smallest to largest (e.g. $X_{[1]} = X_{[2]} = ... = X_{[n]}$). Then compute **k** where:

$$\mathbf{k = \frac{n}{2}} \qquad \textit{if n is even}$$

$$\mathbf{k = \frac{n-1}{2}} \qquad \textit{if n is odd}$$

The coefficients $\mathbf{a_1}$, $\mathbf{a_2}$,..., $\mathbf{a_k}$ for the observed **n** data can be found in Table A6 (Gilbert, 1987).

The W test statistic is then computed as follows:

$$\mathbf{W = \frac{1}{d}\left[\sum_{i=1}^{k} a_i (X_{[n-i+1]} - X_{[i]})\right]^2}$$

The data are tested at the a = 0.05 significance level. The a significance level represents the probability of rejecting the null hypothesis, when it is, in fact, true, i.e., the percent of false indications of non-normality. Reject $\mathbf{H_0}$ at the a significance level if W is less than the quantile given in Table A7 (Gilbert, 1987).

The Shapiro-Wilk test of normality can be used for sample sizes up to 50. When the sample size is larger than 50, the Shapiro-Francia test is used instead.

Shapiro-Francia Procedure:

Calculation of the Shapiro-Francia **W'**-statistic to test the null hypothesis is presented in detail by EPA (U.S. EPA, 1992). The test statistic, **W'**, is computed as follows:

$$\mathbf{W' = \frac{\left[\sum_i m_i x_i\right]^2}{(n-1)S^2 \sum_i m_i^{\,2}}}$$

Where:

x_i = The *i*th ordered value of the sample;

m_i = The approximate expected value of the *i*th ordered normal quantile; n = The number of observations; and

S = The standard deviation of the sample

The values for $\mathbf{m_i}$ can be approximately computed as:

$$\mathbf{m_i} = \quad \Phi^{-1}\left(\frac{\mathbf{i}}{\mathbf{n+1}}\right)$$

Where:

F $^{-1}$ = The inverse of the standard normal distribution with zero mean and unit variance.

Reject $\mathbf{H_0}$ at the a = 0.05 significance level if **W'** is less than the critical value provided in Table A-3 (Appendix A; U.S. EPA, 1992). When the sample size is larger than 100, the Chi-Squared Goodness-of-Fit test can be used instead.

Chi-Squared Goodness-of-Fit Procedure:

First divide the **N** observations by four to compute **K**, where **K** will be the number of subgroups or 'cells' for the dataset. Second, standardize each observation, $\mathbf{X_i}$, by subtracting the group mean and dividing by the group standard deviation as follows:

$$\mathbf{Z_i} = \frac{(\mathbf{X_i} - \overline{\mathbf{X}})}{\mathbf{s}}$$

Where:

$\mathbf{Z_i}$ = The standardized value;

$\overline{\mathbf{X}}$ = The group mean; and

$\overline{\mathbf{X}}$ **s**= The group standard deviation.

Once the standardized values and **K** have been calculated, the third step is to subgroup the $\mathbf{Z_i}$ according the cell boundaries designated for **K** cells in Table 4-3 (EPA, April 1989). The Chi-Squared statistic, C ^{2}, may be calculated as follows:

$$\mathbf{X^2} = \sum_{\mathbf{i=1}}^{\mathbf{K}} \frac{(\mathbf{N_i} - \mathbf{E_i})^2}{\mathbf{E_i}}$$

Where:

$\mathbf{N_i}$ **=** The number of observations in the i*th cell*; and

$\mathbf{E_i}$ **=** **N/K**, The expected number of observations in the i*th* cell.

Last, compare the calculated C^2 to a table of the chi-squared distribution (Table 1, Appendix B; U.S. EPA, 1989) with a = 0.05 and K- 3 degrees of freedom. If the calculated value exceeds the tabulated value, then reject $\mathbf{H_0}$ that the data are normally distributed.

Trend Analysis Statistics

Sen's Slope/Mann-Kendall Trend Analysis

Description:

A temporal trend is the general increase or decrease in observed values of some random variable over time. Trend analysis can be used to determine the significance of an apparent trend and to estimate the magnitude of that trend. The Mann-Kendall test for temporal trend (Hollander & Wolfe, 1973) and Sen's slope estimate (Gilbert, 1987) can help to evaluate the correlation of selected constituent concentrations with time.

The Mann-Kendall test for temporal trend is nonparametric, meaning that it does not depend on an assumption of a particular underlying distribution. The test uses only the relative magnitude of data rather than actual values; therefore, missing values are allowed, and values that are recorded as nondetects by the laboratory can still be used in the statistical analysis by assigning values equal to half their detection limits (Gilbert, 1987).

The null hypothesis to be tested is:

$\mathbf{H_0}$: No trend of a constituent exists over time.

The alternative hypothesis is:

$\mathbf{H_A}$: A significant upward (or downward) trend of a constituent concentration exists over time.

For stations having fewer than 41 data points, an exact test is performed. If 41 or more data points are available, the normal approximation test is used (Gilbert, 1987).

Exact Test (n < 41) Procedure:

The Mann-Kendall method assigns a positive or negative score based on the differences between the data points. The first step is to list the data in the order in which they were collected over time, and then determine the sign of all possible differences $\mathbf{x_j - x_k}$, where $\mathbf{j > k}$:

$$
\begin{aligned}
\mathbf{sgn(x_j - x_k)} &= \mathbf{1 \text{ if } x_j - x_k > 0} \\
&= \mathbf{0 \text{ if } x_j - x_k = 0} \\
&= \mathbf{-1 \text{ if } x_j - x_k < 0}
\end{aligned}
$$

Where:

j = $k + 1$;

x_j = The value of the jth observation; and

$\mathbf{x_k}$ = The value of the kth observation.

The Mann-Kendall statistic, **S**, is then computed, which is the number of positive differences minus the number of negative differences.

$$
\mathbf{S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)}
$$

Where:

n = The total number of observations.

If **S** is a large positive number, measurements taken later in time tend to be larger than those taken earlier, i.e., an upward trend. Similarly, if **S** is a large negative number, measurements taken later in time tend to be smaller, i.e., a downward trend.

For a two-tailed test to detect either an upward or downward trend, the tabulated probability level corresponding to the absolute value of **S** (Gilbert, 1987) is doubled and $\mathbf{H_0}$ is rejected if that doubled value is less than the *a priori* a significance level of the test.

Normal Approximation Test (n > 1) Procedure:

The Mann-Kendall test statistic, **S**, is calculated using the same method as the exact test. When there are no tied values, the variance of S, or **VAR(S)** is computed:

$$\mathbf{VAR(S)} = \frac{\mathbf{n(n-1)(2n+5)}}{\mathbf{18}}$$

S and **VAR(S)** are then used to compute the test statistic, **Z**, as follows:

$$\mathbf{Z} = \frac{\mathbf{S-1}}{[\mathbf{VAR(S)}]^{1/2}} \qquad \textbf{if } \mathbf{S > 0}$$

$$\mathbf{Z = 0} \qquad \textbf{if } \mathbf{S = 0}$$

$$\mathbf{Z} = \frac{\mathbf{S+1}}{[\mathbf{VAR(S)}]^{1/2}} \qquad \textbf{if } \mathbf{S < 0}$$

When tied values (data points having equal values) are present, the variance of **S** is computed:

$$\mathbf{VAR(S)} = \frac{\mathbf{1}}{\mathbf{18}}\left[\mathbf{n(n-1)(2n+5)} - \sum_{p=1}^{g} \mathbf{t_p(t_p-1)(2t_p+5)}\right]$$

Where:

g = The number of tied groups; and

$\mathbf{t_p}$ = The number of observations in the *p*th group.

If the null hypothesis of no trend is true, the test statistic, Z, has a standard normal distribution.

To test for either an upward or downward trend (a 2-tailed test), an a -level of significance must first be chosen. WQStat Plus tests for trends at the confidence levels 80%, 90% and 95%. For a two tailed test, we reject $\mathbf{H_o}$ of no trend if the absolute value of Z is greater then $Z_{1-\alpha/2}$.

For example, the **Z-value** associated with the 0.05 significance level is 1.96, from Table A-1 (Hollander and Wolfe, 1973). The area under the normal curve lies between -$\mathbf{Z}_a$ = -1.96 and $\mathbf{Z}_a$ = 1.96.

A positive (negative) value of **Z** can indicate an upward (downward) trend. At a confidence level of 95%, any **Z-value** above 1.96 signifies an upward trend, and any value below -1.96 signifies a downward trend. In such cases, $\mathbf{H_0}$ of no trend would be rejected. For values that fall between -1.96 and 1.96, it cannot be determined with statistical significance that a trend exists.

Sen's Slope Estimator Procedure:

This simple nonparametric procedure was developed by Sen (1968) and presented in Gilbert (1987) to estimate the true slope. The advantage of this method over linear regression is that it is not greatly affected by gross data errors or outliers, and can be computed when data are missing.

The **N**' individual slope estimates, **Q**, are computed for each time period:

$$\mathbf{Q} = \frac{\mathbf{x_i' - x_i}}{\mathbf{i' - i}}$$

Where:

X_i' and X_i = The data values at time i' and i (in days), respectively, i'> I;

and

N' = The number of data pairs for which i' > i.

A value of one half of the detection limit will be substituted for $\mathbf{X_i}$ values below the detection limit.

Sen's Slope estimator is the median slope, obtained by ranking the N' values of Q from smallest to largest, and choosing the middle-ranked slope as follows.

$$\mathbf{Q_{[N'=n(n-1)/2]}} \quad \text{if N' is odd}$$

$$\mathbf{\frac{1}{2}\left(Q_{[N'/2]} + Q_{[N'=n(n+2)/2]}\right)} \quad \text{if N' is even}$$

Where:

n = The number of time periods.

This value is multiplied by 365 to give the yearly slope value.

Seasonal Kendall Test

Description:

The Seasonal Kendall Test is an extension of the Mann-Kendall test that removes seasonal cycles and tests for trend.

Seasonal Kendall Procedure:

Compute the Mann-Kendall statistic, S, for each season. Let S_i denote this statistic for the *ith* season, that is:

$$\mathbf{Si} = \sum_{k=1}^{n_i-1} \sum_{l=k+1}^{n_i} \mathbf{sgn}(x_{il} - x_{ik})$$

Where l > k, n_i is the number of data for season *i*, and:

$$\begin{aligned} \mathbf{sgn(x_{il} - x_{ik}) = 1} &\quad \mathbf{if\ x_{il} - x_{ik} > 0} \\ \mathbf{= 0} &\quad \mathbf{if\ x_{il} - x_{ik} = 0} \\ \mathbf{= -1} &\quad \mathbf{if\ x_{il} - x_{ik} < 0} \end{aligned}$$

VAR(S_i) is computed as follows:

$$\mathbf{VAR(S_i) = \frac{1}{18}\left[n_i(n_i - 1)(2n_i + 5) - \sum_{p=1}^{g_i} t_{ip}(t_{ip} - 1)(2t_{ip} + 5) - \sum_{q=1}^{h_i} u_{iq}(u_{iq} - 1)(2u_{iq} + 5)\right]}$$
$$\mathbf{+ \frac{\sum_{p=1}^{g_i} t_{ip}(t_{ip} - 1)(t_{ip} - 2)\sum_{q=1}^{h_i} u_{iq}(u_{iq} - 1)(u_{iq} - 2)}{9n_i(n_i - 1)(n_i - 2)} + \frac{\sum_{p=1}^{g_i} t_{ip}(t_{ip} - 1)\sum_{q=1}^{h_i} u_{iq}(u_{iq} - 1)}{2n_i(n_i - 1)}}$$

Where:

$\mathbf{g_i}$ = The number of groups of tied data in season *I*;

$\mathbf{t_{ip}}$ = The number of tied data in the *pth* group for season *I*;

$\mathbf{h_i}$ = The number of sampling times(or time periods) in season *i* that contain multiple data; and

$\mathbf{u_{iq}}$ = The number of multiple data in the *qth* time period in season *i*.

After S_i and $VAR(S_i)$ are computed, we pool across the K seasons:

$$\mathbf{S' = \sum_{i=1}^{K} S_i}$$

and

$$\mathbf{VAR(S') = \sum_{i=1}^{K} VAR(S_i)}$$

Next compute:

$$\mathbf{Z = \frac{(S'-1)}{[VAR(S')]^{1/2}} \qquad if\ S' > 0}$$
$$\mathbf{Z = 0 \qquad if\ S' = 0}$$
$$\mathbf{Z = \frac{(S'+1)}{[VAR(S')]^{1/2}} \qquad if\ S' < 0}$$

For a two tailed test, we reject $\mathbf{H_o}$ of no trend if the absolute value of Z is greater than $Z_{1-\alpha/2}$. WQStat Plus tests at the 80%, 90% and 95% confidence levels.

Seasonal Kendall Slope Estimator Procedure:

First compute individual N_i slope estimates for the *ith* season:

$$\mathbf{Qi = \frac{x_{il} - x_{ik}}{l - k}}$$

Where:

- $\mathbf{x_{il}}$ = The datum for the ith season of the *lth* year; and
- $\mathbf{x_{ik}}$ = The datum for the ith season of the *kth* year, where l > k.

Do this for each of the K seasons. Then rank the N’1 + N’2 + …+ N’K = N’ individual slope estimates and find their median. This median is the seasonal Kendall slope estimator.

Summary

and

Key Terms

SUMMARY

The tasks of managing and protecting South Africa's water resources are being performed by the Department of Water Affairs and Forestry (DWAF), although the requirement to protect water resources are also entrenched in the policies and acts of other departments. DWAF has also recognized over the past ten years the importance of international co-operation with regards to water issues.

As part of South Africa's commitment to the realization of Agenda 21 and related international water management commitments, the South African Department of Water Affairs and Forestry has committed itself to participating in the Global Surface Water Quality Monitoring Programme. The programme falls under the management of the United Nations Environmental Programme and is administrated by the UN Global Environmental Monitoring System/Water Programme (GEMS/Water).

The aim of the study was to develop a strategy that would enable SA to effectively participate in this global water quality monitoring programme, by making use of existing programmes and infrastructure. A very important aspect of this study was also to test the scientific and operational ability of SA to honour this commitment, as the submission of unreliable and irrelevant data for use in international reports by the UN can lead to embarrassment on a political level.

Clear objectives, based on international requirements, were formulated to serve as the basis for the design of a scientifically sound monitoring system. Three different types of monitoring data, namely global river flux, global trends, global baseline data were identified as the main focus areas.

A wide variety of techniques such as statistical analyses of national water quality data, specialist workshops, meetings with international data users, geographic information system (GIS), performance auditing of existing monitoring programmes and extensive field visits were used to design a monitoring system that would enable SA to meet the set objectives. Special attention was also given to the design of a comprehensive ISO 9001:2000 based quality management system and operational structures that would ensure the production and submission of reliable data in a sustainable manner. The importance of producing a documented monitoring strategy cannot be over emphasized. Such a strategy must clearly link the information needs with monitoring objectives, which in turn must be clearly linked to the design of the monitoring programme

During the design process a number of potential shortcomings in the existing systems and programmes were identified and specific recommendations are made. Some of the main recommendations related to the implementation of a quality management system for new and existing national monitoring programmes, placement of sampling sites, alteration of sampling frequencies and expansion of monitoring variables currently being tested for.

It was finally concluded that South Africa does have the ability to honour their commitment to the UN GEMS/Water Programme, provided that the recommendations emanating from this study are implemented.

Key Terms: Global Monitoring – UNEP – South African Water Quality Monitoring – Quality Assurance – Monitoring Network Design – Global Trends – Global River Flux – Global Baseline – International Co-operation – Agenda 21

OPSOMMING

Die bestuur en bewaring van Suid-Afrika se waterhulpbronne is hoofsaaklik die verantwoordelikheid van die Departement van Waterwese en Bosbou (DWB), alhoewel dit ook vervat word in die beleid en wette van ander departemente. DWB het ook oor die afgelope tien jaar die belangrikheid van internationale samewerking op hiedie gebied erken.

As deel van Suid Afrika se verbintenis tot die verwesenliking van Agenda 21 en verwante waterbestuur ooreenkomste, het die DWB homself tot deelname in die Wêreld Watergehalthe Moniterings Program verbind. Die program val onder die bestuur van die Vereenigde Nasies (VN) Omgewings Program en word deur die VN Wêreld Omgewings Monitering Stelsel/Water programme (GEMS/Water) geadministreer.

Die doel van hierdie studie was om ‘n strategie te ontwikkel wat SA instaat sal stel om op ‘n effektiewe wyse te kan deelneem in die wêreld moniteringprogram deur gebruik te maak van bestaande programme en infrastruktuur. ‘n Baie belangrike aspek van hierdie studie was ook om te toets of SA die wetenskaplike en operationele vermoeë het om sukselvol aan hierdie program kan deelneem. Aangesien die verskaffing van nie-relevante of onbetroubare data aan die VN vir gebruik in internationale verslae tot verleentheid op politiese vlak kan lei.

Duidelike doelwitte, gebaseer op internationale vereistes, is geformuleer om te dien as die basis vir die ontwerp van ‘n wetenskaplik korrekte moniteringstelsel. Drie verskillende tipes watergehalte data, naamlik globale rivier fluksie, globale neigings en globale agtergrond data is as die hoof kokusareas geïdentifiseer.

‘n Wye veskeidenheid van tegnieke, naamlik statistiese analises van nasionale watergehalte data, spesialis werkswinkels, vergadering met internasionale rolspelers, geografiese inligtingstelsels (GIS), ouditering van die werksverrigting van bestaande nationale monitering data en veldwerk is gebruik om ‘n stelsel te ontwerp wat sal verseker dat SA die daargestelde doelwitte sal kan bereik. Baie aandag is ook gegee aan die ontwikkeling van ‘n allomvattende ISO 9001:2000 gebaseerde gehaltebestuurstelsel en ‘n operasionele stelsel om die volhoubare versameling en verskaffing van betroubare data te verseker. Die belang van die dokumentering van so ‘n moniteringstrategie word beklemtoon. Hierdie strategie moet die inligtingsbehoeftes duidelik met die moniteringdoelwitte verbind, wat weer met die moniteringprogram ontwerp gekoppel moet wees.

Gedurende die ontwerppros es is ‘n verskeidenheid van tekortkominge in die bestaande stelsels en programme geïdentifiseer en spesifieke aanbevelings is gemaak. Van die hoof aanbevelings hou verband met die implementering van ‘n gehaltebestuurstelsel vir bestaande en nuwe nationale moniteringsstelsels, plasing van moniteringspunte, verandering van moniteringsfrekwensies en die uitbreiding van veranderlikes waarvoor daar getoets word.

Die finale gevolgtrekking was dat Suid Afrika wel die vermoeë het om hulle ooreenkoms met die VN Water Program na te kom, op voorwaarde dat die aanbevelings wat uit hierdie studie spruit, geïmplimenteer moet word.

Trefwoorde: Globale monitering; UNEP; Suid-Afrika waterkwaliteitmonitering; gehalteversekering; Moniteringsnetwerk ontwerp; globale neigings; globale rivier fluksie; globale agtergrond data; Internasionale samewerking; Agenda 21.