ASSESSMENT OF WATER QUALITY THROUGH A MENU-DRIVEN USER INTERFACE ON A GEOGRAPHIC INFORMATION SYSTEM PLATFORM

Dale Cobban

Institute for Water Quality Studies
Department of Water Affairs and Forestry
Pretoria

ABSTRACT

Water quality is an elusive and fluctuating component of the hydrological system, affected by a range of environmental factors which vary on independent time and spatial scales. The quality of water supply is a limiting factor for resource utilisation, with different user groups able to tolerate differing conditions. Attempts to quantify, assess, interpret and explain the variable water quality conditions throughout the country are dependent on an holistic consideration of a range of disparate data. A development project currently in progress at the Institute for Water Quality Studies aims to integrate all relevant databases within the context of a Geographic Information System (Arc/Info v 6.1.1.), possibly the only tool sufficiently powerful to attain such a goal. Ready access to water quality databases maintained by the Department of Water Affairs and Forestry, within the framework of background information facilitates the process of water quality assessment.

INTRODUCTION

Integrated information management for diverse applications in the field of water quality assessment entails access and control of large aspatial and spatial data sets. The efficiency of electronic storage and processing media has led to the establishment of a wide variety of databases, on different computer hardware and software platforms. Mechanisms to integrate and navigate through information using locational and associated aspatial attributes, with the capability to process selected data subsets are unique to Geographic Information Systems (GIS). Such systems are ideal for applications that need to integrate a variety of relevant data, including those that have not necessarily been gathered for spatial processing. This data, while not inherently spatial, can be incorporated in a GIS through defining spatial association.

Recognising the time constraints in training users to the level of proficiency needed to optimise the GIS, the Institute for Water Quality Studies (IWQS), in partnership with the CSIR, has developed a menu-driven interface which allows rapid access to a wide range of data in an integrated fashion, previously impossible to achieve. Conventional spatial data incorporated include infrastructure, environmental, geographic, demographic and hydrological features such as rivers and dams. Monitoring networks maintained by the Department of Water Affairs and Forestry (DWAF) constitute an additional spatial component, to which the vital temporal water quality data is linked. Although tied to monitoring point locations, the water quality record can be extrapolated to explain changing conditions over a wider area, with the potential for classifying river reaches in terms of user-related criteria.

Water quality cannot be considered independently of the spatial context within which it occurs, as changes in physiographic conditions over time and space may be reflected in the water quality record, after lag times ranging from hours to years. Water quality indices measure the conditions at a monitoring point location for an instantaneous moment in time but reflect the influence of the wider environment, possibly events taking place several hundred kilometers from the site of sampling and several days, months or years prior to the time of sampling. The menu-based GIS development will ultimately provide the capability to correlate land use conditions with associated water quality parameters, which will provide an indication of potential impacts likely to arise with future development.

WATER RESOURCE MANAGEMENT

Effective understanding of water quality must take diverse factors into account, and relies on information from a variety of sources and a range of scales. Such information must be assimilated and presented in a logical, accurate and timely way to support real time management of water quality. Until recently, the tools for holistic integration of relevant data were not available, and comprehension of the water quality perspective could only be achieved through the intuition and experience of the water resource specialist.

The purpose of the IWQS is to investigate water quality conditions throughout the country, and support the effective management of national water resources. Primary tasks include the measurement, assessment, evaluation and reporting of water quality. These tasks are addressed through a number of detailed functions. Figure 1 illustrates the continuum between data gathering, processing, interpreting and management, where a multi-directional feedback loop exists between all stages.

Water Quality Monitoring and Laboratory Analysis

Design, establishment and maintenance of monitoring networks on national, regional and local scales are the first steps in data gathering. New and emerging trends in monitoring technology must be identified and additional networks are designed where necessary to meet additional monitoring needs. Currently, a monitoring network for microbiological indices is under investigation, and protocols for

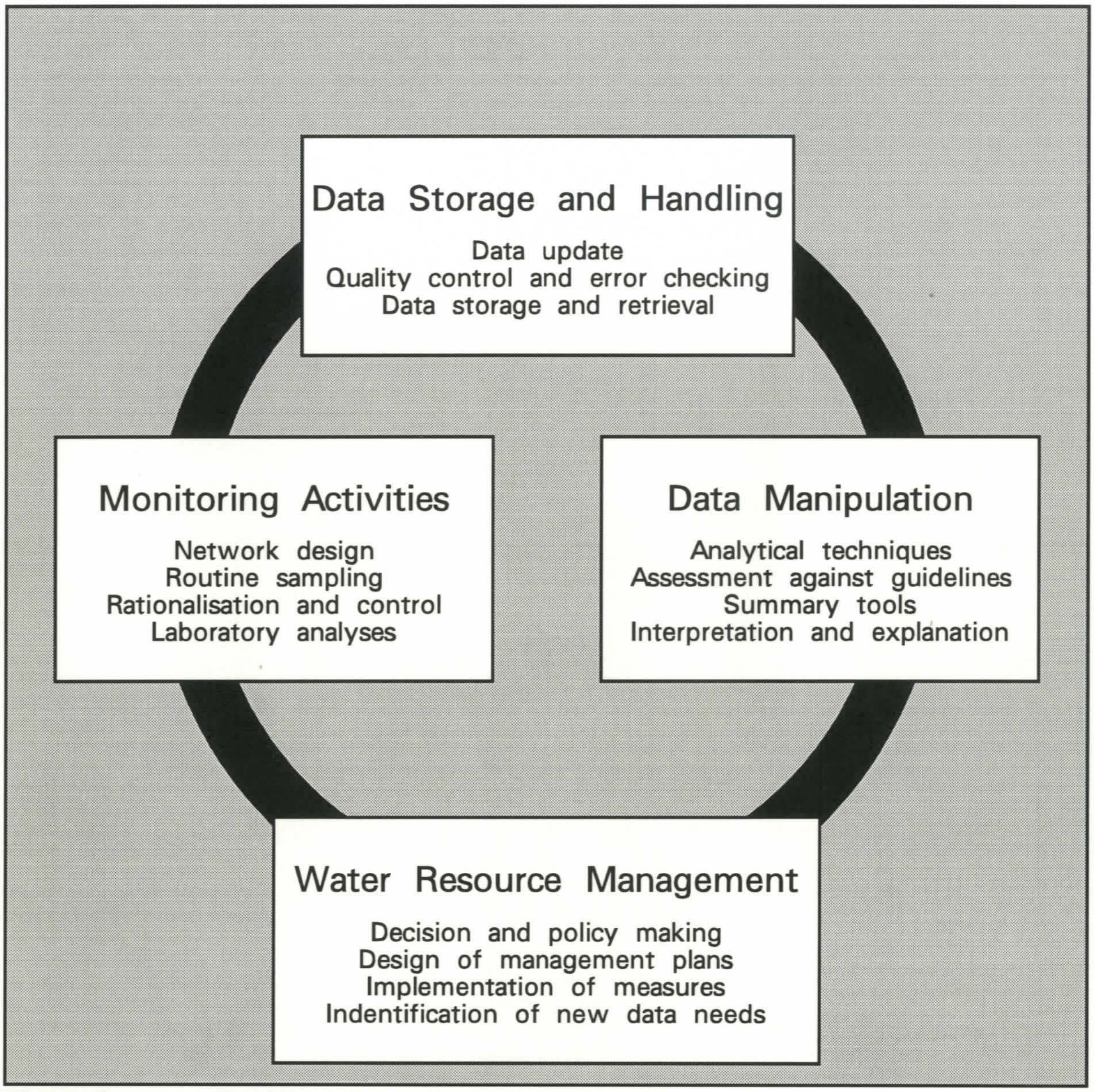


Figure 1: Continuum in approach to water quality management

macroinvertebrate and fish monitoring are in the testing phase.

Once in place, a monitoring network yields a regular supply of raw data. Water samples are analysed for a comprehensive range of constituents, laboratory techniques and equipment are evaluated and new techniques for gauging water quality, including ecological, biotic and toxicity indices, are tested. Laboratory data are stored in a computer database, and are available for reporting on the country's water quality status to managerial, scientific and public forums, at a range of resolution from national to regional levels, and localised where specific problems arise.

Ongoing re-evaluation of monitoring networks to provide requisite data must be carried out in view of rapid changes in both natural and built environments. New demands for water, technological developments, urban and industrial growth introducing more and new kinds of contaminants, and growing environmental awareness stimulate management needs, leading to concomitant changes in monitoring needs. Monitoring technology is advancing into fields such as telemetry, toxicity, ecosystem health indices and biotic status indicators. These new methods in turn provide challenges for management to incorporate and extend policy and existing strategy.

Table 1: Recognised user groups identified for water quality guidelines (DWAF, 1993)

User Group	Sub-user Groups
Domestic	Potable
Recreation	Full contact Intermediate contact Non-contact
Agriculture	Irrigation Livestock water Fresh water aquaculture
Industrial	Iron and steel Pulp and Paper Leather and Tanning Petrochemicals Power Generation Textiles
Natural Environment	(in preparation)
Coastal and Marine	(in preparation)

Water Quality Assessment

Assessment of water quality is done against selected criteria for different recognised user groups (Table 1). Research into the validity of established water use guidelines against local and international norms leads to recommendations for new criteria where necessary. Guidelines have not been established for all water quality indices for all recognised users, and more detailed sub-user groups are continually identified.

As water quality cannot be considered independently of the environmental context, the impact of different landuses as diffuse pollution sources on water quality is assessed through comparison between water quality and spatial data largely obtained through the use of remotely sensed data. Techniques for the analysis and interpretation of satellite imagery have been developed with the emphasis on water quality related features. Widespread informal settlements are a major source of microbiological contamination of the surface water supplies on which the communities depend. There is little cadastral data on the location and geographical extent of these settlements, and remote sensing techniques are successfully applied to delineate the areas of informal settlement. Substantial point source effluent contributors must comply with permit regulations specified by the DWAF, and the discharge is monitored with data stored on the POLMON system, a database designed for this purpose.

Water Quality Evaluation and Managment

Effective management incorporates an understanding of relations between spatial and aspatial data, such as how changes in the natural and man made environment affect changes in water quality. Environmental monitoring reveals the unsustainable consumption of natural resources such as site specific crises and long term gradual degradation over widespread areas, reflected in loss of biodiversity, resource quality and bioaccumulation of pollutants (Woodrow, 1993). A concept of accountability can only be based on a foundation of appropriate monitoring information. Activities that degrade or consume natural resources generate the need for policy and the information to make that policy.

Development of decision-support tools, including predictive models, allow testing of different management options to address real world problems. The development of modelling and other non-intrusive monitoring techniques such as remotely sensed data challenge existing data structures for storage, manipulation and access, and require new applications and approaches from management.

Better understanding of hydrological and environmental processes, and changes in political and economic interests are among the many factors influencing the realm of water resource management. Such a dynamic field requires dynamic and flexible tools, with the requisite processing capacity to handle large databases.

GEOGRAPHIC INFORMATION SYSTEMS CAPABILITIES

Geographic Information Systems (GIS) are computer-based tools that store, analyse and manage spatial data (Burrough, 1986; Lanfear, 1989; Openshaw, 1987). The essential roots of GIS technology lie in its foundations within the cartographic profession, and addressing the question "where" (Muller, 1993). The data processing and analysis capabilities of GIS have received comparatively little developmental attention, with the database remaining limited and essentially isolated from associated spatial and aspatial data. This restricts the potential information that can be obtained from the data, which in turn limits the cost effective utility of data which has been expensive to accumulate. Automated map and output production has been and remains a primary function of GIS, and increasingly applications attempt to manage diverse data types and distil more than different mapping methods from the database.

In a review of GIS applications, Muller (1993) reports that a substantial proportion focus on natural resources and environmental issues, reflecting an awareness that we are engaged in a world-wide race between environmental threats and the technological, methodological and institutional solutions to remove those threats. Spatial science, of which GIS is a tool, can play a decisive role in promoting economically and socially feasible solutions to environmental related problems (Muller, 1993). Over the past 5 years, concern for the natural environment has seen water companies utilising the potential of GIS to explore environmental applications such as river basin management and pollution modelling (Woodrow, 1993). GIS offers convenient tools to monitor and analyse the availability of physical resources required for human survival, and to make policies designed to protect and manage those essential resources (Atkinson, 1993).

Muller (1993) observed that the greatest challenge to GIS users is no longer technical, but lies in the organisational ability to maximise the potential of GIS through project management and planning. Technological issues will continue to be resolved, but issues of management and optimal application are not specifically addressed. Successful GIS projects depend on thorough planning of all levels of GIS application, from data capture, structure, quality and final presentation phases.

Data capture and storage

Spatial databases are becoming increasingly available through data capture technology and greater capacity storage media. The ability to capture and manipulate massive amounts of data is due to developments in computing and electronic technology, increased processing power and speed, and drastic reductions in cost and size. Available data sources can virtually bury the scientific and professional communities in information (Muller, 1993). Many organisations are engaged in data gathering for diverse programmes. A major component of this data is generated from remotely-sensed imagery, providing "seamless" synoptic views of large and often inaccessible areas. According to Morrison (1991) by the year 2000 most map series revisions will be done from monoscopic imagery, removing the need for manual mapping and surveying.

The result of this development is the large scale increase in the size of available databases, extending in multiple directions:

- the *horizontal data dimension* is extending as more spatial data is gathered and at finer resolutions than previously possible. Areal data is increasingly obtained from remotely sensed satellite imagery, as the most accurate and cost effective means of repeatedly covering a wide spatial extent, for an instantaneous and hence comparable picture of prevailing conditions. The resolution of spatial data is dependent on the resolution of the imagery, with the trend towards greater resolution reflected in satellite imagery developments. The early satellite Multi-Spectral Scanner data first available in the 1970's had a resolution of 80m, while the Thematic Mapper imagery first available in South Africa in 1989 had a resolution of 30m. SPOT data allowed resolution of 10 m in 1991, and imagery from the Russian satellites and other planned satellites are expected to allow resolutions of from 5 down to 1 m. Concomitantly, the resolution of spatial data extracted from the satellite imagery has also increased, with a greater visibility for fine details.

- the *vertical data dimension* extends as more layers of different data types are added to the GIS. Information previously stored on non-digital media is being converted to electronic format, such as scanning of topographic maps. Demographic information from census and municipal records is also being electronically stored. New categories of landuse are emerging, and existing categories are subdivided into more detailed classes as the spectral range and resolution of satellite and airborne scanners improves.

- the *temporal data dimension* encompasses all data that changes over time. The extension of geographical and landuse data over time may be limited only by the orbiting frequency of different satellites and the cloud cover during overpass, where remote sensing is used. Routinely collected aspatial datasets including climatic and hydrological data, are usually electronically stored, and these databases are continually incrementing with time.

Data structure

To utilise such massive datasets, the database must be structured in an efficient manner. Optimal use of space and layout will allow manipulation and navigation through various levels and types of data. Lengthy extraction and conversion processing activities, previously the norm on mainframe-type storage facilities, can be avoided through the use of a GIS which has an internal data structure facility.

Data quality

The accuracy of the database and not the accuracy of the map which depends on the database is most relevant in quality control of spatial data (Muller, 1993). The use of variable resolutions for data capture leads to difficulty in matching disparate datasets, and comparisons between features captured at different scales may be erroneous. Remotely sensed spatial data must have a measure of positional or classification accuracy, together with a level of confidence applied to it (Aronoff, 1991). Ultimately, the quality of analysis of either spatial or aspatial data is dependent on the accuracy of the data, and not the capacity of the GIS.

Spatial Decision Support Systems (SDSS)

SDSS are intelligent systems developed within the GIS environment to support spatial decisions and resolve problems (Muller, 1993). Development of these systems is economically hindered as the highly specific nature of each application limits wide marketing. Expert system technology to support the intuition and experience of human experts through integration of a GIS and other computerised tools, can be expanded to provide the basic knowledge for sound decisions where untrained individuals are required to make decisions, such as in many Third World countries.

MATCHING GIS CAPABILITY TO WATER RESOURCE MANAGEMENT NEEDS

Water resource assessment requires an integrated view of a variety of factors, including background environmental conditions, prevailing climatic conditions and landuses under human activity. Knowledge of the water users and potential water impacters must be available, together with information regarding the direction and magnitude of change in any of the relevant factors. Accurate assessment, evaluation and forecasting of the quality of surface water resources must be based on a wide range of data types, both spatial and temporal in nature, and the tools to integrate and process this data must be sufficiently powerful to allow rapid outputs, ideally in real time where crises occur. The question that must be addressed moves beyond the simple "WHERE", fixing features in space, moving to an understanding of "WHY" and "HOW"; only with this understanding can resource managers attempt to solve real world problems for the dynamic conditions and rapidly changing demands and impacts (Muller, 1993).

As most water resources data can be referenced geographically, GIS is ideally suited as a management tool (Lanfear, 1989). The ability to store and manipulate large volumes of spatial and associated data, and to present the data in summarised and analysed forms renders the GIS an essential tool for resource management. The developmental roots of GIS as an automated cartographic facility have left a legacy of well developed mapping output capabilities, in combination with powerful integrative and processing facilities.

However, unrealistic performance claims, high capital costs involved in hardware and software acquisition, lengthy training periods and slow and expensive data gathering has led to disillusionment among GIS users. It has been argued that limited manpower and economic resources might be better directed to manual data processing and reporting on small spreadsheet packages where results are proven. If the GIS capacity can be harnessed without the excessive time investment necessary for adequate training that is often not feasible for water quality managers and policy makers it will be of great value to the assessment of water quality. Recognising the utility of GIS as a support tool for decision-making the IWQS embarked on a project aimed at developing a system that reduces the time and training deficit, allowing major projects to be rapidly completed.

Research in the field of natural resources in South African has consisted of numerous "pilot" studies carried out on the GIS, using its capabilities to different degrees and leading to an accumulation of discontinuous datasets and findings of limited general use. This pattern reflects that of many other countries, including Britain, where there is an attempt to coordinate work done across governmental Departments and other Authorities, and to facilitate the wider implementation of data and research (Peel, 1993).

The primary approach of the IWQS research is generic, designed to incorporate a range of data, at a range of scales and resolutions with the potential to expand as more data becomes available over time. The system is flexible enough to include both discontinuous datasets from intensive localised studies and nation-wide data. As more data is received through completion of small studies the database is incremented and gradually a more complete picture of the factors influencing the quality of our national water resources will be built up.

The water quality specialist can select any area of interest within the country, access any data that is available, and carry out relevant statistical analyses. Different combinations of data can be selected, and a camera-ready hard copy output created once the analysis phase is complete. Routine reporting, special studies into problem areas and assessment of long term trends are readily supported by the system. Where temporally changing landuse data is available, it can be correlated with temporal changes in associated surface water quality, and the system can support investigations into the relationship between landuse and its impact on receiving water quality. The identification of pollutant inputs to river systems previously difficult to isolate is now possible, and the partitioning of various pollutant source contributions to river water quality can then be determined.

Assessment of the monitoring networks themselves can be carried out through correlation between water quality constituents at different sampling stations. For example, if the variation in water quality at adjacent upstream and downstream monitoring points is statistically identical, then both are measuring the same parameters and one can be removed or relocated to a more suitable position.

METHODOLOGY

A framework for the development of a menu-driven interface, anchored to a broad spectrum of spatial and aspatial data was outlined in a project proposal initiated at the IWQS. A literature survey and investigation of the ESRI-L Bulletin Board revealed that there was nothing available to meet the specific requirements for water quality reporting, assessment, evaluation and presentation of the IWQS.

The main aims of the project were:

- The integration of a range of diverse databases from different sources, relevant in the consideration and assessment of water quality, to facilitate rapid and easy access to data on a coherent platform.
- The development of a menu-driven interface allowing access to the database established. On viewing the data in a holistic fashion, many trends and potential applications may become apparent.
- The development of tools for detailed assessment and analysis of water quality data, within its spatial context. Standard statistical routines are to be incorporated into the menu structure, with maximum flexibility for customised applications.
- The development of a mapping facility, to allow production of high quality maps for inclusion in reports, papers and other communication documents.

In partnership with the CSIR: Watertek, the project was carried out in two phases. Phase one consisted of a systematic itemisation of needs - both real and perceived - for fulfilment of water quality assessment tasks. Phase two consisted of a technical development phase where user requirements were operationalised on the GIS platform. Ongoing development was planned for continuation beyond the completion of the initial phases.

The success of the first phases can be attributed to the well-defined and highly structured nature of the project, where deadlines were set and adhered to and the modularity of development allowed incremental growth of the system into more advanced and sophisticated functionality.

PHASE ONE: Needs Analysis

The initial phase of this study established the nature of tools required to carry out the functions of water quality assessment and reporting. The needs outlined by a selection of water quality specialists were itemised and a detailed user-needs document was produced after a series of meetings throughout the initial development of the system (Development of Water Quality Assessment Procedures, 1994). Primary requirements and expectations were tailored to the GIS environment through demonstrations of the developing system and a gradual "education" of the target professionals. Priority needs were identified at each level of the analysis, with the overall goal being to streamline and automate repetitive and data-intensive analysis methods.

PHASE TWO: Interface Development

Concomitant with the needs analysis was the interface development. A menu-driven system was developed on a modular basis, where functions were partitioned into discrete programme routines. This allowed incremental development of the system, with continual expansion of functionality as additional modules were completed and incorporated. Feedback from the needs analysis ensured the direction of development remained focused on the user requirements, which in turn became increasingly sophisticated with the educative impact of regular demonstrations.

Data Requirements

A range of data types were identified as necessary for water quality assessment. A major task was to organise widely varying datasets into a master database that allowed rapid navigation and user-defined selections of relevant information.

Two main categories of data were identified: spatial and aspatial. Spatial data is defined as geographic locational data, such as geology, rivers and towns, comprising conventional GIS feature layers or coverages. Aspatial data consists of the temporal data records that have been accumulated by numerous agencies, primarily the water quality data collected by the DWAF, but using the Computing Centre for Water Research (CCWR) to access climatic data such as mean annual rainfall from the Dept. of Agricultural Engineering, Natal University. These data constitute a record of changes in selected water quality or climatic parameters over a long time period and so are termed temporal, although spatially linked to a geographical locality.

The aspatial data was arranged into a database structure designed to allow regular update. Access to aspatial data is achieved through an indicator common to the spatial layer representing the sampling or measurement points. Although stored separately, the user is not aware of seams between the spatial and aspatial data.

Spatial Data

Diverse datasets identified as relevant to understanding water quality during the needs analysis were located where possible and the geographic projection standardised to Albers equal area; 24°E, standard parallels of 18°S and 32°S, Clarke 1880 spheroid. Stable geographic feature layers were incorporated into a map library, which affords protection against corruption and damage that may occur in a multi-user network environment. Fluctuating features, such as monitoring points which are periodically updated, are stored in an independent directory and are not part of the library.

Table 2: Geographic feature layers assembled for reference during water quality assessment

COVERAGE	SCALE	SOURCE
Geology	National 1: 1 500 000	Geological Survey
Vegetation	National 1: 1 500 000	Acocks Veld Type Map (1988)
Climate Zones	National	CCWR
Ecoregions	National 1: 1 500 000	IWQS
Perennial Rivers	National 1: 1 000 000	DCW*
Seasonal Rivers	National 1: 1 000 000	DCW*
Perennial Dams and Lakes	National 1: 1 000 000	DCW*
Seasonal Dams and Lakes	National 1: 1 000 000	DCW*
Springs	National 1: 1 000 000	DCW*
Boreholes	National 1: 1 000 000	DWAF
Altitude	National 1: 1 000 000	DCW*
Political Boundaries	National 1: 1 000 000	DCW*
Cities	National 1: 1 000 000	DWAF
Roads	National 1: 1 000 000	DCW*
Railways	National 1: 1 000 000	DCW*
Power Lines	National 1: 1 000 000	DCW*
Drainage Regions	National 1: 1 000 000	DWAF
Catchment Boundaries	National 1: 000 000	DWAF
Landuse	National and localised	Various
Water Quality Monitoring Points	National and localised	DWAF; IWQS

* DCW = Digital Chart of the World, compiled from 1:1 000 000 aeronautical charts (DCW, 1992)

Geographic data consists of two types, listed in Table 2, the predominate form being nationally available spatial layers. The second form of spatial data is discontinuous, gathered from localised studies and comprising a patchwork of different landuse and landcover categories, derived largely from classification of satellite imagery for isolated areas. While the objective of this study is to develop a generic system, equally applicable to any area of interest, the discontinuous datasets have also been included within the framework. In this way a more complete picture will emerge as more studies are completed and incorporated into the database. The user is able to access any information available for the area defined, and data from such isolated studies provides the potential for enriching the historical perspective of the catchment concerned.

Table 3: Aspatial datasets available for water quality assessment

DATASET	SCALE	SOURCE
Inorganic chemistry	National	DWAF
Organic chemistry	National	DWAF
Trace metals	Regional (A,B,X)	DWAF
Trihalomethanes	Localised	DWAF
Algal identification	Localised	DWAF
Habitat diversity	Localised	DWAF
Invertebrates	Localised	DWAF
Sediment concentration	National	DWAF
Flow	National	DWAF
Water physical parameters: temperature, turbidity	National	DWAF
Bacteriology	Localised	DWAF
Toxicity	Localised	DWAF
Ecological Health	Localised	DWAF
Groundwater chemistry	National	DWAF
Effluent discharge	Regional (Highveld)	DWAF
Rainfall	National	CCWR
Temperature	National	CCWR
Evaporation	National	CCWR
Wind speed/direction	National	CCWR

Aspatial Data

Temporal data sets currently available on the database are listed in Table 2. As with geographical data the aspatial monitoring networks exist on a range of scales from national to regional and localised. Many areas of southern Africa lack substantial water quality data records and some monitoring networks, such as biomonitoring and bacteriology, are in preliminary planning phases with little measured data available.

Sampling periods vary between datasets, from intensive and continuous for recordings at flow gauging stations, to weekly or monthly intervals for water quality sampling. Some types of monitoring require specific sampling intervals, such as the biotic integrity index which requires a six week recovery period between sampling exercises (Moore and McMillan, 1992). Other surveys are conducted annually or over longer time intervals, such as the bioaccummulation survey of the Middle Vaal fish which was conducted in 1983 and 1991 (Grobler, 1994). All sampling intervals are subject to interference depending on the presence of flowing water, and sampling may become sporadic during prolonged drought conditions. As new networks come on line and regular sampling takes place the data can be rapidly incorporated into the database if it is locally analysed, through a slow serial line to the Laboratory Information Management System.

Interface modules identified for development

A structure for interface development was outlined, based on functions that could be grouped into logical modules (Table 4). Priorities identified in the needs and technical discussion groups directed the order of development where system constraints permitted. Although a high priority, the output module used for generating maps and presentation documents was developed towards the end of the project, as it was dependent on development of the other modules. The database module was planned as the first logical module to be developed on which the subsequent functions would be tested, but was the last module to be finalised due to continual additions of new datasets.

The developmental procedure followed was to develop the functionality of the system to carry out the required task, irrespective of speed or efficiency. Once in working order, different programming options were explored to optimise each functional process. A major drawback encountered in the early demonstration stages before optimisation was in demonstrating the system to users who grew impatient with a slow and clumsy interaction. Fine tuning and streamlining of algorithms is painstaking and time-consuming in a field with little available information and much experimentation. Where possible, analytical programmes were re-written in C Programming Language, which proved superior in execution speed to the GIS Arc Macro Language (AML). A network of "parent" AML programmes control the interface with C programmes called where necessary, writing results to temporary files. The temporary file is then accessed by the calling AML which then performs the user defined request, such as drawing box and whisker plots based on C calculated median values.

Methods of statistical analysis of water quality data include measures of central tendency (maxima, minima, arithmetic and geometric means, percentiles) for user defined time increments and display in a range of standard symbols including time series, box plots, proportional circles, user-related symbology, rose and star diagrams. All water quality presentation symbols, with the exception of Maucha Diagrams, are referenced against the water quality guidelines for use as outlined by the DWAF (1993) selected by the user (Table 1), as water quality cannot be meaningfully assessed in absolute terms but must be balanced against the user requirements. The system is flexible to allow manipulation of guidelines other than the recommended concentrations. This means scenario testing can be carried out at a simplistic level. For example, in the planning stages of a catchment management strategy the existing water quality can be assessed against suggested water quality objective values, and those

Table 4: Modular components of the interface structure, showing selected functions for each module

MODULE	FUNCTION
Database	Design, populate, quality control and error checking. Update facilities. Access control and temporary work space allocation. Speed optimisation.
Spatial query and interrogation	Navigational facility. Display options for color and symbol. Overlay facility, zooming function.
Aspatial data query	Navigational facility. Examine data properties, sampling intervals, number of records, parameters measured, missing data. Examine and display monitoring points. Select dataset for detailed analysis
Aspatial data analysis	Suite of analytical tools for central tendency, trend analyses and correlational analyses with reference to guidelines for use. Deseasonalisation of water quality data. Assessment against water use guidelines.
Presentation symbology: all referenced against the water use guideline selected to indicate exceedance, level of exceedance, duration of exceedance or compliance.	Conventional symbols: Colored shapes Water use symbols Pie diagrams Proportional circles Star diagrams Box and whisker plots Time series Non-conventional symbols: Maucha diagrams Box plots - time series Box plots - radial
Multiple output design	High quality hardcopy maps in a range of standard sizes and layouts, routinely required for reporting, wall map display and communication of results: A5, A4, A3, A1, A0 Landscape and portrait Color, black and white Draft, final Formats for Pen Plotter, HP Printer, Electrostatic Plotter, Laser Printer

sampling sites most affected will be easily isolated. Attention can then be directed towards ameliorative procedures in such problem areas.

Different scenarios can also be investigated where a new landuse is planned for development, and existing user requirements will be modified. The new water requirements can be selected in the system, and the most suitable location for the development determined in water quality terms. Conversely, the least disruptive location relative to existing water users in the catchment can also be selected in water quality terms.

Although further considerations will have to be assessed which may eventually determine the final location chosen, the ability to evaluate multiple options provides valuable input to the decision making process.

TESTING AND APPLICATION OF THE SYSTEM

During development the system is continually tested as new programming routines are incorporated. The statistical accuracy of C programmes is tested against both manual calculations and results obtained from commercially available statistics packages, including STATGRAPHICS and WQSTAT. The system has been applied to a number of different water quality investigations, from a national scale to primary and tertiary catchment scales.

National Assessment

National assessment of surface water quality in streams and reservoirs has the advantage of summarising water quality conditions at a coarse scale. Even at this level trends and problem areas can be detected. The user can then focus on these areas where attention to detail may help in explanation. Figure 2 illustrates median total salts concentrations in reservoirs throughout the country during the summer period October 1992 to March 1993. The national status can be readily assessed against the guideline for domestic use of 450 mg/L.

While Figure 2 gives a general picture of the status of water quality, more detail can be gauged from a consideration of selected individual water quality constituents (Figure 3). Clear spatial patterns are now identifiable, and the overall salt concentration is partitioned into primary contributing ions:

* characteristically high sodium-chloride concentrations along the coastline in the Southern Cape, the Wilderness Lakes and St Lucia.
* inland the water quality is marked by increased alkalinity levels, concomitant increases in calcium and magnesium, and a relative decline in sodium and chloride concentrations.
* sulphate levels in the Eastern Transvaal, notably the Witbank area, are the highest of the entire country and warrant closer investigation.
* sodium levels in the PWV province are locally elevated, without the related chloride increase characteristic of coastal waters.
* Eastern Cape diagrams show the imported water from the Orange-Fish interbasin transfer scheme with a "bat" shape symmetry, which is distinct from the naturally occurring water in the area with bipolar sodium-chloride dominance or the alkalinity dominated water of the Buffalo River.

At a national level, inclusion of too much detail can obscure the map, so environmental parameters such as landuse and settlement patterns cannot be incorporated in an attempt to explore detailed reasons for the variation in water quality. However, broad patterns identified using generalised criteria can be investigated in more detail, according to the catchment or area of concern. A selection of case studies focusing on different aspects of water quality assessment illustrates the wide application potential of the system.

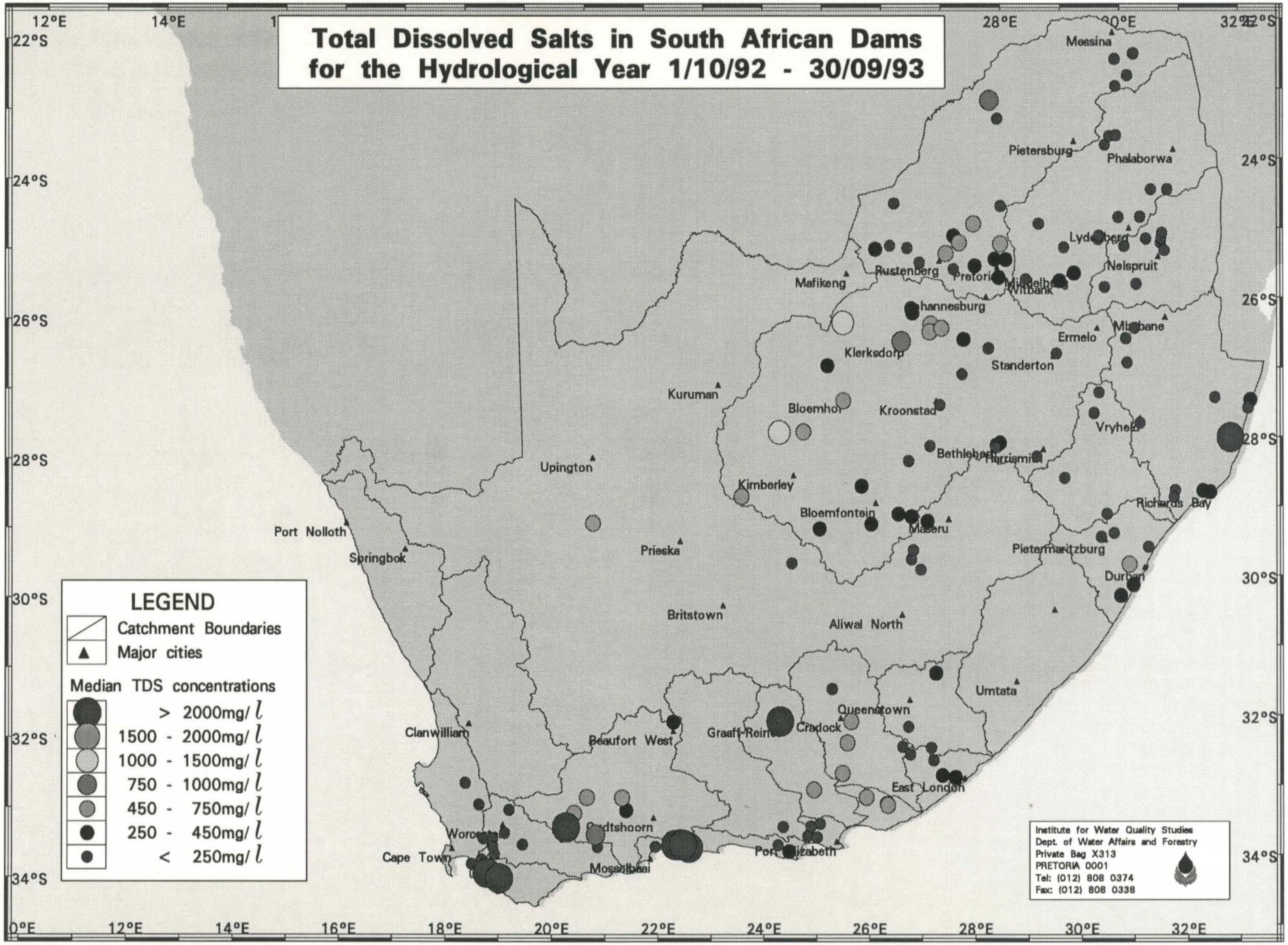


Figure 2: National water quality assessment of total dissolved salts in South African reservoirs

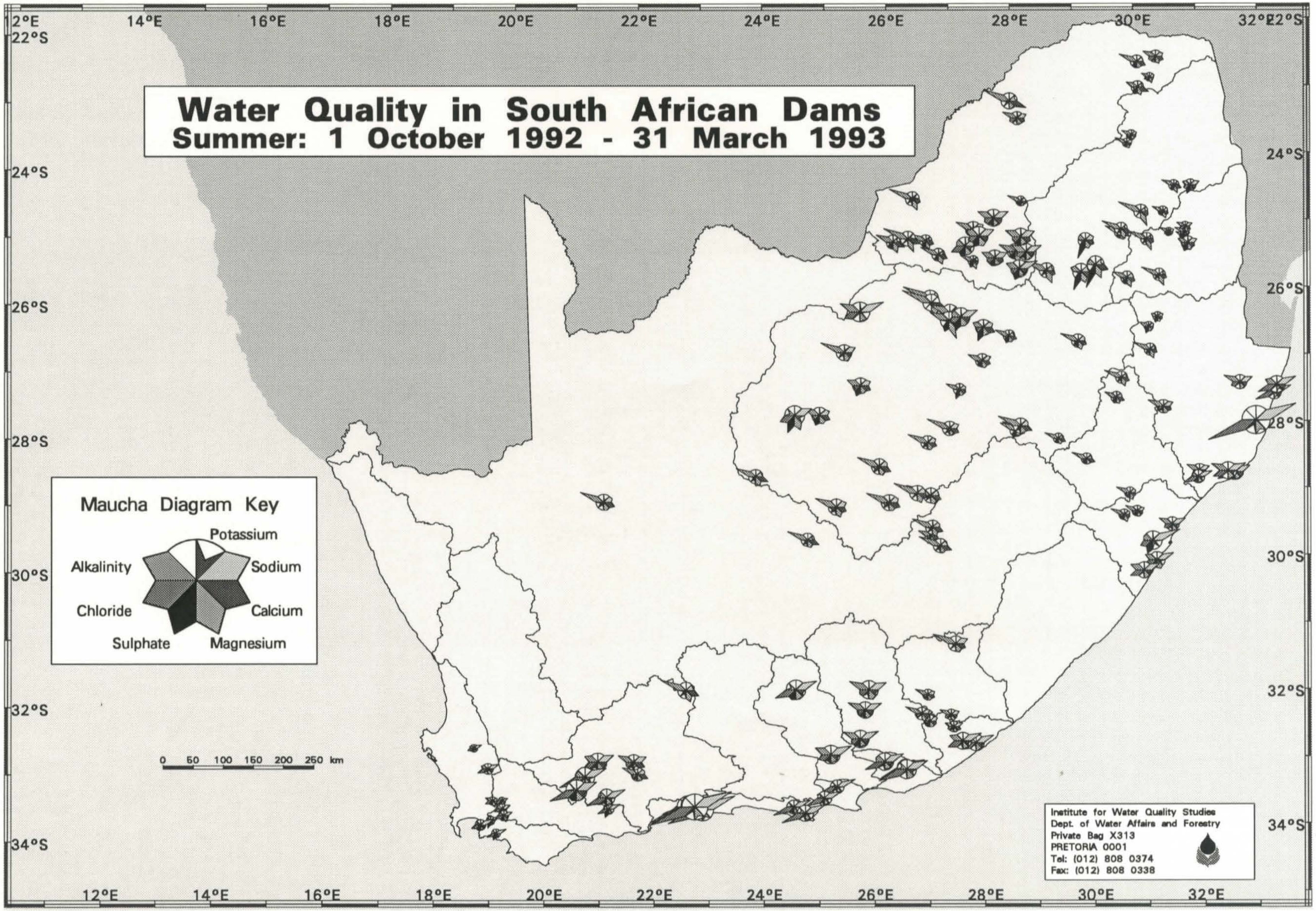


Figure 3: Water quality constituents in South African Dams

Case Study 1: *Witbank Mining Area*

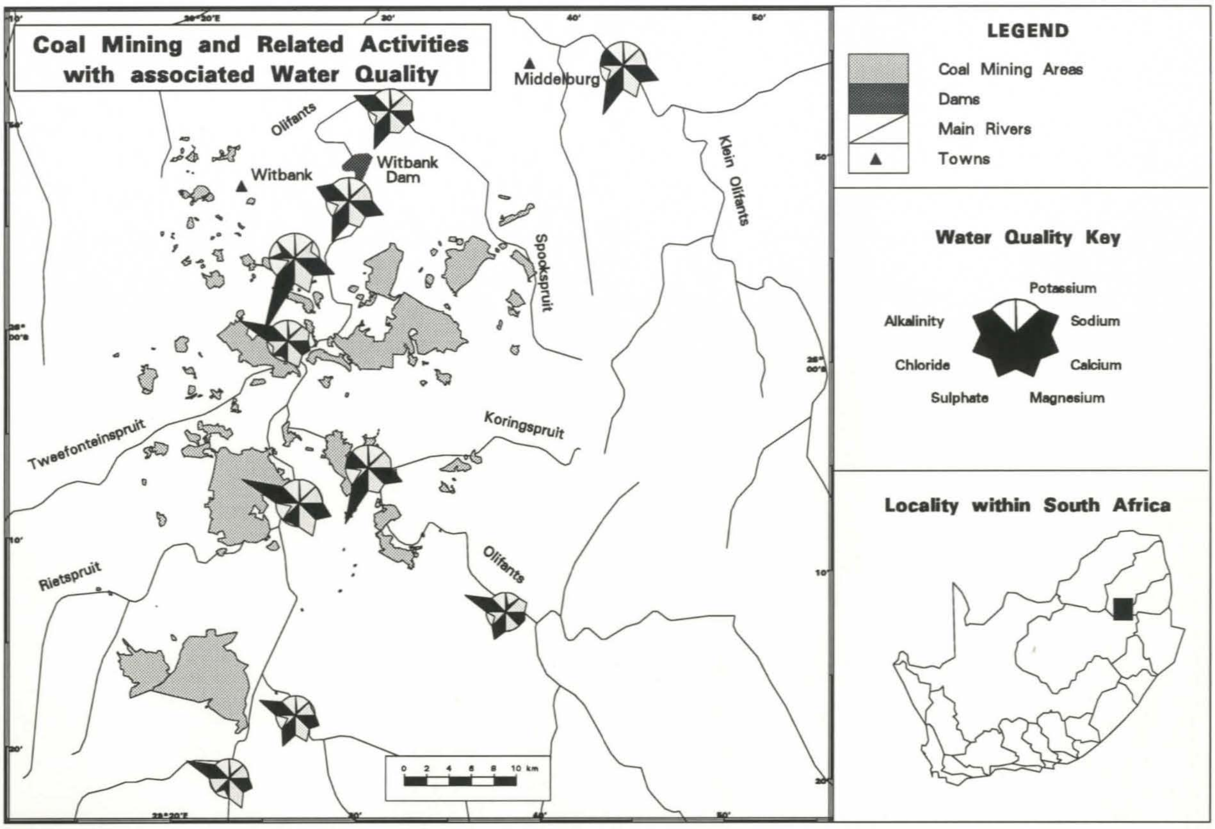


Figure 4: Witbank mining area, showing sulphate enrichment due to mining and related activities

Landuse classification data from a localised study (Vadeveer and Carter, 1993) was used in an assessment of water quality in the intensive coal mining area around Witbank. Coal mining and related activities have led to sulphate enrichment in the associated surface water, through surface runoff and acidic leachate seeping into the rivers. Figure 4 illustrates the trend where sulphates are preferentially enriched in rivers adjacent to and downstream of mining and related activities. Water quality conditions upstream of mining activity are summarised in the symbols on the southernmost limbs of the Olifants River. Natural water shows a relative predominance of alkalinity (carbonates and bicarbonates), which is significantly reduced where sulphate dominates the water quality. Note the recovery of the sulphate levels in Witbank Dam, possibly due to storage attenuation.

Case Study 2: *Jukskei River Catchment*

The Jukskei River catchment is intensively developed in the upper reaches, which drain parts of Johannesburg and Midrand. The total dissolved salts concentrations are assessed against the recommended guideline for domestic use, as there are large informal settlement communities living

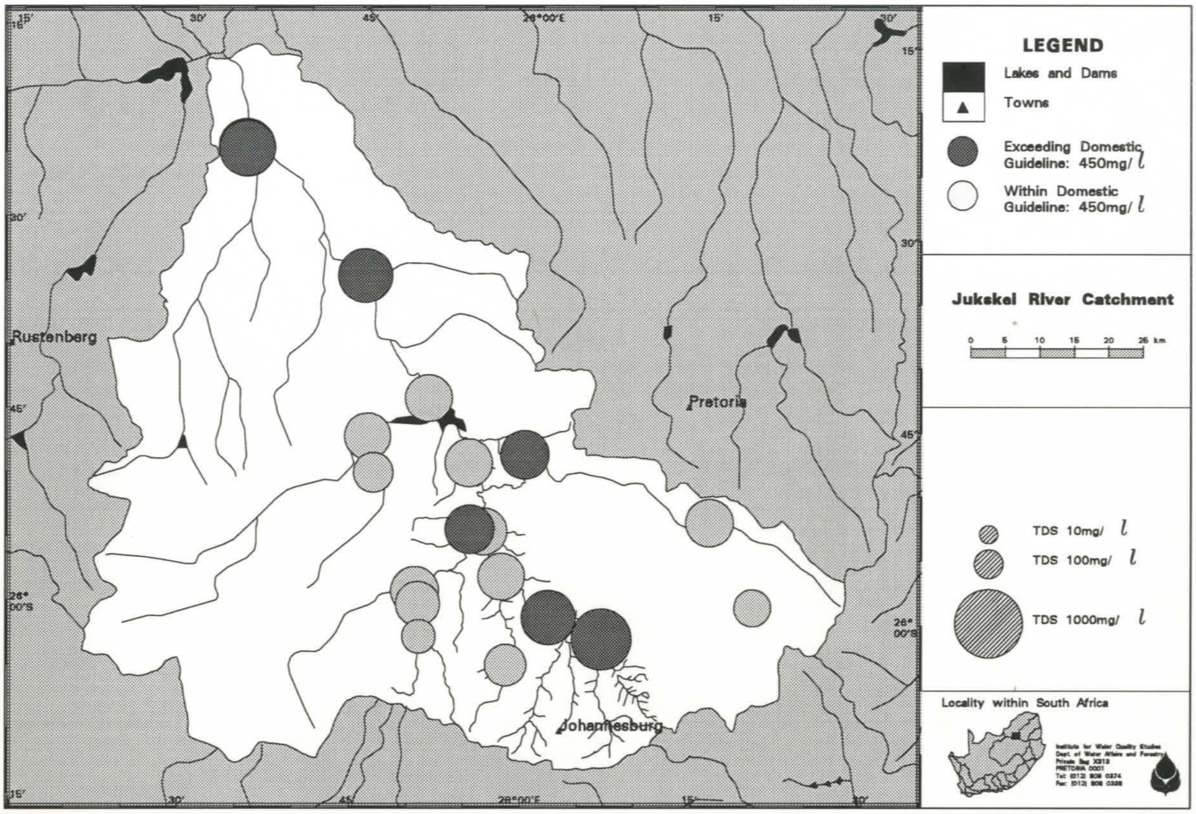


Figure 5: Median total dissolved salts concentrations, for the period June - December 1993, in the Jukskei River catchment, central Transvaal

along the river which may serve as a water source. Figure 5 shows the exceedance of total salts concentrations for the period June - December 1993.

Case Study 3: *Olifants River System*

The Olifants River system in the Eastern Transvaal has a long history of mining and industrial activities. The ecosystem health of an aquatic environment reflects the degree of disturbance from natural conditions. A healthy, balanced aquatic ecosystem reflects the status of the water, and in turn assists the recovery of the surface water after pollutant inputs. The ability of a river to absorb pollution is termed the "environmental capacity", where low capacities indicate highly impacted catchments and require ameliorative management intervention. Figure 6 shows the gradual recovery of biotic health downstream of mining and industrial activity measured using the SASS2 scoring system, a biological index for biotic health assessment (Roux, et. al., 1994). Acid drainage from mining in the upper catchment near Witbank results in severe biotic impairment in the Olifants River. In an immediately adjacent catchment, a monitoring point downstream of Bronkhorstspruit Dam shows the aquatic health to be unimpaired. The aquatic ecosystem recovers to moderate and considerable impairment upstream of Loskop Dam. At Groblersdal, only moderate impairment exists.

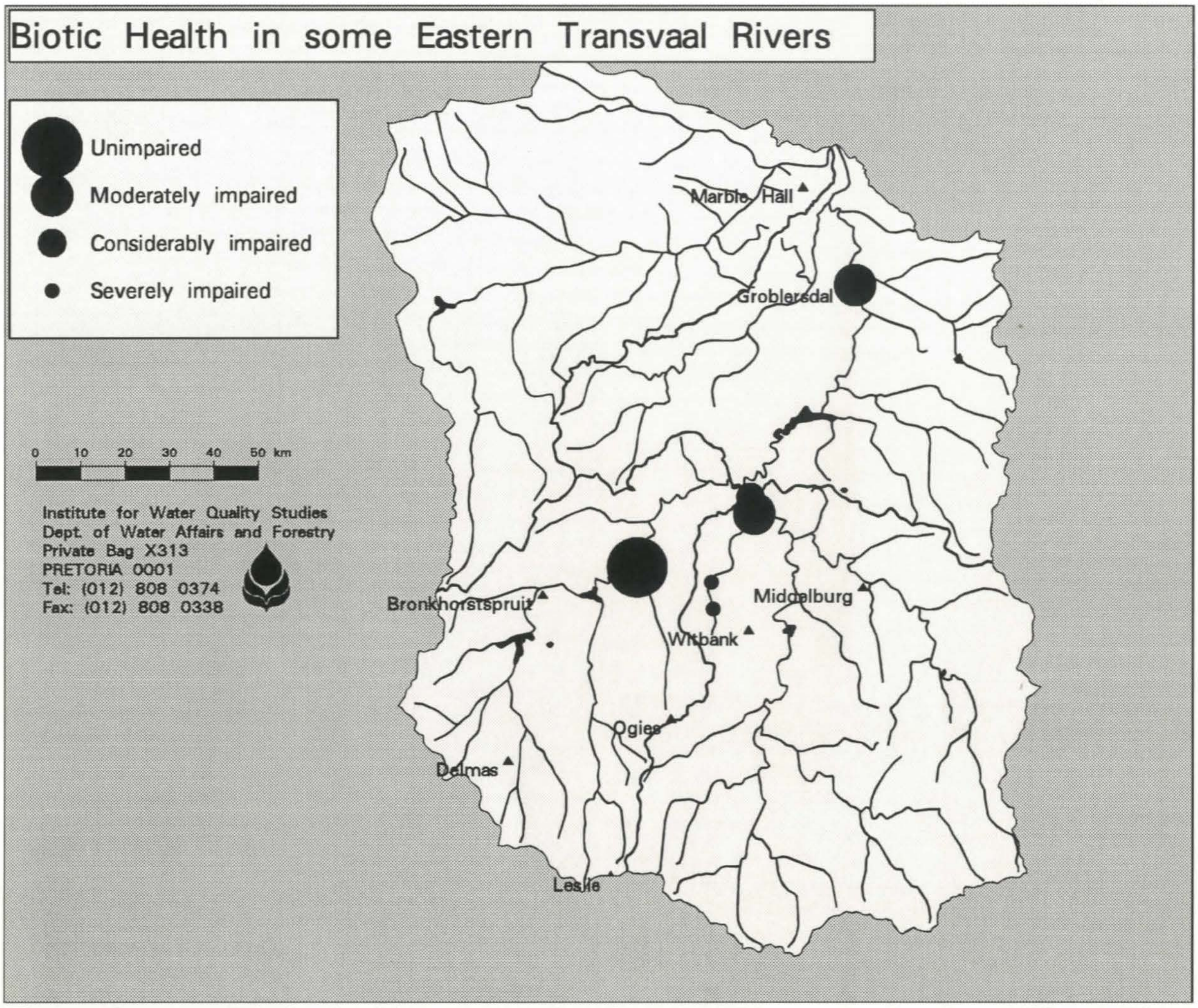


Figure 6: Biotic health, measured using SASS2 scores in the Olifants River Catchment, Eastern Transvaal

CONCLUSION AND FUTURE DEVELOPMENT

This research initiative has produced a menu-driven system on a GIS platform that offers a simple interface which is tailored to meet the needs of water quality assessment and reporting. The main goal of the research is to provide an holistic means to distil useful information from data, and to base understanding of a highly fluid system on sound analyses. Multiple levels of the interface meet differing requirements, from paging through the data to detailed searches for trends and correlations, and more advanced statistical analytical procedures whereby multiple variables are taken into account. The spatial component is used as an integrator, with the map as a visualisation tool within which water quality can be explored and from which knowledge and understanding of real world problems is attained.

Phases 3 and 4, scheduled in the original study proposal, have started and expand on the skeleton system developed in the initial phases. Problems concerning the database already identified will be investigated, additional datasets must be located and incorporated or captured. Important datasets to be obtained are continuous flow records, the known point- and non-point sources of pollution to surface water resources, which will be obtained through the Regional Offices database POLMON, and the use of remotely sensed satellite land use classifications.

The ability to assess upstream sources against downstream users should be possible through the use of a networking facility within the GIS, Arc/Info's NETWORK module, in which parcels of inputs can be passed through the river network allowing for temporary storage, channel and evaporative losses, and riparian abstraction. A plethora of enhancements emerging almost on a daily basis must be evaluated for feasibility within the established structure and prioritised for incorporation. Training programs must be devised, including detailed training and users manuals, and the system must be installed and stabilised on platforms other than the workstation currently used for development.

Wherever possible AML programmes must be translated to C programming language. With the development moving increasingly into the Unix C environment, the incorporation of predictive water quality and landuse models is the logical step. Before this takes place, however, a test exercise must determine the efficiency of incorporating models into an ever-growing, data-hungry, disk-hungry system. The existing modular system should allow easy integration, and selected models may be built into the system to support water quality scenario testing, once the assessment and evaluation stages have been attained. As a database interface is already in place the system will allow rapid inputs to management models running in C, and the outputs can be fed back into the GIS environment for display of predicted results in conjunction with actual water quality data.

ACKNOWLEDGEMENTS

All those IWQS and CSIR staff who contributed to the success of the project are gratefully thanked. The CCWR and other sources of data are acknowledged.

REFERENCES

Aronoff, S., 1991. Geographic Information Systems: A Management Perspective. Ottawa. WDL Publications

Atkinson, R., 1993. GIS and the environment: what's really happening? Mapping awareness & GIS in Europe. Vol 7 No 6: 17-19

Burrough, P.A., 1986. Principles of geographic information systems for land resources assessment. Clarendon Press, Oxford, United Kingdom

Cobban, D.A. and Silberbauer, M.J., 1993. Water quality decision-making facilitated through the development of an interface between a Geographic Information System and a water quality database. Proceedings of SANCIAHS Annual Conference, Pietermaritzburg, 1993

Department of Water Affairs and Forestry. 1993. South African water quality guidelines, VOL I - IV. Government Printer, Pretoria

Development of Water Quality Assessment Procedures. March 1994. Watertek, CSIR. Pretoria

Digital Chart of the World, 1992. Originally compiled by the United States Defense Mapping Agency (DMA) from DMA Operational Navigation Charts and Jet Navigation Charts at 1: 1 000 000 scale. Currently in Arc/Info format, provided by Environmental Systems Research Institute, Inc., Redlands, CA USA.

Grobler, D., 1994. PCB trends in the Middle Vaal River system. In press.

Lanfear, K.J., 1989. Editorial: Geographic information systems and water resources applications. Water Resources Bulletin. 25:3 v-vi

Moore, C.A. and McMillan, P. 1992. Biological monitoring of rivers and streams using SASS2 - a user manual. HRI Report No N 0000/00/REQ/3392. Dept. Water Affairs and Forestry, Pretoria

Morrison, J., 1991. Educational essentials for today's and tomorrow's jobs in cartography and geographic information systems. Cartography and Geographic Information Systems. Vol 82: 275-288

Muller, J., 1993. Latest developments in GIS/LIS. Int. J. Geographical Information Systems. Vol 7 No 4: 293-303

Openshaw, S., 1987. Guest Editorial: An automated geographical analysis system. Environment and Planning. 19: 431-436

Peel, R., 1993. Departmental GIS pilots: a catalyst for data integration. Mapping awareness & GIS in Europe. Vol 7 No 6: 38-40

Roux, D.J., Thirion, C., Smidt, M and Everett, M.J., 1994. A Procedure for assessing biotic integrity in rivers and its application to three river systems flowing through the Kruger National Park, South Africa. Dept. Water Affairs and Forestry. IWQS Report no. N 0000/00/REQ/0894.

Vadeveer, S. and Carter, J.A., 1993. The use of remotely sensed data for observing spatial and temporal changes in mining areas and the implications for water quality monitoring, with emphasis on coal mining in the Witbank area. Dept. Water Affairs and Forestry. HRI Report No N 0000/00/RIH/2593

Woodrow, D., 1993. Environmental applications of GIS in the water industry. Mapping awareness & GIS in Europe. Vol 7 No 6: 22-23

Session: 1 GIS - Trends

Dale Cobban
Lisa vd Merwe
Kathleen Caselli
Liz Marrao

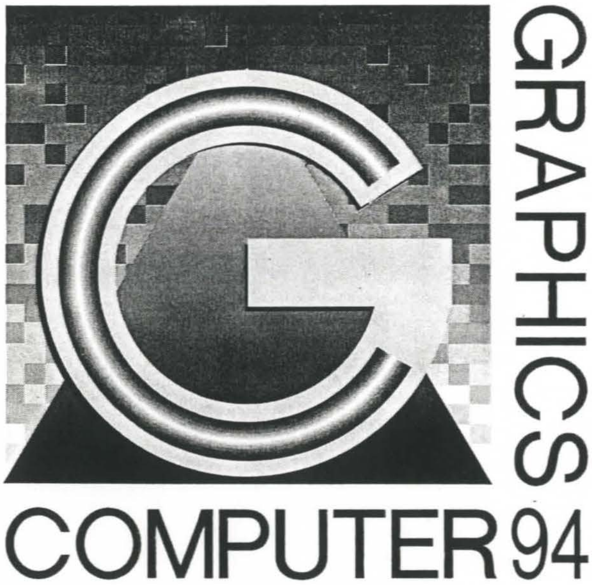
926

Michael
Silberbauer

COMPUTE
GRAPHICS
'94

• • • CONFERENCE • • •

Incorporating the 14th annual
SA Computer Aided Design Symposium
and Annual SAPGIS/TAGIS Conference



SEP 6 - SEP 9 1994
Gallagher Estate

Organised by: General Computer Consulting