WATER QUALITY INFORMATION SYSTEM FOR INTEGRATED WATER RESOURCE MANAGEMENT

BY

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DECLARATION

I the undersigned hereby declare that the work contained in this thesis is my own work, and has not previously, in its entirety or in part, been submitted at any university for a degree.

Signature: Date:

ABSTRACT

The processes of monitoring, modelling and managing the water quality of a catchment system including all its unique complexities and interrelationships requires an innovative tool or set of tools to help water managers with their decision making.

Numerous methods and tools have been developed to analyse and model the real world. However, many of these tools require a fair degree of technical expertise and training to operate correctly and their output may have to be translated or converted to meaningful information for decision-making using a further set of analytical and graphical display tools. A more appropriate technique for management would be to combine all these functions into a single system. The objective of this research was to develop one such tool, an integrated water quality information system (WQIS).

A review of the literature revealed that there has been extensive research and development of tools for the management of individual aspects of water resource distribution, augmentation and quality. However, these tools have rarely been integrated into a comprehensive information system offering decision support to a wide variety of river users and managers. Many of the literature sources also noted that a process of interactive development and integration (i.e. including the intended users in the decision of which components to include, the interface design and the graphical display and output) was vital to ensuring the information system becomes an integral part of the users routine work and decision-making.

The WQIS was developed using the recommendations from numerous knowledgeable persons in response to questionnaires, interviews and a prototype demonstration. It includes the results of hydrodynamic river and reservoir simulations and the ability to perform operational river scenario testing. However, the development process is continual and always evolving based on the current or local requirements of water managers. These further developments and research needs are discussed in more detail in the conclusion.

OPSOMMING

Die proses om die waterkwaliteit van ‘n opvanggebied, met al die unieke kompleksiteite en onderlinge verhoudings van so ‘n stelsel te monitor, modelleer en bestuur, vereis ‘n innoverende instrument om waterbestuurders te ondersteun in hul besluitnemings.

Talle instrumente en metodes vir die ontleding en modellering van die werklikheid is reeds ontwikkel. Die gebruik van hierdie instrumente vereis gewoonlik ‘n redelike mate van tegniese kundigheid en opleiding. Dit mag verder nodig wees om die uitvoer van sulke instrumente te vertaal en/of om te skakel na betekenisvolle inligting vir besluitneming deur die gebruik van bykomende analitiese en grafiese vertoon instrumente. ‘n Meer toepaslike bestuurstegniek sou wees om al die funksies in ‘n enkele stelsel te kombineer. Die doel van hierdie navorsing was om een so ‘n instrument, naamlik ‘n geïntegreerde waterkwaliteit inligtingstelsel (WQIS), te ontwikkel.

‘n Hersiening van bestaande literatuur het getoon dat daar omvattende navorsing en ontwikkeling van instrumente gedoen is vir die bestuur van individuele aspekte van waterbronverspreiding, waterbronaanvulling en waterkwaliteit. Integrasie van hierdie instrumente, in ‘n uitgebreide stelsel wat besluitnemingsondersteuning aan ‘n verskeidenheid riviergebruikers en bestuurders bied, kom egter selde voor. Verskeie literatuurbronne het ook aangedui dat ‘n proses van interaktiewe ontwikkeling en integrasie (m.a.w. in agname van die voorgenome gebruikers se behoeftes in die kense van komponente, die gebruiker raakvlak ontwerp en grafiese vertoon instrumente en uitvoer) noodsaaklik is om te verseker dat die inigtingstelsel ‘n integrale deel word van die gebruiker se daaglikse roetine en besluitnemingsproses.

Die WQIS is ontwikkel deur gebruikmaking van die insette en aanbevelings van verskeie kenners in reaksie op vraelyste, onderhoude en ‘n demonstrasie van ‘n prototype. Dit sluit in die resultate van hidro-dinamiese rivier en dam simulasies en die vermoë om operasionele rivier scenario ontledings uit te voer. Die ontwikkeling is egter ‘n deurlopende proses, gebaseer op huidige of plaaslike behoeftes van waterbestuurders. Hierdie verdere ontwikkelings- en navorsingsbehoeftes word meer breedvoerig in die gevolgtrekkings bespreek.

ACKNOWLEDGEMENTS

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DISA	-	Daily Irrigation and Salinity Analyses Model
DWAF	-	Department of Water Affairs and Forestry (South Africa)
ESRI	-	Environmental Systems Research Institute
GCTMA	-	Greater Cape Town Metropolitan Area
GIS	-	Geographical Information System
GUI	-	Graphical User Interface
RSE-BR	-	Riviersonderend-Berg River System
WDM	-	Watershed Data Management System
WQIS	-	Water Quality Information System
WRC	-	Water Research Commission

Chapter One

INTRODUCTION

1.1 BACKGROUND AND CONTEXT

The increasing pressure on water supplies and the high cost of augmentation means that every reasonable effort should be made to maximise the efficiency and effectiveness of water use from existing sources. Considerable improvements could be made to the efficiency with which this water is distributed by effective control of upstream releases and river abstractions. In a corresponding vein, water quality management in systems impacted by effluents or incidental pollution events, could be improved by enhanced information management tools.

Recently, with the introduction of 'integrated' water resources management, aspects such as environmental management, public health and the social needs of people have become increasingly important. Added to the traditional concerns of water supply and distribution, these water management concerns give rise to a complex management and planning scenario involving multiple users, multiple goals and the mitigation of a range of unforeseen impacts (Ubbels and Verhallen, 2000).

Numerous methods have been investigated and employed to overcome existing and potential water shortages and to minimise adverse impacts caused by the continued development of new water sources. These methods include water demand management, establishment of organisations to monitor water supply and clearing of invasive vegetation (DWAF, 1997).

However, the processes of managing and monitoring the flows and water quality of a river catchment system, including all their unique complexities and interrelationships, would benefit greatly from an innovative tool or set of tools to help water managers with their decision making through enhanced information access.

Numerous methods and tools have been developed to analyse and model real-world water systems; however, many of these tools require a fair degree of technical expertise and training to be configured and operated correctly. Often, they have focused on one, or a limited number of water management issues. The output of these tools may also have to be translated or converted into meaningful information for decision-making, by using a further set of analytical and graphical display tools. This project aims to develop an appropriate technique to support management by combining all the above modelling, analysis and display functions into a single system.

1.2 MOTIVATION FOR THIS RESEARCH

To demonstrate the principles and dynamics involved in creating a tool to assist with the water resources management of a complex river system, the Riviersonderend-Berg River System was selected as a suitable Case Study. This system contains many of the archetypal complexities, such as impoundments, bulk water supply infrastructure, limited water resources, and deteriorating water quality due to human impacts, that offer challenges to water managers and that require innovative management tools and philosophies.

In the Berg River catchment, particularly, the planned construction of the Skuifraam Dam in its upper reaches, will also bring with it the need to make releases to match the specified environmental instream flow requirements (Görgens and Moolman, 1998). Water quality is becoming an increasingly important issue, especially in the lower reaches of the Berg River catchment. In the vicinity of Paarl and Wellington the sandstone formations give way to Malmesbury Shale. Below this reach high salt loads are leached into the main stream, in tributary flows and via irrigation return flows. Excessive salinity has been an issue for several decades and high nutrient loads are also becoming an issue of increasing importance and concern (Görgens and Moolman, 1998).

As described in Section 1.3, a key objective of this study was to develop and apply a water management tool, referred to as, *an integrated Water Quality Information System (WQIS)*, to the Riviersonderend-Berg River System. The aim of the WQIS and its linked simulation models was to offer supporting information, useful to the immediate planning of new water supply schemes or to water quality management decisions related to pollution incidents or licensing under the National Water Act (South Africa, 1998).

Interaction with water managers raised the need to include facilities in the WQIS for devising short-term operating policies to ensure minimisation of water wastage or sudden quality problems. Several different water quality interests were also noted and, for this reason, the concept of a multi-constituent water quality model was introduced. To quantify the water quality problems, a range of water quality guidelines should also be offered, with which the simulation and observed results may be compared. These water quality guidelines are available in the relevant volumes of the South African Water Quality Guidelines produced by the Department of Water Affairs and Forestry (DWAF, 1996).

It was intended that the framework created here would also be applicable to many other cascading type river-based bulk water supply systems in South Africa and provide sound information and decision support to water managers and other interested river users.

1.3 OBJECTIVES

The primary objective of this project was to combine existing simulation models through a consistent, user-friendly interface, incorporating Geographical Information Systems (GIS) and sound graphing and analytical capabilities in order to satisfy as many as possible of the information and modelling needs of the technical user or the water manager.

The sub-objectives of this research were:

- To interact with potential users to gain a good understanding of their information, modelling and decision support requirements.
- To integrate relevant simulation models in appropriate ways.
- To critically assess, based on management and potential technical user feedback, the ability of the simulation models originally chosen for integration into the WQIS to perform the different functions of planning and operational management.
- To research alternative methods or models for integration into the WQIS, where the simulation models did not provide the required management options.
- To apply the WQIS to the Berg River System.

1.4 OVERVIEW OF METHODOLOGY

To determine the requirements of the system, it was necessary to interview the potential users of the WQIS (as defined in Section 1.2) and establish their needs and preferences in terms of modelling (input and output), display of results and interface environment characteristics. These requirements, in turn, determine the software characteristics, methods of integration, operating step and types of output required when developing the WQIS.

1.4.1 Modelling Tools

The focus of this aspect of the research was to determine, by way of interviews, the key functions required of streamflow simulation and quality models, by water managers, to perform their every day operational and planning duties. Long-term hydrodynamic simulation/planning models were suggested/required for use in this project and their relevance, applicability to the users' requirements and methods of integration were investigated and compared with alternatives.

1.4.2 Interface Environment

When researching an appropriate interface environment, the aim of the software development was not to just fulfil new technical modelling requirements, but rather to develop a uniform environment into which existing, or still to be developed, models can be integrated. In the past, the development of modelling systems has often focussed on a single category of information or output requirement (e.g. river flow or quality modelling). The development of an integrated environment expands the focus of the water manager by combining a range of models such as river flow and quality routing applications, as well as reservoir simulation components, into one application.

The tools used for developing the database support and the modelling interface also needed to be carefully considered. In most cases, managers have extensive field knowledge and experience in decision-making, using the results of model output and graphical/spatial representation of information, but are rarely proficient in using the tools that create the output. It would, therefore, be unwise to develop an application within an advanced environment where the user would require fairly extensive technical training before using the new application.

As stated in the primary objective, the interface environment was required to incorporate GIS and good analytical and graphing facilities. Therefore, the numerous GIS and programming products available were also researched in order to choose the product or combination of products that would best address the needs of the project while also catering for various levels of expertise.

1.5 FRAMEWORK FOR THE WQIS

Effort spent on the technical development of the WQIS, although essential, was considered no more important than the gathering of knowledge about, and understanding of, user needs. Therefore, this document focuses on the process of interactive development and integration of a water quality information system that addresses the needs, comments and recommendations of the target user, throughout its development and in its final function, while still fulfilling the technical requirements for which it was designed. It also aims to provide a consistent environment for the user to view the results of the various function specific models.

The initial list for WQIS components is as follows:

- Hydrodynamic flow and water quality river model,
- Hydrodynamic flow and water quality reservoir model,
- GIS to store, analyse and display spatial information,
- One or more databases linking the input and output from the above components, and
- A User-friendly Graphical User Interface (GUI), which seamlessly interacts with all the components and provides the means to analyse and display data and the results of scenario testing with the models. This enables the user to become familiar with the conventions and environment rather than continually expose them to new technology and models, each with their own styles and look.

The actual mechanisms for interfacing the components, and the final component list were confirmed after reviewing the technical management and communication needs of the target groups (see Figure 1.1). This will hopefully develop the WQIS into an indispensable tool in constant use, rather than being a one off modelling exercise.

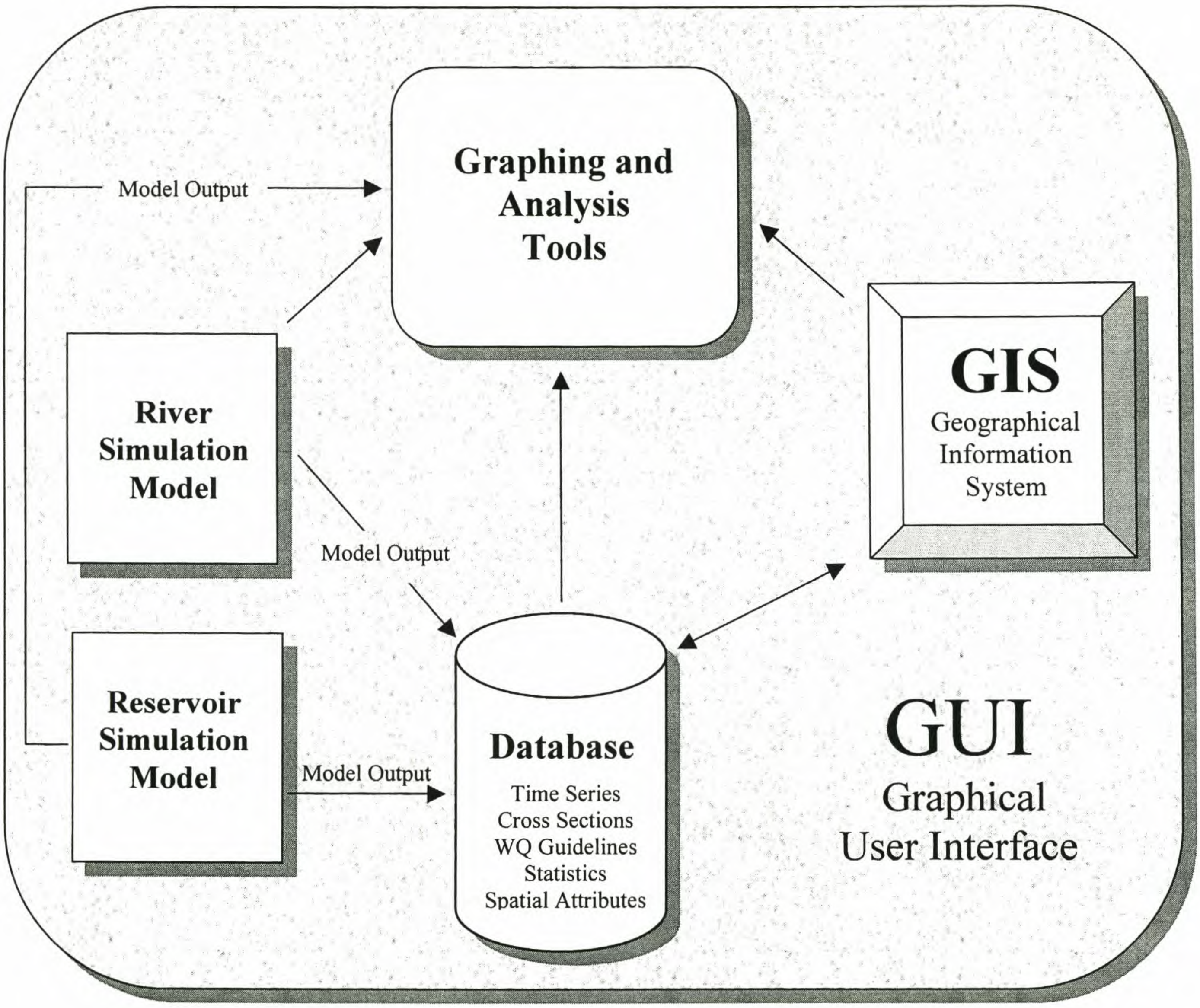

Figure 1.1: Conceptual Model

1.6 STRUCTURE AND CONTENT OF THE DOCUMENT

The concepts and objectives of the project have been stated and discussed briefly in this chapter. The discussions in the following chapters attempt to describe the unique development of a hydrological tool, without focussing exclusively on either the technical software development or hydrological aspects. However, for a complete understanding of both aspects of the complex development process, some technical programming and hydrological modelling issues will be mentioned.

Chapter 2 provides an overview of the study area, in terms of catchment characteristics, climate, hydrology, landuse and management issues.

The building blocks or components of an integrated information system will vary according to the purpose for which it was intended. However, to ensure that the information system is generic, flexible and useful, there are certain key components that should form the foundation of any information system. An attempt is made to define these key components in Chapter 3

Chapters 4 to 7 deal with the sub-objectives stated in Chapter 1. The process of interactive development and the subsequent benefits to the successful implementation of an information system are discussed in Chapter 4. The appropriate level and mechanisms for integrating components in an information system is discussed in Chapter 5 as are the individual components selected for inclusion in the WQIS. Some existing water quality information systems are investigated and a full description of the functionality the WQIS is given in Chapters 6 and 7 respectively.

An evaluation of the simulation model integration and compatibility is dealt with in Chapter 8 and Chapter 9 describes how some operational modelling issues are overcome to facilitate scenario analysis.

Chapter 10 contains a discussion of the achievements of this study and suggests avenues for future investigation.

Chapter Two

THE BERG RIVER CATCHMENT AS A CASE STUDY

As mentioned in Chapter 1, the Berg River catchment has been used as the study area for the application and development of a Water Quality Information System. The biophysical characteristics of the catchment are described below and their unique interrelationships and management issues are discussed.

2.1 PHYSICAL CHARACTERISTICS

The Berg River has its source in the mountainous area of the Groot Drakensteinberge. The upper region of the Berg River basin is surrounded by high mountain ranges to the south, east and west. The river basin is fairly narrow (10-15km) between the source and Wellington. North of Wellington, the Limietberge bound the valley to the west, and in the east the basin levels out and the river valley widens to approximately 25km (see Figure 2.1).

From the source the Berg River flows north and joins the Franschoek River in the Franschoek Valley. It is joined by two more tributaries, the Wemmershoek River to the east and the Banhoek River to the west, halfway between Franschoek and Paarl.

The Berg River then flows through Paarl and Wellington where it is joined, from the east, by the Krom River. This tributary has its source in the Limietberge and drains the valley above Wellington.

North of Wellington, the Berg River is joined by various other tributaries including the Klein Berg River, Kompanjies River and the Twenty Four Rivers.

The Klein Berg has its source in the high lying Winterhoek Mountains in the north-east of the Tulbagh Valley. Further southwards it is joined by the Boontjies River. From there, it flows westwards between the Obiekwa and Voëlvlei mountains into the Berg River Valley and joins the Berg River to the west of Saron. Approximately 3km north, is the confluence of the Twenty Four Rivers and the Berg River.

STUDY AREA

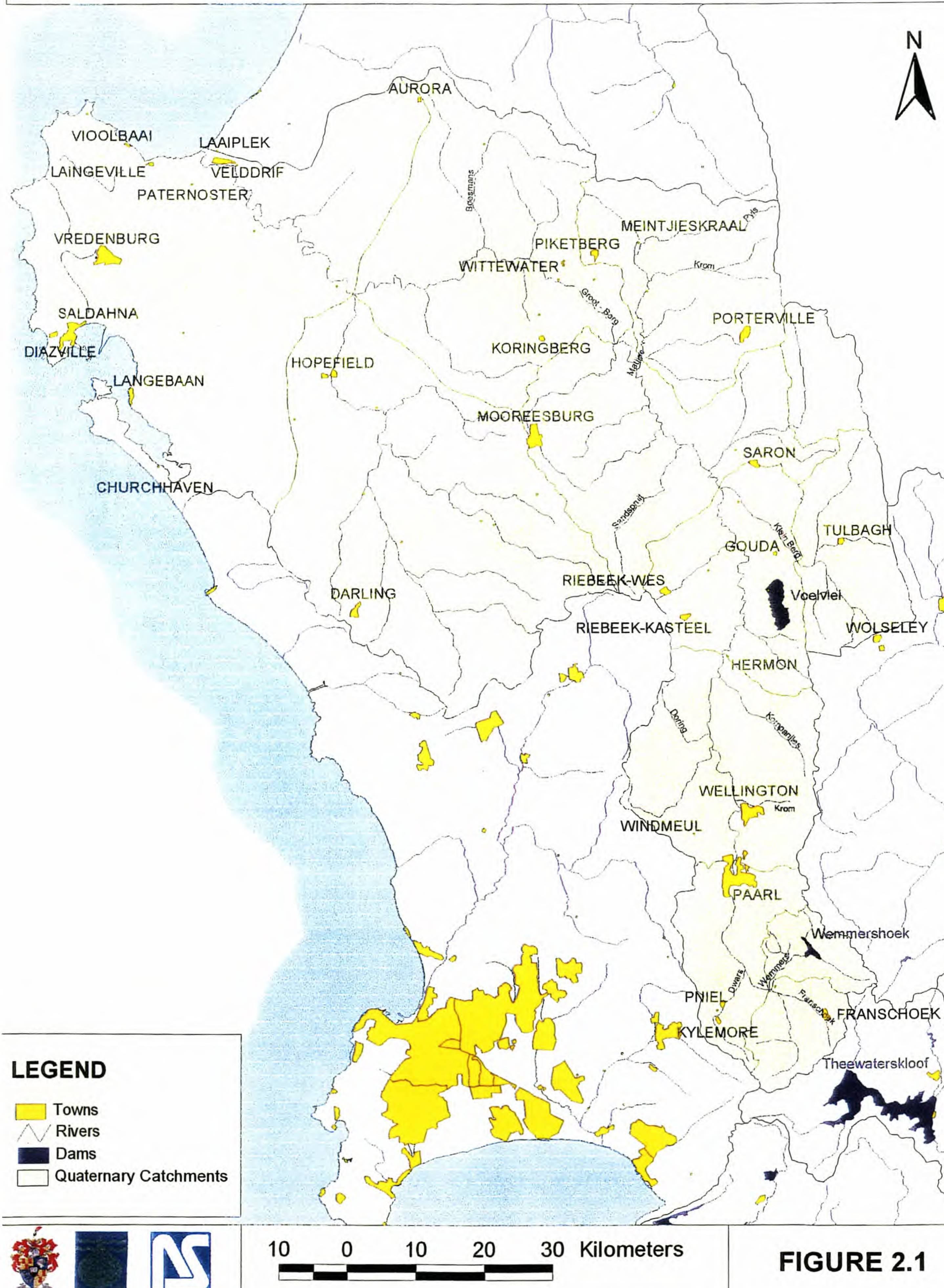

FIGURE 2.1

After a further 10 to 15km, the Berg River flows over the Misverstand Weir. Upstream of the weir, it is joined by the tributaries that drain the areas north of Porterville and Moorreesburg. The river flows in a northwestward direction and drains into the Atlantic Ocean at Velddrift (DWAF, 1993).

The main stem river is about 160 km long from the headwaters to the sea and its width varies from 1 to 5m near the headwaters to between 30 to 40m at the coast. (Bath, 1989). The Berg River is geologically an old river system which can be seen from the rapid fall in profile from headwaters and which then flattens out in the Paarl area.

2.2 CLIMATE AND HYDROLOGY

The climate in the Berg River catchment is typical of the Western Cape Region. This region is classified as the humid zone and experiences winter rainfall and high summer evaporation (see Figure 2.2). Precipitation occurs as a result of the cold fronts approaching from the northwest.

In the high lying areas of the Groot Drakenstein, the Mean Annual Precipitation (MAP) is above 1500mm but reduces steadily to under 500mm further northwards where the Berg River levels out. The MAP then drops further to below 300mm at the mouth (Midgley *et al.*, 1994).

The Mean Annual Evaporation (MAE) in the southern and western regions of the catchment is between 1400mm and 1500mm and increases to over 1600mm in the northeast. There are significant seasonal variations in monthly evaporations which fall typically between 40 and 50mm in winter and 230 – 250mm in the summer months (Midgley *et al.*, 1994).

The number and distribution of flow gauging stations recording runoff in the upper and middle reaches of the Berg River is adequate for water resource purposes. The details of the active gauges are summarised in Table 2.1 (DWAF, 1990b). The Misverstand Weir is the most downstream site where a reliable continuous runoff record is available.

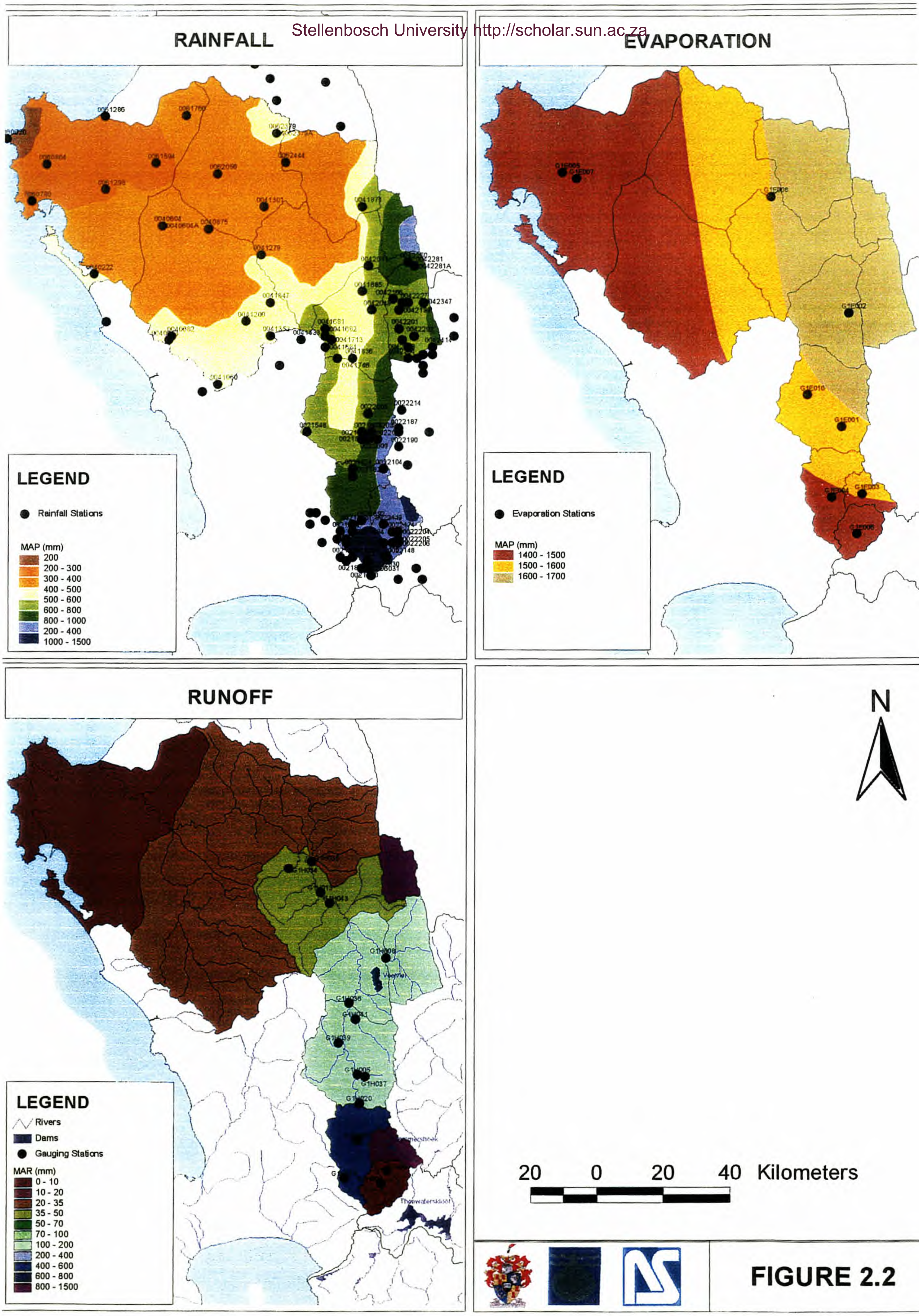
RAINFALL
LEGEND
Rainfall Stations
MAP (mm)
200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 800
800 - 1000
200 - 400
1000 - 1500
EVAPORATION
LEGEND
Evaporation Stations
MAP (mm)
1400 - 1500
1500 - 1600
1600 - 1700
RUNOFF
LEGEND
Rivers
Dams
Gauging Stations
MAR (mm)
0 - 10
10 - 20
20 - 35
35 - 50
50 - 70
70 - 100
100 - 200
200 - 400
400 - 600
600 - 800
800 - 1500
N
20 0 20 40 Kilometers

FIGURE 2.2

Table 2.1: Streamflow Gauges in the Berg River Catchment

Gauge Name	River	Location	Catchment Area
G1H003	Franschoek River	Le Mouillage la Motte	46 km^2
G1H004	Berg River	Bergriviershoek – Driefontein	70 km^2
G1H005	Berg River	Lady Loch – Zanddrift	717 km^2
G1H007	Berg River	Katryntjiesdrif	713 km^2
G1H008	Little Berg River	Nieuwkloof	395 km^2
G1H013	Berg River	Drieheuwels	2934 km^2
G1H019	Banghoek River	Jonkershoek – The Sanctuary	25 km^2
G1H020	Berg River	Dal Josafat – North Paarl	609 km^2
G1H034	Moorreesburgspruit	Hollerivier	134 km^2
G1H035	Matjies River	Matjiesfontein	676 km^2
G1H036	Berg River	Vleesbank – Hermonbrug	1312 km^2
G1H037	Krom River	Wellington	69 km^2
G1H039	Doring River	Grensplaas – Diepe Gat	43 km^2
G1H041	Kompanjies River	De Eikeboomen	121 km^2
G1H043	Sandspruit	Vrischewaagd	152 km^2
G1H048	Pipeline to Withoogte	Misverstand Dam	-
G1H065	Canal from Voëlvlei Dam	Vogel Vallij	-
G1H071/72	Pipeline - Wemmershoek Dam	Winterhoek	-

2.3 RESERVOIRS

There are three existing reservoirs within the Berg River catchment. Voëlvlei and Wemmershoek are relatively large dams and Misverstand Weir is considerably smaller.

Wemmershoek Dam: The catchment area of Wemmershoek Dam is approximately 86km^2 and is situated on the Wemmers River in the reaches of the Upper Berg River. The dam has a capacity of 58.8M.m3 and is operated to supply a portion of the Greater Cape Town Metropolitan Area water requirements. Previous compensation flows to the Upper Berg River are no longer released from the dam but are now released through the Theewaterskloof Tunnel (DWAF, 1994).

Voëlvlei Dam: This is an off-channel dam with a limited natural catchment and is supplied by diverted runoff from the Klein Berg River, Twenty-four Rivers and Leeu River catchments through canals. The present capacity of the dam is $172M.m^3$. The dam presently supplies urban demands required for Cape Town and the Swartland Scheme as well as irrigation water for downstream riparian users. This irrigation water is released into the Berg River along with the water for the Withoogte Scheme which is then abstracted from Misverstand Weir further downstream (DWAF, 1994).

Misverstand Weir: Misverstand is situated on the lower reaches of the Berg River and has a present full supply capacity of $6M.m^3$. Its purpose is to supply water to the Withoogte Scheme urban users (DWAF, 1994).

2.4 IRRIGATION

There are numerous, formal irrigation schemes in the Berg River catchment which, for the most part, fall under the operation of the Upper Berg River Irrigation Board. Irrigation is predominantly during the summer months with the exception of the Paarl Municipality which irrigates throughout the year when necessary. The main types of irrigated crops are vines, fruit and vegetables and are illustrated in Figure 2.3 (Midgley *et al*, 1994). Each irrigation scheme has limited annual quotas.

2.5 CATCHMENT MANAGEMENT ISSUES

The demand for water in the Greater Cape Town Metropolitan Area (GCTMA) is increasing as a result of population growth, improved living standards and irrigation expansion. This sustained growth will necessitate expansion of the Riviersonderend-Berg River (RSE-BR) system in the near future.

LAND USE

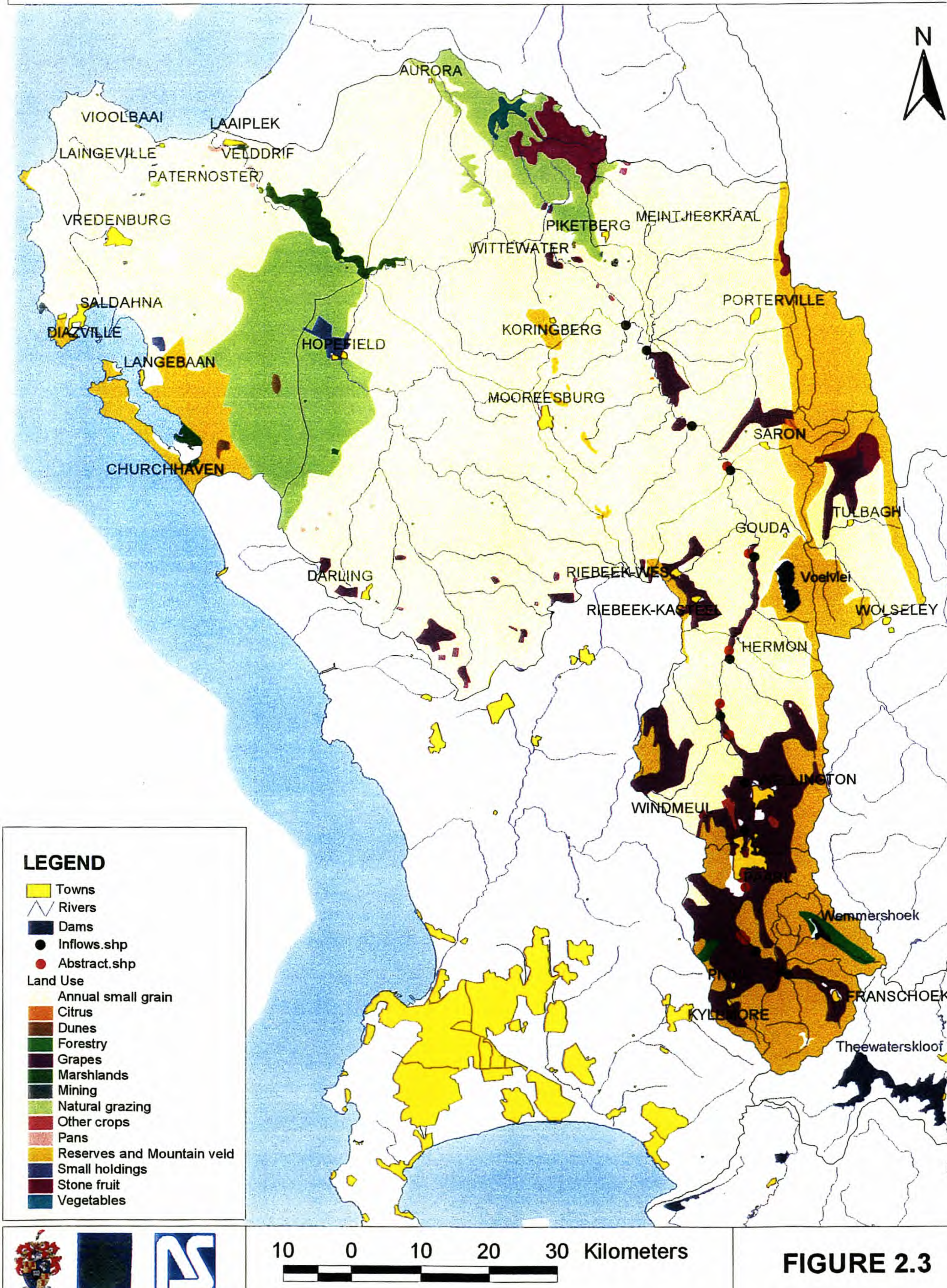

FIGURE 2.3

The combined impoundments of the RSE-BR catchment system currently contribute more than 80% of the total annual water yield of 450 million m^3 available to the bulk water supply system of the GCTMA. In order to overcome potential shortages of water and to minimise adverse impacts caused by continued development of new water sources, strategies to augment supplies and moderate the demand for water are required. The following schemes are being investigated for imminent implementation in the Berg River:

- Skuifraam Dam in the Upper Berg and
- Skuifraam Supplement Pump Scheme downstream of Franschoek and Lorelei Diversion to an enlarged Voëlvlei Dam in the Middle Berg.

These schemes also aim to provide improved water supply and sanitation to a number of disadvantaged communities as part of numerous RDP projects. Development of irrigation schemes for emergent farmers from these communities will also be made possible. In addition, irrigation extensions by currently established farmers will also be possible.

The implementation of these schemes is likely to remove an additional 20% of fresh water from the Berg River main stem and will lead to a strongly regulated river system between Skuifraam and Misverstand. The real possibility that these planned developments will go ahead has caused concerns about the water quality fitness for use and ecological deterioration.

New irrigation areas will receive fresh water from the water supply developments mentioned above. However, these extended irrigation areas will increase the saline irrigation return flows reaching the Middle to Lower Berg system and possibly exacerbate the moderately high salinities already recorded in those reaches. An understanding of the soil types, their distribution and their leaching characteristics would prove useful to demarcate "salinity hazard zones" where new irrigation development should be restricted. This issue is being investigated in a concurrent WRC study conducted at the University of Stellenbosch.

High summer releases for irrigation are made from Voëlvlei Dam (and Skuifraam in the future) which stratifies during summer. These large volumes of cool water are unusual for a winter rainfall area and may also cause river temperatures and oxygen levels to be unacceptably low. In addition, the volumetric In-Stream Flow Requirements (IFR) of the river system, particularly the wetlands near the Berg River Mouth and the tidal zone of the estuary, need to be considered.

Another potential water quality risk is the increase in nutrient levels. Due to the increase in population in the catchment, increased volumes of treated waste water effluents and non-point source loadings are augmenting nutrient levels in the Middle Berg River. This, in turn, may lead to eutrophication hazards in Voëlvlei and Misverstand Dams.

2.6 DISCUSSION

The unique characteristics of the Berg River catchment and the numerous, on-going and planned developments within the catchments require collaborative and continual management from all interested parties. The development of a single decision support or information tool that can be used by all those involved in the management and use of the river catchment, is an intuitive way of stimulating discussion, offering solutions and reaching consensus.

This tool needs to be developed with the continual input of the relevant managers and users so that it becomes a workable, well-used system. The components of the system also need to be considered carefully to ensure that they correctly describe the processes occurring in the catchment. A number of components may be integrated into an information system to offer the best solution.

These processes of interactive development and system integration are discussed in general, and in terms of their application to the current project, in Chapters 4 and 5 respectively.

Chapter Three

DESIGN PRINCIPLES OF MANAGEMENT INFORMATION SYSTEMS

There are many processes that act and interact in our everyday business, government and environment. These processes rely on "resources" in their various forms (staff, time, finance, water etc.) as driving forces. However, there are almost always limitations on these resources, as they are generally unevenly distributed in space and time. The management of these resources within an atmosphere of continual change is a very complex task and research and expertise are often specialised or focussed on selected aspects of resource management. This 'modular' approach is losing popularity as an effective management strategy and new methods of integrated resource management are being sought.

A similar pattern has occurred in the development of the software tools that have resulted in or corresponded with, the type of research discussed above. The rapid progress in computing capability produced a plethora of computer simulation models to simulate many aspects of the business world or environment. As Dent (1993) remarks, computer simulation models formalise, in a quantitative manner, the knowledge that we have about a process. Many of these models have been very successful in providing insight into specific processes, but rarely address the significant impacts that these processes may have on any number of related aspects.

There is a drive to develop information and decision support tools that will enable knowledge seekers and concerned individuals to make informed decisions based on large volumes of information on a wide range of aspects at the same time. Turban (1993) suggests that these technologies have the potential to create a synergy that greatly impacts on the effectiveness of managerial decision making. However, there is an on-going debate concerning the kinds of information, the structure and major components required by the decision support or management information system. Wijers (1993) states that in such a multi-faceted environment, the concerned parties need to be in a position to see the whole picture, to assess the current needs and future aspirations of all users and to make decisions in the interests of all concerned.

To this end, some of the many challenging tasks in the implementation of an information system are listed below and discussed in the following sections.

- Data and information collection.
- Design of a database structure to suit the information requirements of all disciplines involved.
- Design of data capture and data management facilities.
- Population of the database
- Incorporation of models and other management tools.
- Incorporation of analysis and graphical tools.
- Creation of a user friendly interface and menu system
- Creation of an organisational structure responsible for information maintenance.

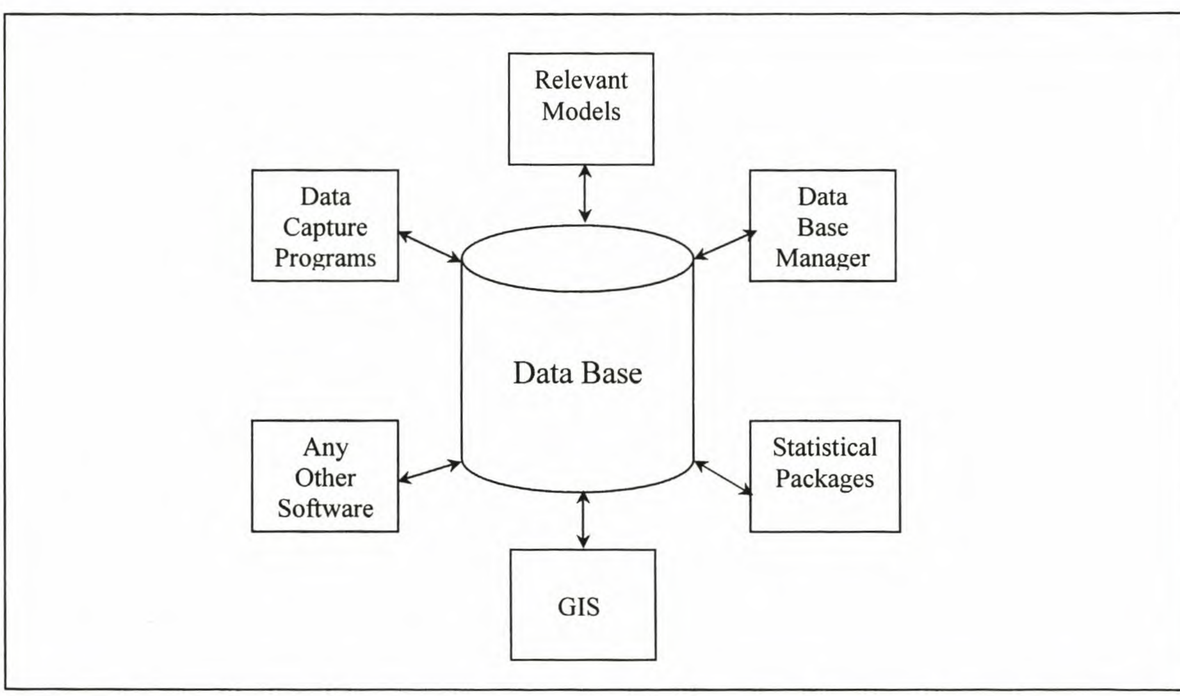

Figure 3.1: Simplified Structure of a Management Information System (after Wijers (1993))

A management information system is a formal, computer-based system, intended to retrieve, extract and integrate data from various sources in order to provide timely information necessary for decision making (Turban, 1993). Figure 3.1 illustrates the typical, simplified structure of an information system, the aim of which is to satisfy the decision support, modelling and general information requirements of as many users as possible. To provide these functions, the structure of the information system needs to be flexible enough to accommodate a variety of components that cover the wide spectrum of disciplines involved. The main components that would ideally form the basis of an effective management information system are discussed below.

3.1 DATA MANAGEMENT

The effective management of any resource, process or organisation relies to a large degree on the availability and accessibility of adequate and accurate data and information. Rob and Coronel (1993) agree that organisations usually prosper when their managers act on the basis of efficiently generated, relevant information.

Although data is the fundamental building block of most modelling and information systems, it rarely receives the attention it requires. More often than not, incomplete and outdated data is used for modelling exercises, the results of which are used to make fundamental decisions.

The consistent and conscientious collection of data should be encouraged and a database structure that accommodates easy access by a wide range of applications and users should be devised to store the data and information. Efficient data entry facilities need to be developed to facilitate, firstly, the initial population of the database and then any subsequent updates, in a consistent format.

Once established, the database needs to be continually maintained. For this reason, a data manager should be included in the system to run quality checks and backups and maintain a data dictionary or metadata. Another important function of the data manager would be data conversion, i.e. provision of data in a suitable format to other system components or to other information users.

3.2 MODELS

The type and nature of the models required (if any) by a management information system will obviously be dictated by the system's ultimate function and the environment it aims to represent. No matter which models are used, there should be an efficient and effective way of converting the model output to and from the database format so that the information can be accessed and used by any of the other models and components that make up the information system.

Before the models are integrated into the information system, they should be well researched, concentrating on issues such as:

- software platform compatibility,
- nature and size of model input and output,
- licence agreements and portability,
- setup and running time,
- model purpose.

3.3 ANALYSIS

Tools for analysing data and the results of the various modelling components are essential elements of an information system. These tools provide the facility to convert vast amounts of data into meaningful information which in turn can be used to make essential management decisions.

Standardising these analysis tools in the information system precludes the need for a variety of stand alone applications, each with its own data formats, operating procedures and visual environment. The user will become familiar with a single analysis environment and, therefore, will easily understand the graphical results of each model. Inconsistencies in analysis methods will be eliminated.

3.4 GEOGRAPHICAL INFORMATION SYSTEMS

According to the ESRI President, J Dangermond, "Knowing where things are and why is essential to rational decision making". In all areas of decision making, a visual representation of the process often provides a good overview of the situation and can highlight points of significance. A few examples of this are:

- Business: office floor plan for most effective/least disruptive staff communication
- Government: location and distribution of voters within constituencies
- Environment: geographical map showing the distribution of rainfall and runoff gauges
- Systems: layout and interconnectivity of PC stations within a network

Although GIS is a fairly new addition to most information systems, it is relatively easy to integrate and has enormous potential for describing the system and processes about which decisions need to be made.

3.5 RESPONSIBILITY AND OWNERSHIP

The concepts and motivation behind implementing an information system may seem exciting, productive and even essential for future decisions and operations. However, even after successful design and implementation phases, the information system needs to be "maintained". This requires an organisation or department within an organisation to assume responsibility for the new system, i.e. provide user support, implement upgrades, monitor backups and design and develop new features based on user feedback, new technology and new procedures. A well-maintained system will become an indispensable and well-used application, if the data, tools and technology are kept current and operational.

3.6 DISCUSSION

Effective management requires the definition of clear goals and objectives, an efficient organisation and a reference framework for decision support. To this effect, effective management requires an information system which provides (at least) the following list of functions:

- Contains and allows easy access to large volumes of data concerning a multiplicity of themes and disciplines,
- Provides relevant information at an appropriate level of detail in a user friendly format,
- Provides an information platform flexible enough to accommodate a wide range of applications.

These information systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions (Turban, 1993). It is essential to make information systems as generic as possible for ease of transfer to other scenarios and simulation cases. Systems should be transparent and always evolving, based on user's comments. In this way, information systems are a means of stimulating discussion and new ideas, making good use of data and detecting areas where new information is lacking and hence may need research effort (Dent, 1993).

Chapter Four

PROCESS OF INTERACTIVE DEVELOPMENT

The development of an effective decision support information system involves complex communication and design challenges. To fulfil the aims of this project, both sets of these challenges had to be dealt with effectively to produce an information system that satisfies the requirements of the intended users. Two crucial concepts that feature here were "interactive" and "integrated".

Interactive development comprises ongoing communication between the developer and users and mutual inputs and responses regarding the conceptual and general design of the required information system. Integration refers to the linkage and communication between the actual components of the system. The components and level of their integration required to appropriately meet user needs should be agreed upon as part of the interactive development process.

Both interactive development and system integration are crucial objectives (see Section 1.3) of this project and as such have been researched and implemented. Interactive development is discussed in this chapter and integration is dealt with separately in Chapter 5.

4.1 INTERACTIVE DEVELOPMENT

4.1.1 Learning from Past Experience

"We developed a system for them – so why don't they use it?"

Shepherd (1997) admits that this is probably a question asked by many developers and even managers, after a new system has been designed and implemented. The key to the success or failure of any system is the level of communication between user and developer during the entire analysis, design and implementation of the system.

Dearnley and Mayhew (1983) agree that the conventional approach to systems design is one in which the user is passive, only being interviewed during the fact-finding investigation, and the analyst or developer is active, doing the design and development. This approach concentrates on technological development, creating a 'new' system, and neglects the process of interactive development and implementation.

A contrasting approach is one in which the user takes an active, or participative role in the system design process. In this way, not only is the process of technological development examined, but the critical interactions between the system developer, the technology and the user are also analysed. It is important that the developer engages in a process of 'interactive development' **with** the user rather than just **for** the user. A system's acceptance by a user depends not only on system attributes, but also on the process by which it is integrated into the user's work routine (Shepherd, 1997).

Dearnley and Mayhew (1983) list numerous tools that can be used during the different stages of the participative design process to achieve a system that satisfies as many requirements as possible. These include surveys, field tests, prototypes and simulation.

As a first step, a process of initial knowledge acquisition should be performed, where the developer would observe and interview the experts and users to gain insight into the basic requirements and processes required. This could be done by means of surveys/questionnaires or interviews.

Once the basic requirements and components of an information system have been established the process of development begins. Shepherd (1997) warns that the mere development of, or decision to adopt, a new information system does not necessarily guarantee that the target users will make use of the system. Although there may already have been extensive negotiations as to the type of system required, a constructive process of iterative, interactive development should be re-enforced.

Interactive involvement promotes acceptance of the product and creates a sense of ownership, responsibility and commitment. This interactive, adaptive approach to development and implementation will create a better system, as the expertise, feedback and needs of the user will be incorporated, thereby increasing the acceptance of a system that was developed with input from the user.

Using a prototype of the final system is a good way to stimulate interest and feedback. A prototype is an approximation of the required system and contains certain essential aspects of the final system that need to be tested in some manner (Tate, 1990). The prototype is by nature, incomplete, unreliable and has limited functional capabilities, but has value in that it reduces project risk that arises from incomplete knowledge of what is required, or how to achieve it. Tate (1990) states that the primary reason for prototyping is to buy knowledge and thus reduce uncertainty, and increase the likelihood of success of the software project. The knowledge gained from demonstrating the prototype (running test cases and scenarios) can provide vital clarification of requirements, feasibility, user acceptance, marketability, system behaviour and critical performance factors (Tate, 1990). The system would then be modified and demonstrated again in an iterative process (within a given budget) until the users are satisfied (Shepherd, 1997).

If an attempt is made to follow the steps outlined above, there is a greater chance that the new system will 'include' the user in its operation and will function using the user's knowledge and not disregard it totally by imposing new methods. The system will incorporate the user's familiar methods, but hopefully also facilitate progress if the user's "comfort zone" is outdated. Increased user acceptance would also occur if the developer focused more on ways to support users in the way they make a decision rather than on sophisticated algorithms to make the decision for them.

The system should be critically assessed throughout the development process. The many small loop back steps shown in the Systems Life Cycle diagram in Figure 4.1 illustrate the iterative nature of the investigation, analysis and design steps.

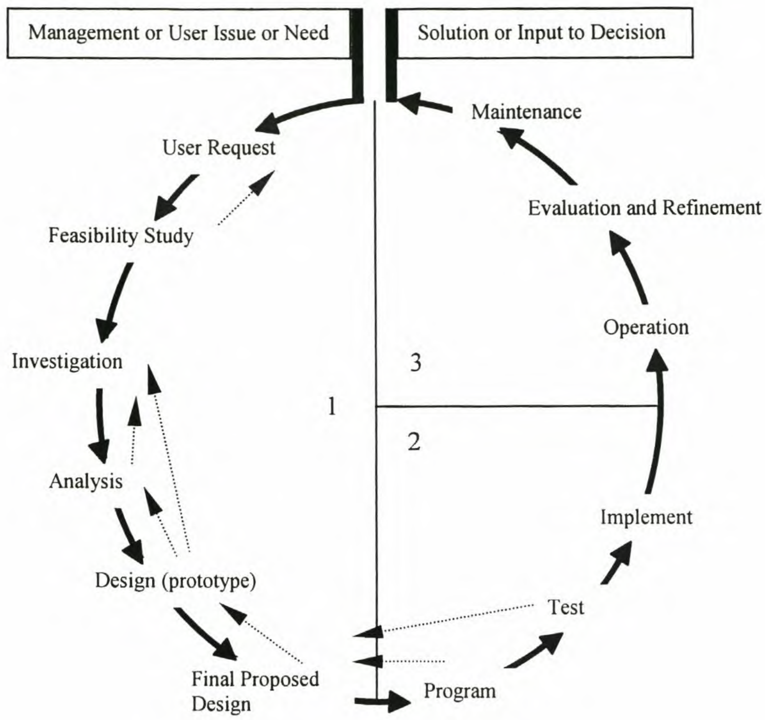

Figure 4.1: Systems Life Cycle - Stage 1: study and design, Stage 2: implementation, Stage 3: operation (Dearnley and Mayhew (1983) modified)

An enforced change or discovery of shortcomings in any one step may result in a loop back to another step. Some of the questions that should be posed during this iterative procedure are listed below, modified from Shepherd (1997). To make the system truly successful and to avoid excessive revisiting of the System Life Cycle steps, the answers to a majority of the following questions should be positive.

For the user: Does the system

- help the user to be actively involved rather than be a passive observer,
- help to improve and refine the user's skills,
- focus on the user's needs,
- let the user carry out practice as usual,
- improve the quality of the user's operating decisions?

General system: Does the system

- provide reliable decision support,
- improve the efficiency of decision making,
- provide trustworthy advice,
- promote positive innovation in the work place,
- incorporate good teaching tools,
- incorporate good learning tools,
- function as a tool for regular use,
- provide useful feedback,
- allow flexibility?

4.1.2 Implementing Past Experience for this Study

For this project, a number of the basic system components had already been outlined in the project proposal. To gain insight into how these components would best be linked, operated and displayed, a questionnaire was distributed to potential users and those with valuable knowledge in the relevant fields. A prototype was then developed based on decisions made regarding software, methods of integration and technical feedback from the questionnaires. The prototype was then demonstrated at a series of interviews and demonstrations where further feedback was recorded and further software adjustments were made.

Finally, a comprehensive demonstration of the near-final WQIS was undertaken for a Steering Committee for this project, comprising persons in management or scientific roles. Their comments and requests were incorporated to produce a final version of the WQIS.

4.2 METHODS FOLLOWED IN WQIS

The steps taken as part of the participative approach to the design and development of the WQIS in this project are discussed in detail in the following sections.

4.2.1 Questionnaires

A questionnaire was drawn up and distributed (see address list and sample Questionnaire in Appendix A) to a number of knowledgeable persons who could provide valuable input and have experience in any of the following project related fields: management of water quality, planning of water resources, model/software development, model/software use. The questionnaire outlines the research project and stipulates the intention and aims of the WQIS. The questions were divided into five sections, namely:

- ***Water Quality River Hydrodynamics Model***: to determine the best method to display information and what indices and statistics are generally required for river management decision support.
- ***Water Quality Reservoir Hydrodynamics Model***: to determine the best method to display information and what indices and statistics are generally required for reservoir management decision support.
- ***Soils Information***: to ascertain which soils coverages would be most useful to display and use in river management decisions.
- ***General***: to develop an understanding of the general attitude towards information systems and simulation models, where they are applicable and how to enhance their usefulness.
- ***Computing Skills***: to determine the general level of computer literacy among target audience.

The time spent on the questionnaires by those who responded (approximately 50%) is much appreciated and the replies provided valuable input and guidelines for the development of the information system.

The information provided in each response varied according to the particular area of interest of the respondent. However, the general agreement concerning water quality modelling in rivers was that a short time step, preferably daily (dependent on data constraints and monitoring programmes), would best provide the information required to highlight and manage point and non-point pollution sources. The water quality information (concentrations and loads) should be displayed in time series (compare time frames), spatial graphs (compare river reaches) and box and whisker plots for a statistical overview of the catchment.

4.2.2 Interviews

The aim of the interviews was to speak to a broad spectrum of "water managers" with operational, water quality, planning or decision support interests as listed in Table 4.1.

Table 4.1: Organisations and Representatives Visited

Organisation	**Representatives**
Cape Metropolitan Council	Mark O'Bree, Brian Nicolson, Ezelle Nel, Charles Young (Southern GIS)
Dept. of Agriculture, Elsenberg	Spine van Niekerk, Francois Knight, Ryk Taljaard
WAM Software Solutions	Willem Botes
DWAF, Pretoria	Pieter Viljoen, Geert Grobler Brendon Wolff-Piggott (with input from Malcolm Watson)
DWAF, Belville	Gerrit van Zyl, Bertrand van Zyl, Willie Enright, Gareth McKonkey, Ben du Plessis, John Roberts
Ninham Shand	Hans Beuster, André Greyling
University of Stellenbosch, Department of Geography and Environmental Studies	Adriaan van Niekerk
University of Stellenbosch, Department of Civil Engineering	Prof. André Görgens

A prototype of the WQIS was used during the interviews to facilitate discussion and stimulate suggestions and modifications necessary to enhance the WQIS within the project limits. Each interviewee was asked to comment on a number of specific issues and also to provide feedback on personal preferences. The specific issues included:

- Display environment
- Graphical display format and content,
- Input and output resolution,
- Simulation model output representation.

The prototype version of the WQIS is described in detail in Chapter 7. It was designed to incorporate the general concepts outlined in the original proposal for this research to the Water Research Commission and the responses obtained to the questionnaires. The prototype aimed at giving the interviewees an idea of what was envisaged from the WQIS and also provided an opportunity for them to challenge or agree with the processes, concepts and specifications used in the WQIS.

4.2.3 Responding to Steering Committee Comments

As indicated earlier in Section 4.1.2, once the comments from the interviews and questionnaires had been collated and implemented in the prototype, a near-final version of the WQIS was demonstrated to the Steering Committee for this project. The members of the committee had further comments and suggestions, some of which were implemented and are discussed in the description of the WQIS in Chapter 7 and in Chapter 9, which deals with scenario analysis.

Other issues such as the future connectivity of WQIS to a Watershed Data Management file system (WDM) developed by the US Geological Survey (Lumb *et al*., 1988) and the need for further research into more detailed water quality constituent modelling, are discussed in the Chapter 10 in the section on future research. These issues were considered outside the scope of this thesis but will be researched as part of the ongoing WRC project.

4.3 DISCUSSION

The prototype demonstrations and accompanying discussions provided valuable insight into the preferences and expectations of those most likely to use, or manage the use of, the WQIS. These preferences and expectations are discussed under headings dealing with overall display and presentation, level and resolution of the information, and the purpose of the information system.

4.3.1 General display and presentation

There was some concern that information systems are too often written by technical experts for users with technical competency. As a result, the graphics, tools and language used in the applications are too technical and clinical. Screens with many buttons and toolbars might be somewhat alienating. An alternative would be to provide a much simpler interface where the user is guided from a main menu, through a series of screens by clicking one of very few, larger buttons on the screen. This approach is used for public participation exercises with non-technical persons.

The prototype falls primarily into the first category and, on the assumption that potential users would be highly computer literate, uses Windows type menus and toolbars and a fairly standard GIS interface. However, a few screens were developed to represent and test the interest in the less technical approach.

These two options were presented at each interview and, in all but one case, the more technical approach was preferred. The reasoning behind these decisions was that, in most cases, the users of the WQIS would be computer literate and would therefore be familiar with the Windows environment. The procedure of moving through screens would be intuitive and would not require large ‘leading’ buttons.

It was agreed that the simpler interface had merits as a display or discussion tool, to be used in meetings with community Forums for conveying summarised technical information in a simplified and more understandable format.

4.3.2 Level and resolution of data and information required

It was agreed that information and data should be available at multiple levels, i.e. raw data through to processed statistics. This builds confidence and trust in the information presented by the WQIS and therefore offers the potential for wider and more appropriate application.

The results of statistical analysis are often presented without a description of the methods used for calculating them. This could lead to scepticism or misuse of the results. If the raw data is supplied, the users may perform their own statistical analyses to verify the results and satisfy their mistrust. In addition, if the results are explained fully, or "de-mystified", as one interviewee put it (O'Bree, 1999), there is no need for double-checking, and the results become dependable and useful for decision-making.

The purpose of the WQIS dictates the level and resolution of input and output information required. If the WQIS is being used for day-to-day operational management of the river or reservoir system, then reliable, measured data is necessary, usually at a fine resolution (daily). However, if the WQIS is being used for long-term planning such as statutory or water allocation decisions, a more broad-brush approach is required. Here, several months, or even years, of data can be summarised to extract trends, long-term averages, minimums and maximums.

4.3.3 Identifying the Purpose of the WQIS

The purpose of the WQIS prescribes the relevant models required for integration into the WQIS. From the discussions it became clear that most managers and operators are concerned with the day-to-day operational management of rivers, or with responses to water quality changes. Their primary focus is short-term decision support and management of urgent situations such as water quality spills, irrigation releases or flood management. Therefore, simulation models with short setup and run times would be required to produce the necessary decision support results. This analysis is discussed in Chapter 9.

Chapter Five

INFORMATION SYSTEM INTEGRATION

According to the research objectives described in Section 1.3 of Chapter 1, the overall configuration of the information system required by this project, necessitated the integration of various simulation models to investigate the management of processes in main stem river systems and impoundments. These models would be required to transfer information to and from a database and operate within a graphical and spatial display environment. A Geographical Information System (GIS) offers a suitable environment for handling and displaying the information and data.

Integration, as mentioned in Chapter 4, refers to the linkage and communication between the components of the system. The process of integration is discussed in this chapter, as are the characteristics of a GIS and the benefits of its inclusion in the current information system.

In Chapter 6, some existing applications with integrated GIS components are investigated and discussed in terms of their relevance in the context of the current project. The simulation models, GIS and interface environment of the WQIS are described in Chapter 7.

5.1 INTEGRATION

Integration describes the method by which all the system components are joined, including how each component interacts with each other and the interface environment. The integration of simulation and analytical models has been a common way to combine the individual functionalities of two or more systems (Lilburne *et al.*, 1997). Modellers can take advantage of extended functionality by integrating analytical, graphical, spatial and simulation tools in one of two general approaches: *loose or tight coupling*.

Coupling (or linking) suggests the extent to which the components are integrated within the information system. Loosely coupled modelling is primarily for taking advantage of database and visualisation tools, which can be improved by capitalising on analytical tools and techniques. The GUI and interface software is used to construct input files that a simulation program can read and the results of the simulation are then read back into the GUI for display and analysis (Bennett, 1997). Tightly coupled models are completely encapsulated within the interface environment and take full advantage of its analysis capabilities (Karimi and Houston, 1996). Once integrated, the information system then offers a virtual environment within which decision-makers and scientists can explore the interaction of simulated processes and evaluate competing management strategies (Bennett, 1997).

The way in which simulation models exchange input and output may also vary. Models can be integrated either in series or in parallel. Parallel linking is fairly complex and involves using the output from one model as input to another, in the same time step. This method would be appropriate when "real-time" exchange of data is required. However, the simpler and more common method of integrating simulation models is in series which involves allowing the first model to complete a run and then using its output as input for the next model (Jewitt, 1998).

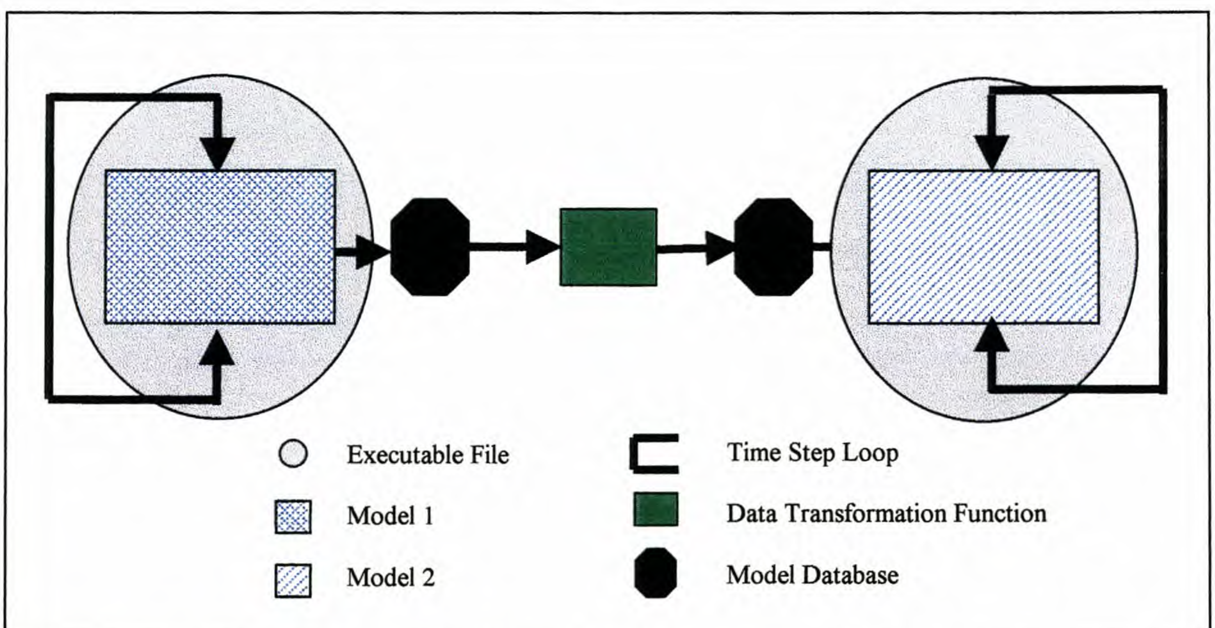

Figure 5.1: Linking models in series (after Jewitt (1998)).

For this project, the loose coupling approach, as illustrated in Figure 5.1, was adopted which enables the user to view and analyse the simulation model output, graphically and spatially, using the functionality provided by the interface environment and incorporated GIS. Originally, the simulation models were designed to operate in series, but due to output and input constraints, this information exchange was adjusted. Each item on the initial component list of the final section of Chapter 1 is discussed in this chapter. The problems encountered and necessary adjustments required due to programming difficulties and user preference are discussed in Chapter 8.

5.2 INITIAL SIMULATION MODEL SELECTION

As stated in Chapter 1, one of the primary objectives of this study was to combine various, existing models within a consistent, user-friendly environment. The aim of creating this tool was to satisfy as many as possible of the technical user's or water manager's information and modelling needs, using the Berg River as a case study.

Most of South Africa's regulated river systems are operated on a time resolution of days to weeks, i.e. distinctly sub-monthly. Some of these systems have relatively high gradients and shallow soils which result in fast runoff response to rainfall and unsteady flows during the wet season. The models currently used for water resource planning in South Africa operate primarily on a monthly time step, assume steady flow and do not satisfy the water quality simulation requirements of the aforementioned objectives (BKS and SSO, 1988). The daily models in use cater only for the salinity component of water quality (DWAF, 1990) and because of their requirement to be intensively calibrated, may be seen to be too site-specific.

It was therefore clear that typical South African rivers, of which the Berg River is no exception, require simulation models that adhere to numerous criteria:

- The information system should operate at a daily or sub-daily time-step.
- The information system should cater for river flow hydrodynamics and simulate a range of water quality processes such as salt and nutrient transport, eutrophication and temperature and oxygen variation. A range of water quality guidelines (DWAF, 1996) should also be provided to check water quality compliance of the output of this multi-constituent model for particular management scenarios.
- Simulation of reservoir hydrodynamics and stratification.
- The information system should provide a uniform, user-friendly interface that would allow interactive access to a range of catchment data and physical characteristics. These

would include historical water quality data and flow time series and extra quality data collected under this project, cross sections, photographs, landuse, soils information, monitoring sites, infrastructure and climate.

- The information system should be easily transferable and affordable.

The reasoning behind the selection of the simulation models for this study is outlined in the following sections.

5.2.1 River Model

In a parallel study (Nitsche, 2000), various models were considered for inclusion into the over-riding WRC project and were compared on the basis of their dimensional characteristics, hydraulics, equations used, numerical solution, water quality transport and variables supported, cost, availability, user-friendliness and user support facilities. Some of the models considered were:

- MIKE-11 (DHI, 1992),
- ISIS (HR Wallingford, 1997),
- WQRRS (Hydrologic Engineering Centre, 1978),
- CE-QUAL-RIV1 (Environmental Laboratory, 1995),
- QUAL2E (Brown and Barnwell, 1992),
- WASP (Ambrose *et al.*, 1993) and
- DUFLOW (STOWA/EDS, 1998).

DUFLOW was selected for its good user support, sound modelling principles and cost effectiveness (Nitsche, 2000). DUFLOW is under the joint ownership of the Faculty of Civil Engineering at Delft University of Technology and the Public Works Department (Rijkswaterstaat), International Institute for Hydraulic and Environmental Engineering (IHE), the Delft University of Technology, the Agricultural University of Wageningen and STOWA. The DUFLOW (STOWA/EDS, 1998) Modelling Studio (DMS) includes three components, namely:

- DUFLOW, the water quantity and water quality model that performs unsteady flow computations in networks of open water courses. It is also useful for simulating the transportation of substances in free surface flow and more complex water quality processes. DUFLOW incorporates two predefined water quality models, EUTROF1 and EUTROF2.
- RAM, the precipitation runoff module that calculates the supply of rainfall to the surface flow by calculating the losses and delays that occur before the precipitation reaches the surface flow.
- MODUFLOW, which simulates an integrated ground and surface water problem by combining the ground water model, Modflow and DUFLOW.

For this study, only the DUFLOW component was activated.

DUFLOW has a Network Editor, which is a graphical editor that enables the user to create new model set-ups in a user-friendly way. Also available is the Scenario Manager that enables the user to set up and compare the results of different scenario runs.

The water quality processes are modelled in special subroutines that allow problem specific processes to be supplied by the user. The flow model is one-dimensional and uses the St Venant equations with numerical solutions to calculate the flow. EUTROF1 includes the cycling of nitrogen, phosphorous and oxygen, as well as the growth of one phytoplankton species. EUTROF2 includes sediment-water interaction and kinetics for three algae species.

5.2.2 Reservoir Model

For the reservoir simulation, a hydrodynamic model was required that could model density stratification and consequent water quality profiles in the impoundment. Two models were considered suitable for this purpose - the water quality version of the daily model 1D-DYRESM (Centre for Water Research, 1992) and CE-QUAL-W2 (Cole and Buckak, 1995).

DYRESM was developed as a one dimensional simulation model of the vertical distribution of temperature and salinity in small to medium size lakes and reservoirs. The assumption of one dimensionality presumes that variations in the lateral direction are small in comparison to those in the vertical direction. DYRESM operates on a DOS based platform and the output results are written in a binary format. This appeared to defeat the aim of producing a Windows based information system, using the latest object oriented programming. The Windows version of DYRESM is due to be released in the near future but the time constraints of the current project did not afford the luxury of waiting for the new version which may still need to be tested and debugged.

CE-QUAL-W2 is a two-dimensional, laterally averaged hydrodynamic and water quality simulation model and was developed by the United States Corps of Engineers. Two-dimensionality is essential to model reservoirs in South Africa, and particularly in the Western Cape, as they are frequently constructed in narrow river valleys and therefore demonstrate significant longitudinal variation. The CE-QUAL-W2 model has been specifically developed for the simulation of hydrodynamics and water quality in rivers, reservoirs and estuaries and is able to predict temperature and constituent profiles in a vertical as well as a longitudinal direction. The model, although also DOS based, has a commercially available, user-friendly Windows based interface with simple buttons and menu commands for quickly building the required input files for a new reservoir simulation. The model is freely available and there also appears to be on-going support and development by the model originators (Wells, 2000).

On the basis of this comparison, CE-QUAL-W2 was accepted as the simulation model for inclusion into information system.

The model's hydrodynamic capabilities include the prediction of surface elevation, velocity and temperature (due to its effect on water density). The water quality component consists of an algorithm that includes 21 constituents. It is modular in design, to allow further constituents to be included as additional subroutines.

The model configuration, input and output are described in a report presented to the WRC Steering Committee for this project (Kamish, 2000).

5.3 GEOGRAPHICAL INFORMATION SYSTEMS

A Geographical Information System can be defined as a computer-enhanced information system that aids decision-making by referencing data to spatial or geographical co-ordinates (Schoolmaster and Marr, 1992). The Environmental Systems Research Institute (ESRI) defines a GIS as "a computer-based tool for mapping and analysing things that exist and events that happen on earth".

GIS were initially developed for functions such as simple mapping and computerised cartography. Further enhancements have provided GIS with greater capability and the ability to store and manipulate large volumes of spatial and associated data and to present this data in summarised and analysed form in a useable and accessible way. According to ESRI, GIS technology integrates common database operations such as query and statistical analysis with the unique visualisation and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make them valuable to a wide range of public and private enterprises as a decision support for explaining events, predicting outcomes, and planning strategies.

Until recently, the analysis, storage, organisation and presentation of spatial data have been the primary functions of a GIS, but the rapid development of the object orientated programming genre and associated GIS components have broadened the capabilities of the GIS. Barandela (1997), suggests that to fulfil GIS's potential as a suitable aid to environmental monitoring, the introduction of knowledge-based concepts and methods into GIS software should be encouraged, as well as improved integration with other techniques such as river and reservoir simulation and washoff models.

It has become increasingly viable to create organised databases, manipulate the data using various models which can be accessed through a simple Graphical User Interface (GUI) and then to present the updated information or results graphically, or in tabular form, using customised interfaces and components. According to Karimi and Houston (1996), using GIS as part of an environmental modelling framework allows modellers to use databases, data visualisation, and analytical tools in a single integrated environment.

5.3.1 Benefits of GIS for model results/display

A GIS provides the potential for powerful geographical analyses and interpretation of data (e.g. hydrological) in a spatial context (Cobban and Silberbauer, 1993). Most information can be related to a spatial index in some way (Mingins, 1996) and the amount or type of information that is required is not limited. Huge databases can be attached to points on a 'map' which, when recalled, can display a wealth of information, thereby turning facts and figures stored in a database into an informative summary of data linked to a geographical reference point (Mingins, 1996).

5.3.2 Decision to use a GIS

As discussed previously, once linked to simulation models and analytical tools, a GIS has the potential to provide focused information in terms of which operational, planning and management decisions can be made. Once it is established that GIS can add value to an information system, the correct level of complexity and integration must be found. Certain applications may provide too much information or complexity, which in turn leads to misuse and frustration. On the other hand, an oversimplified system may not provide the required technical focus on reliability of output.

The need for, and requirements of, the system should be well researched to ensure that the product achieves what is expected and is not just "window dressing". The temptation is often to add all the extra features, which generally do not enhance the basic operation of the system and, in many cases, slow down processing and hamper the efficient output of results. If the environment where the system is to be used is well researched and the exact needs are identified, the integrated GIS can prove to be an asset.

Once it is established that GIS is a necessary component of the system, the choice of which product to use, needs to be made. There are numerous software products available and those considered for this project are discussed in the following section.

5.3.3 Product Comparison

There are numerous GIS products available on the market, each with their own specific features, functionality and merits. To narrow the comparison down and because of the general use among the government departments in South Africa, ESRI products were considered a good standard to commit to.

Within the ESRI suite of products there is also a wide range of useful products to choose from. Each product requires a different level of user proficiency, training, hardware, integration etc. Some of the products considered relevant to this project are discussed below.

ARCVIEW: ARCVIEW is a powerful tool that provides the power to visualise, explore, query and analyse data spatially. The user may also manipulate and update spatial data. However, the product is costly and may only be used by a single user, as a software key is required at all times. Operators also require training to be proficient in using all the functionality offered by the product (ESRI, 1996a).
Approximate Cost: R8500 (excluding VAT)

ArcExplorer: ArcExplorer is data-exploration package and provides powerful display and query tools. It also features drag-and-drop ease of use, legends, overview maps and multiple views. It can save and retrieve views and print maps. This software uses data in the industry standard shapefile format. ArcExplorer is free, simple to use, intuitive and a powerful tool for Web data viewing. This product, however, has limited functionality and cannot be used to update or manipulate spatial data (ESRI, 1996d).
Approximate Cost: May be downloaded free from the ESRI site on the Internet.

MapObjects: MapObjects is a set of mapping software components that allows programmers to add maps to applications they have developed. It is not a product for end-users and should be applied within industry standard programming environments such as Visual Basic, Delphi, PowerBuilder, Microsoft Access and others. MapObjects is suitable for applying many basic mapping functions but does not perform advanced functions such as high-quality cartographic output, projections of mapping co-ordinate systems, sophisticated spatial analysis or topological editing. MapObjects has the advantage that a relatively inexperienced programmer is able to deliver robust and useful programs in which the map may be either an incidental or central feature of the application. MapObjects consumes only modest amounts of memory and more often than not, can draw maps quicker than most other Windows-based mapping software. MapObjects offers the developer great flexibility in building and customising user interfaces and can be used in Internet applications. Applications written using MapObjects can be easily transferred to other users without extra hardware requirements such as a dongle. The drawback of using MapObjects is that it requires the user to have some object-oriented programming experience and must be incorporated into a programming environment, i.e. it cannot be installed and used off the shelf. Applications developed with MapObjects may only be distributed under licence (ESRI, 1996b).

Approximate Cost: R10 000 incl. 5 licences

MapObjects Lt: This is a lightweight version of MapObjects, which provides application developers with the tools to build lightweight data viewing applications or to create new mapping programs to solve specific problems. It is similar to the full version of MapObjects, but not as costly and applications written in MapObjects Lt may be distributed without licence. However, it also requires the user to have some object-oriented programming experience and must be incorporated into a programming environment. Some of the functionality offered by MapObjects is reduced in this version and it cannot be used in Internet applications (ESRI, 1996c).

Approximate Cost: R5 000

For this project, a GIS with limited capability was required to display general orientation information and access results linked to spatial locations. Advanced spatial analysis tools were not required as the bulk of the data and information analysis would be performed by the interface environment. The GIS needed to be easily portable/transferable and easy to use. The full version of MapObjects was therefore chosen to serve the GIS function.

According to van Rensburg and Dent (1997), GIS layers are fundamental requirements of any water resources analysis in which land use is critical to the generation of runoff, as is the use and abuse of water. For this purpose and for general catchment orientation and understanding, the GIS associated with this WQIS, consists of a predefined set of spatial layers containing relevant, catchment information. These are described in detail in Chapter 7.

5.4 INTERFACE ENVIRONMENT

Historically, many simulation and analysis models have been developed using traditional, DOS based programming languages such as FORTRAN and Pascal. Subsequently, a need has arisen for more sophisticated and visual pre- and post-processors and even total development environments for these models to facilitate the input, output and display functions. With the introduction of the object-oriented genre of programming languages, the rapid development of these processors has been made relatively easy.

Visual Basic and Delphi are two such object-oriented programming languages which offer very similar functionality and capabilities. The differences are only in their technical structure. The decision of which one to use is usually down to personal preference.

The author was familiar with Delphi and in particular, applications that included MapObjects in their functionality. Therefore, Delphi was selected as the programming environment to use for the development of the GUI, all the relevant interfaces, analytical and graphing functionality.

Delphi (Borland, 1997) is an object-oriented, visual, component based development environment for rapid application development (RAD) and database development of anything from general purpose utilities to sophisticated data access programs. Using Delphi, the developer can create highly efficient Microsoft Windows applications with a minimum of manual coding. Delphi is a visual programming language, based on Pascal, which allows the user to select visual components from a palette and drop them into a window or form. Delphi then generates the supporting code for the component. It is also an ideal tool for developing database applications that communicate with various local or remote databases, e.g. Paradox, dBASE, ODBC tables. A key attribute that sets Delphi apart from other similar programming languages is a concept known as "inheritance", which allows the user to extend any standard to components to suit any requirements. Delphi also supports ActiveX components and Internet development.

Using MapObjects within Delphi allowed the development of the appropriate level of spatial capability combined with efficient database access and graphing facilities.

5.5 DATABASE

The decision of which database structure/tables to use was all but prescribed by the choice of the GIS component. MapObjects uses spatial layers, called shapefiles, which are the standard ESRI layer format. These shapefiles store the layer attributes in dBASE tables (i.e. with a 'dbf' file extension) and therefore for ease of information transfer dBASE was selected as the preferred choice of database for the storage and access of information and data.

5.6 DISCUSSION

The choice of which components to integrate in to the Information System is a complex task as the requirements of the various users may vary considerably. Each component, be it a simulation model or a GIS, is included for its specific features or functionality. However, this may, for example, be at the expense of software platform compatibility or portability. To overcome or eliminate some of these concerns, each component should be well researched before it is considered for integration, and the Information System should be designed to be as generic as possible to allow the inclusion or removal of components at a later stage to accommodate any required functionality adjustments. Chapter 8 examines some of the problems encountered when integrating the river and reservoir models into the WQIS.

Chapter Six

WATER QUALITY INFORMATION SYSTEMS

Catchment models are used to simulate water quantity and quality in order to examine the outcomes of scenarios of changes in land use, land-use management practices, and water-management operations. Analysing and managing the high volumes of input and output of complex river and catchment models is a major task. Various models have been developed to deal with the task of managing a river catchment and storing and displaying its sizeable input and output in an integrated system. Individual models have their own unique focus, strengths and weaknesses. Some of the currently available models that also incorporate GIS are described below and are discussed in terms of their relevance to this study. The Water Quality Information System (WQIS) developed for this project is described in Chapter 7.

6.1 EXISTING WATER QUALITY RELATED DECISION SUPPORT INFORMATION SYSTEMS

There are numerous water quality information systems available, each with its own merits. To narrow the selection and provide a good base for comparison, only the water quality models that have been developed with a GIS component were chosen for discussion and comparison.

6.1.1 ICIS (Jewitt, 1998)

The integrated catchment information system (ICIS) is a prototype software system designed to assist the meaningful participation of stakeholders in integrated river management. It aims to provide a tool that facilitates productive and effective stakeholder involvement and communication in a process that:

- is regular, affordable and meaningful
- is flexible and iterative
- increasingly reveals more information on the river system dynamics

- is open and transparent
- leads to adaptive and generative management
- will incorporate and reflect the inputs of all stakeholders
- will involve a form of integrated systems simulation modelling which can function in a data poor environment
- overcomes the barriers to communication between stakeholders which arise from geographic & disciplinary separation.

The ICIS system provides a framework of tools to assess impacts of change in a catchment in a spatial context. The system also aims to provide a management tool that can be used to compare different catchment development scenarios. It combines GIS technology with simulation and evaluation tools and provides a decision support system by making use of ARCVIEW and a range of other software (Jewitt, 1998).

ICIS consists of the following sub-systems that interact by exchanging data and information:

- Graphical User Interface,
- System manager,
- GIS functions,
- Display tools,
- Predictive and simulation tools (hydrological, ecological, geomorphological),
- Computerised database,
- Access to a range of pictorial images of river reaches,
- Display and analysis of a range of geomorphological features,
- Windows based tools to link to remote databases.

Using these remote or host databases and simulation tools ensures each remote user is looking at the same version of a simulated output scenario. This information is created through sophisticated simulation modelling at a powerful central computing site.

6.1.2 BASINS 2.0 (Lahlou *et al.*, 1999)

Better **A**ssessment **S**cience **I**ntegrating Point and **N**onpoint **S**ources (BASINS) is a system developed to meet the needs of environmental agencies, particularly in the USA. These agencies are increasingly emphasising catchment and water quality-based assessment and integrated analysis of point and nonpoint sources of pollution. The BASINS model was therefore developed to integrate a GIS, catchment data, and environmental assessment and modelling tools into one convenient package. BASINS concentrates on three key aspects:

- To facilitate the analysis of environmental information.
- To provide an integrated catchment and modelling framework.
- To support analysis of point and nonpoint source management scenarios.

BASINS supports the development of total maximum daily loads, which require a catchment-based approach that integrates both point and nonpoint sources. The model supports the investigation of a variety of pollutants at multiple scales, using a range of simple and sophisticated tools.

The BASINS system is designed to make catchment and water quality studies easier by bringing key data and analytical components together "under one roof", thereby attempting to overcome a lack of integration, limited co-ordination, and time-intensive execution typical of more traditional assessment tools.

BASINS consists of a suite of interrelated components essential for performing catchment and water quality analysis. These components are grouped into five categories:

- national environmental databases in the USA,
- assessment tools for evaluating water quality and point source loadings at a variety of scales,
- utilities including local data import, land-use and DEM reclassification, catchment delineation, and management of water quality data,
- catchment and water quality models including NPSM (HSPF) (Donigan *et al.*, 1984), TOXIROUTE , and QUAL2E (Brown and Barnwell, 1992),
- post-processing output tools for interpreting model results.

All databases and assessment tools in BASINS are directly integrated within an ARCVIEW GIS environment. The simulation models run in a Windows environment, using input files generated in ARCVIEW.

6.1.3 GENSCN (Kittle *et al.*, 1998)

GENeration and analysis of model simulation SCeNarios (GenScn), is an interactive computer program that facilitates the catchment management process by the creation of simulation scenarios, analysis and comparison of the scenarios and their results. GenScn provides an interactive framework for analysis built around an established and adaptable catchment model.

The Hydrological Simulation Program--Fortran (HSPF) (Bicknell *et al.*, 1997) is used for simulating the hydrologic and associated water quality processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. The GUI uses standard Windows 9x/NT components, and MapObjects LT (ESRI, 1996b) is used to provide mapping functionality.

The model uses meteorological records in the Watershed Data Management (WDM) (Lumb *et al.* 1988) format for catchment simulation and, if mapping is to be available, GIS data, in the form of digital spatial "maps" that conform to ESRI standards, must be included. Output options include graphical and tabular display of both observed data and simulated results. The output may be viewed interactively or written to files.

6.2 DISCUSSION

All the above decision support packages, although relevant, useful and aiming to achieve a similar goal as the WQIS, have features that are not applicable to the current study or defeat the main objectives. When revisiting the features required by the system as stated in Section 1.5 the above models have certain shortcomings.

All the reviewed models can simulate conditions at a daily time step and adequately describe the river flow and quality conditions using their various hydrodynamic models. However, to describe the impoundments in the river catchment, both BASINS and GenScn use the HSPF simulation model which is incapable of simulating density stratification and water quality profiles in impoundments as required by this project.

In both the ICIS and BASINS models, ARCVIEW is used to provide GIS capabilities and at the current price of around R9000, is not an affordable option for many of the local councils, authorities and DWAF Regional Office who are targeted to benefit most from the development of the WQIS. ARCVIEW also requires considerable computer literacy and training as well as a software lock key for each user which makes distribution difficult. GenScn has many features that would be useful and relevant to this project as it is user-friendly and can be easily installed on any machine without licence or software keys. However, it also uses MapObjects LT, which will limit future Web enablements.

BASINS, and to a lesser extent GenScn and ICIS, require a fairly comprehensive set of supporting databases. The BASINS system includes a variety of databases that are extracted and formatted to facilitate catchment-based analysis and modelling. Four types of data are required for the BASINS analysis system, namely:

- Base cartographic data
- Environmental background data
- Environmental monitoring data
- Point sources/loading data

This data is, however, pertains to catchments in the USA. To apply BASINS to South African catchments, data in the correct format, in all four of the above categories would have to be assembled. This task, even for catchments where monitoring infrastructure is in place, could prove to be an onerous and time-consuming task.

Chapter Seven

WATER QUALITY INFORMATION SYSTEM FOR THE BERG RIVER

As discussed in Chapter 4, a prototype version of the WQIS was developed and aimed at demonstrating a preview of what processes, concepts and specifications were envisaged for inclusion in the WQIS. The prototype is described below, is followed by a detailed description of the WQIS functionality.

7.1 DEVELOPMENT PROTOTYPE

On startup, the prototype presents the user with a standard GIS interface (see Figure 7.1) consisting of

- a Map View area,
- a legend describing the coverages,
- an overview box for orientation and
- a toolbar containing general mapping tools and customised functionality.

General mapping tools were provided, e.g. zoom in, zoom out, pan, zoom to coverage extent, zoom to full extent to allow focus of the spatial data as required. The overview box indicates, using a red rectangle, the area displayed in the Map View in relation to the full extent. The legend allows the users to select spatial coverages to display. Labels of coverage features may be displayed and coverage properties such as colour, style and line thickness may be set using the "properties" button on the tool bar, or the drop-down box activated by right clicking on the legend.

The customised tools are divided into those dealing with the river modelling and those focused on the reservoir modelling. Where possible, this information was linked spatially to points on the map to allow the user to physically locate points of interest or concern. Once these points have been located, the data and model output can be interrogated and used to form an opinion, or make a decision for operational management, planning or interest.

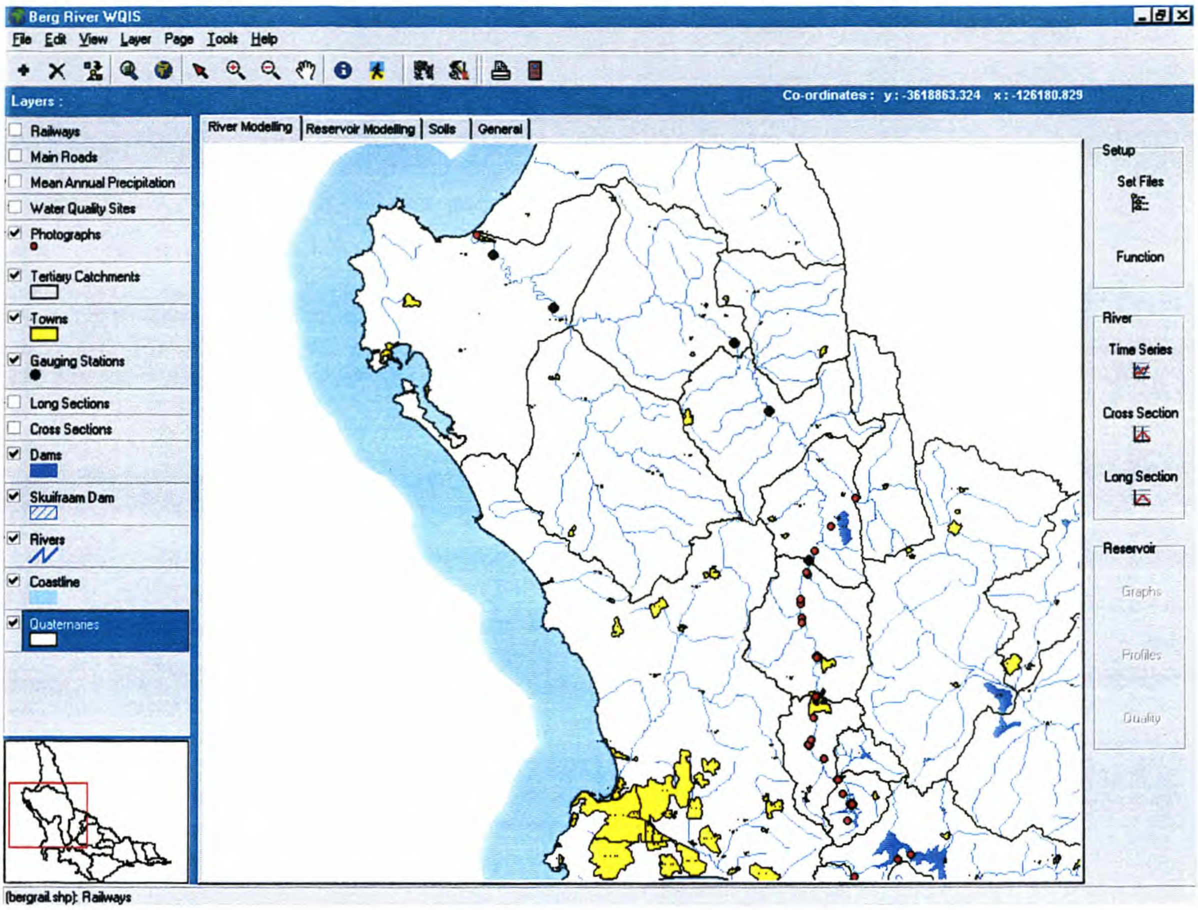

Figure 7.1: WQIS Prototype Main Screen

For the river modelling, various graphing tools have been created,

- time series at a point,
- output variables along a reach for a specified time step,
- box and whisker plots of output variables (Figure 7.2), or
- percentile (duration) curves,
- cross section and long section diagrams (Figures 7.3 and 7.4).

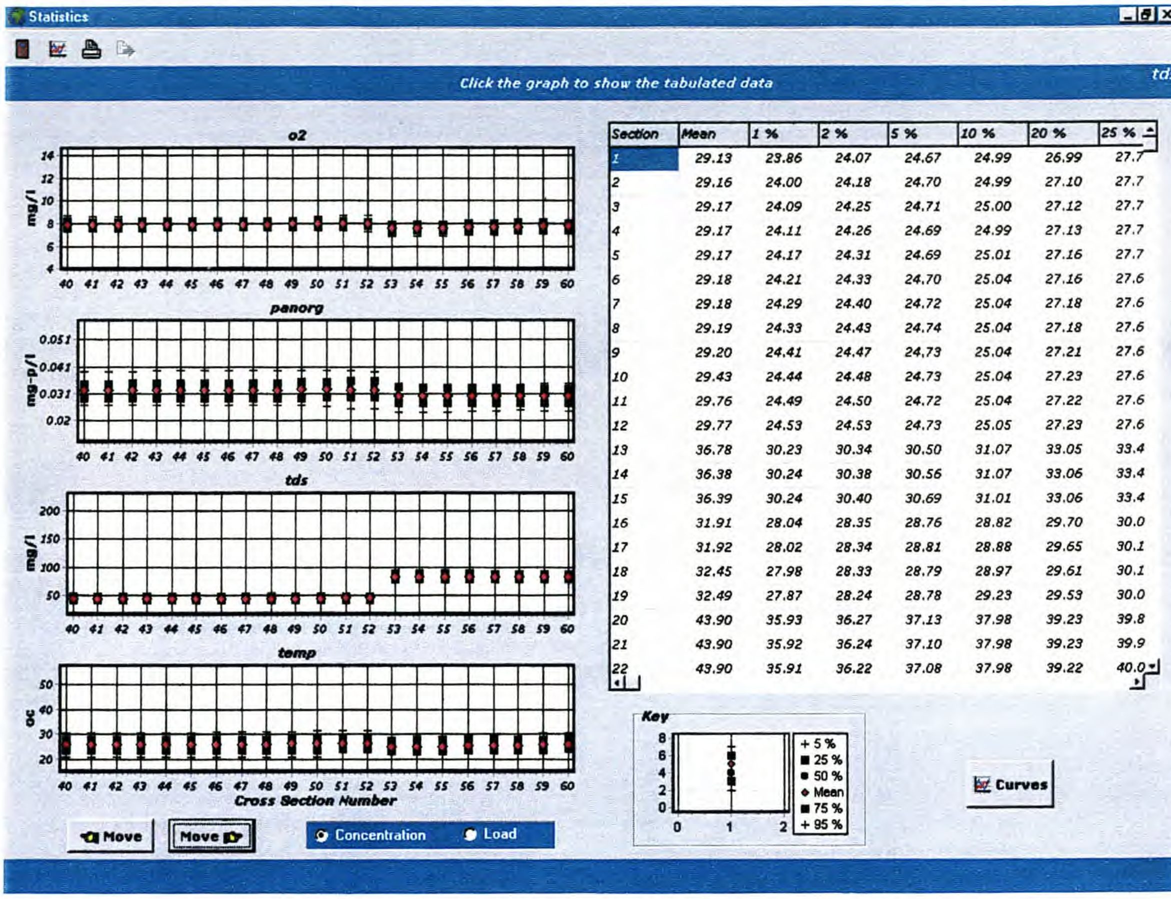

Figure 7.2: Box and Whisker Plots and Percentile Values

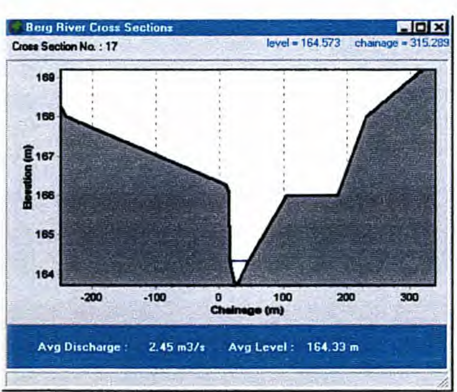

Figure 7.3: Cross Section

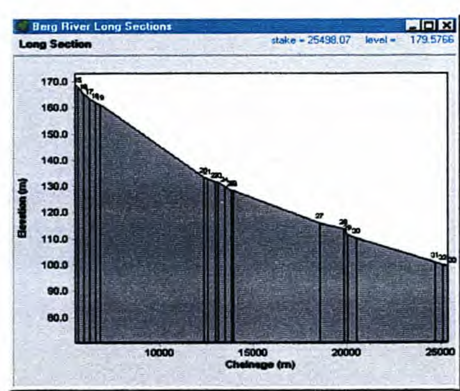

Figure 7.4: Long Section

For the reservoir modelling, sample graphing facilities have been developed (see Figure 7.5), such as:

- a cross section view of the dam showing the concentration of a variable for a time step(s),
- a horizontal view of the dam at a certain depth showing the concentration of a variable for a time step(s) or
- time series plots of various constituents at a point in the dam

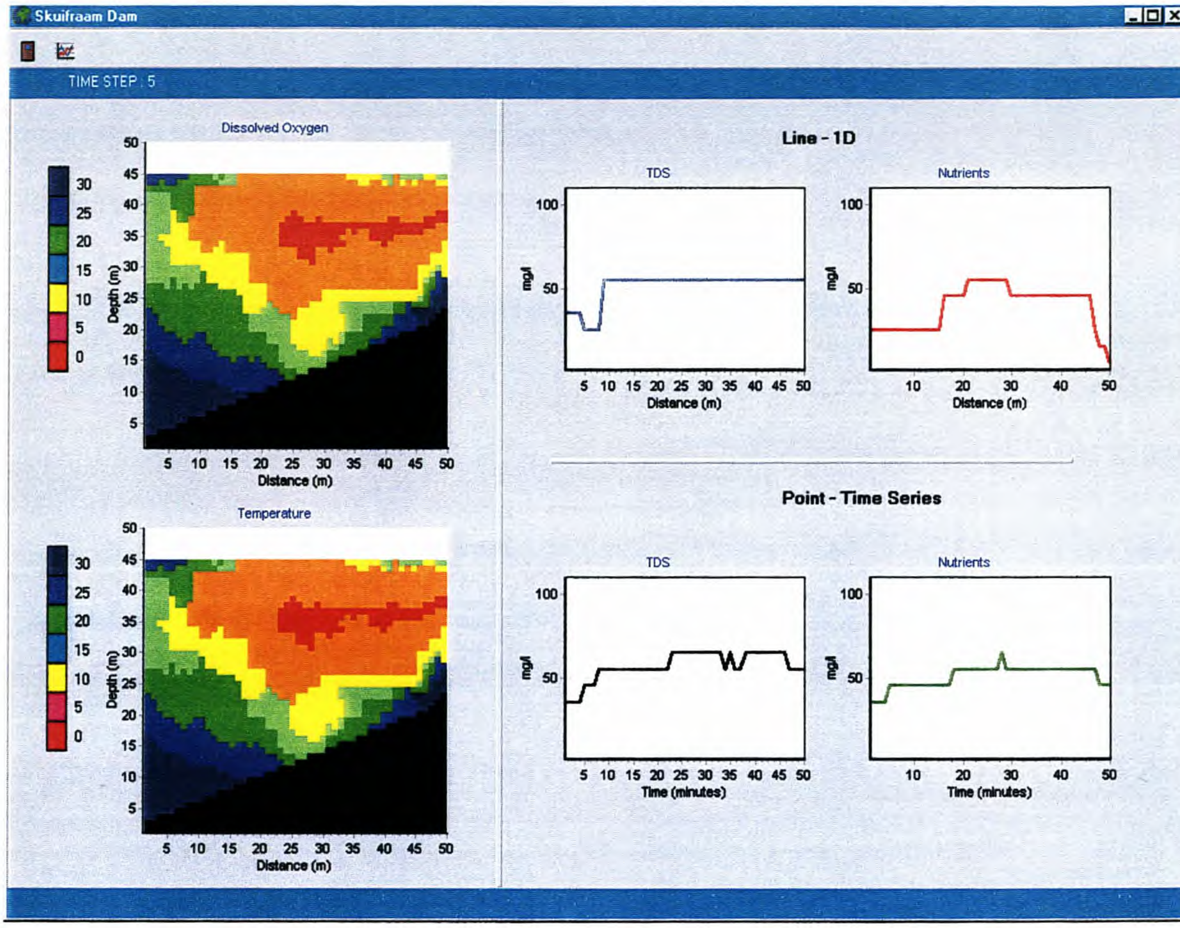

Figure 7.5: Reservoir Sample Graphs

7.2 WATER QUALITY INFORMATION SYSTEM FOR THE BERG RIVER

The WQIS model configuration developed for this project, offers the user access to information in three main categories, namely River, Reservoir and GIS. These are described in Figure 7.6. The reader is encouraged to launch the WQIS demonstration CD that is enclosed and follow the descriptions of the screens that follow in the next sections. A detailed schematic description of the links between, and processes occurring in, the WQIS screens, and printed copies of some the screens, not shown in this chapter are included, for completeness, in Appendix B.

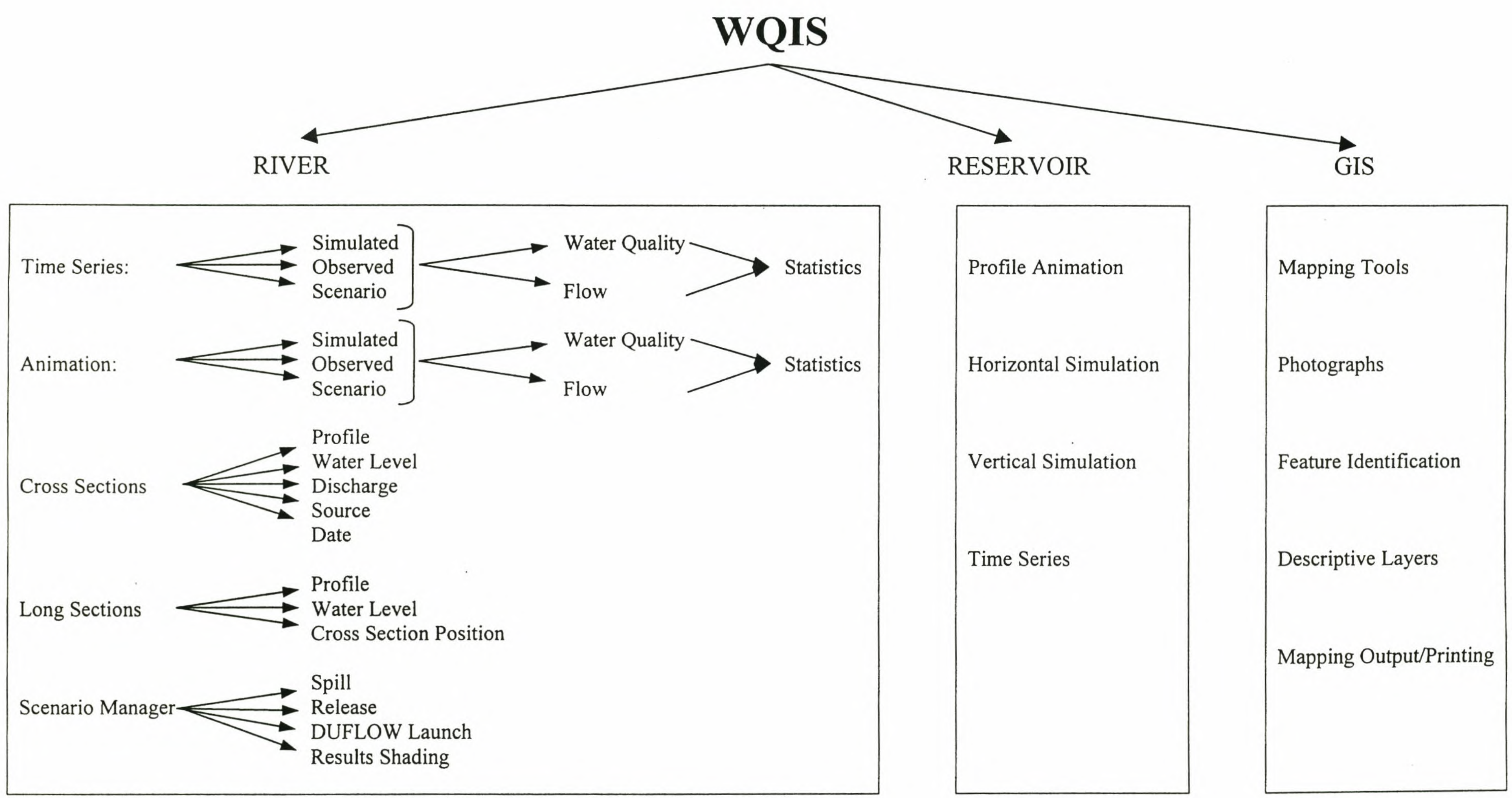

Figure 7.6: Schematic Diagram of the Water Quality Information System

On startup, the Water Quality Information System presents the user with a standard GIS interface consisting of a Map View area, a Legend describing the layers, an Overview Box for orientation and a Tool Bar containing general mapping tools and customised functionality tools. In addition, there are various other buttons on the right-hand panel that provide access to the simulation results. Each model component is discussed in detail in the following sections.

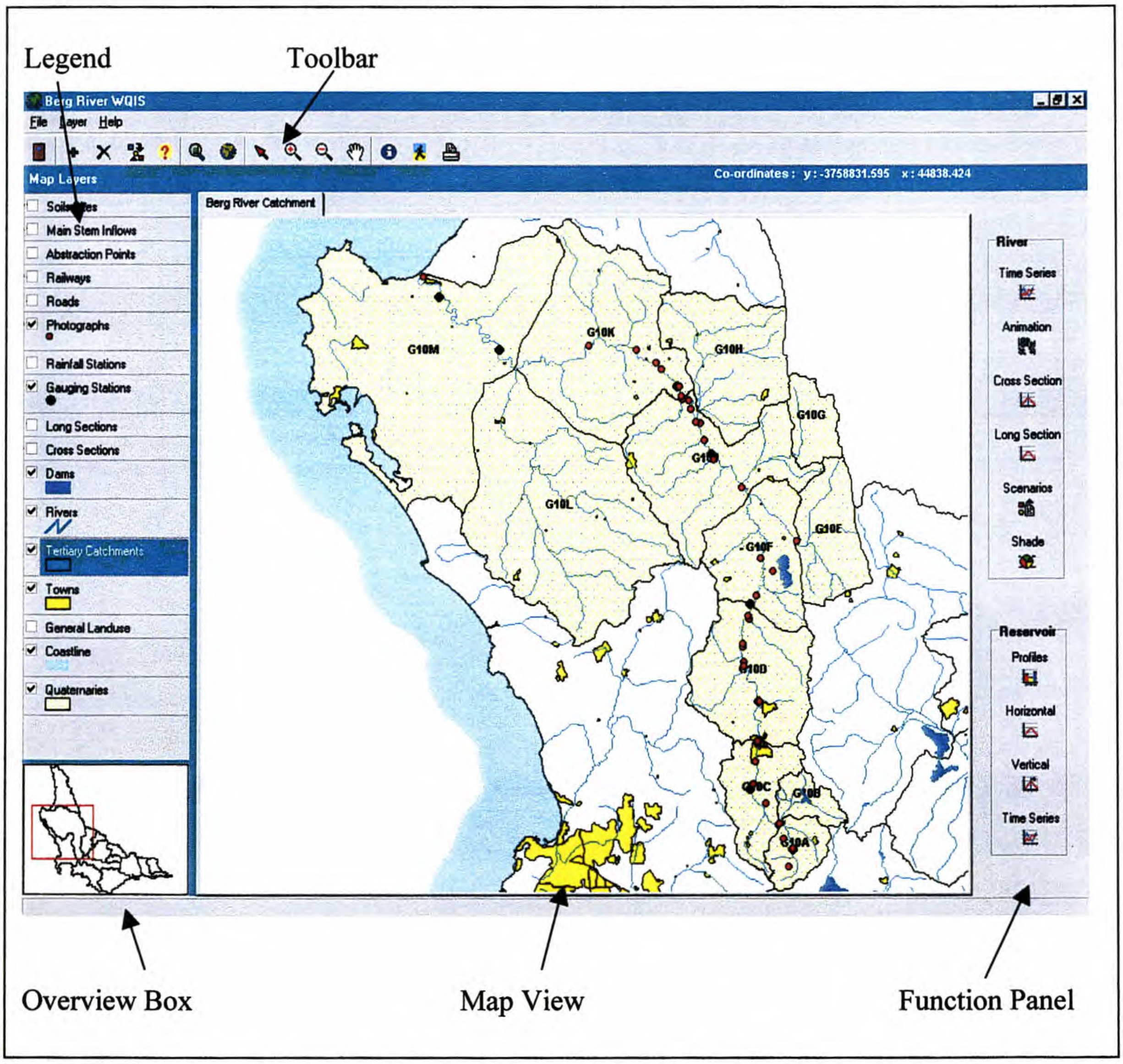

Figure 7.7: Main Screen

7.2.1 Map View

The Map View displays numerous layers that are relevant and aid the decision making process. A list of the included layers and their relevance is shown in Table 7.1 below.

Table 7.1: Layers displayed in the in the Map View

Layer	Type	Reason	Capture Scale
Roads	Line	General orientation	1 : 250 000
Railways	Line		1 : 250 000
Towns	Polygon		1 : 250 000
Quaternary Catchments	Polygon	Hydrological orientation	1 : 250 000
Primary Catchments	Polygon		1 : 250 000
Rivers	Line	Hydrological information	1 : 500 000
Main Dams	Polygon		1 : 250 000
Rainfall Stations	Point	Meteorological information	1 : 250 000
Gauging Stations	Point		1 : 250 000
Cross Sections	Line	Hydraulic information	N/A
Long Sections	Line		N/A
Photograph Sites	Point	Sites of interest – river quality and characteristic comparisons	N/A
Soils	Polygon	Catchment characteristics	1 : 250 000
Land use	Polygon	Catchment development	1 : 250 000
Abstractions	Point		N/A
Inflows	Point		N/A

These layers can be switched on and off as required, depending on the level of detail required in the display (see Legend description). To change the extent of information displayed in the Map View the general mapping tools should be used. The Overview Box indicates, using a red rectangle, the area displayed in the Map View in relation to the full extent.

7.2.2 Legend

The Legend is used to select layers or to access their properties. To switch a layer on or off, the user may click on the small check box to the left of each layer name. By right clicking on a specific layer in the Legend, a drop down property box is activated. The labels of the layer features may be displayed and layer properties such as colour, style, line thickness and gradings may be set using the Property Box. The order of the layers may also be rearranged by dragging the layer name up or down in the Legend while holding down the right mouse button. The Legend reverts to the default settings once the program is closed down.

7.2.3 Toolbar

The toolbar has a selection of general mapping tools that allow the user to specify the extent or focus of the spatial data required.

Figure 7.8: Toolbar buttons (properties, layer extent, full extent, pointer, zoom in, zoom out, pan, information, photograph)

The properties tool activates the Property Box and allows the user to change the attributes of the currently active layer. The zoom in tool allows the user to trace a rectangle in the Map View, to which the Map View is then zoomed. When zooming out, the displayed extent doubles each time the user clicks on the Map View. The layer extent tool changes the display extent to that of the highlighted layer and the full extent tool zooms to the maximum extent of all the layers. The pointer tool allows the user to select specific layer features when using the customised tools.

Additional information tools, specific to WQIS, provide access to project specific information not normally available in 'off-the-shelf' GIS applications. These tools are spatially linked to features of interest in the layers.

- *Identify Tool*: The Identify tool allows the user to click on and identify any spatially represented feature in the Map View. The layer that describes the required feature should be switched on and highlighted in the Legend.

- *Photograph Tool*: A photograph box is activated that shows numerous photographs taken at points of interest down the river, which offer a means of comparing current water levels and river flow and channel conditions with historical conditions.

7.2.4 Function Panel

The Function Panel to the right of the Map View allows the user to connect to the simulation models, read in output information and open results screens. The Function Panel is divided into two sections for River and Reservoir.

River

- *Time Series*: This option enables the user to access the flow or quality time series and statistical analysis of the DUFLOW simulation runs.

- *Animation*: This option enables the user to access the flow or quality spatial simulation and statistical analysis of the DUFLOW results.

- *Cross Section*: Cross Section graph boxes are activated by clicking on the Cross Section tool button and then on the relevant cross section feature in the Map View. The cross section graphs show the cross section profile and the average water level calculated using DUFLOW. The average discharge is provided as additional information below the graph. The date and source of the cross section information is also displayed.

- *Long Section*: The Long Section graph box is also activated by clicking on the interactive map and shows the profile of the river through the lowest points of each cross section. The position of the cross sections and the water level calculated in DUFLOW are also visible.

- *Scenario*: A scenario manager is displayed, which allows the user to choose the event month, spill or release characteristics and then run the DUFLOW model.

- *Shade*: The Berg River layer in the Map View is shaded based on the results of the most current scenario run. A water quality constituent, or river flow condition, as well as the minimum, mean or maximum value should be selected.

Reservoir

- *Profile*: This option displays the two-dimensional graphs of the results of the reservoir analysis for all the modelled constituents.

- *Horizontal*: The variations in time, on a selected horizontal plane, of the concentration of the modelled constituents are displayed.

- *Vertical*: The variations in time, on a selected vertical plane, of the concentration of the modelled constituents are displayed.

- *Time Series*: This option allows the user to view the time series for each modelled constituent for each active cell in the reservoir configuration.

7.2.5 River Model Results Screens

Before entering these screens, the user is required to choose which quality or flow results to view:

- simulated,
- observed, or
- scenario.

If water quality results are required then the necessary Water Quality Target Limits must be set. Four options for water quality user group standards are available, namely, agriculture, domestic, recreation and user defined. The options are provided as guidelines and may be changed by the user on the **Water Quality Limits** screen.

The **Time Series Results** screen has an interactive map showing the Berg River, a set of cross sections and the main channel streamflow gauges for which observed data is available (see Figure 7.9). The standard mapping tools are again available for this map.

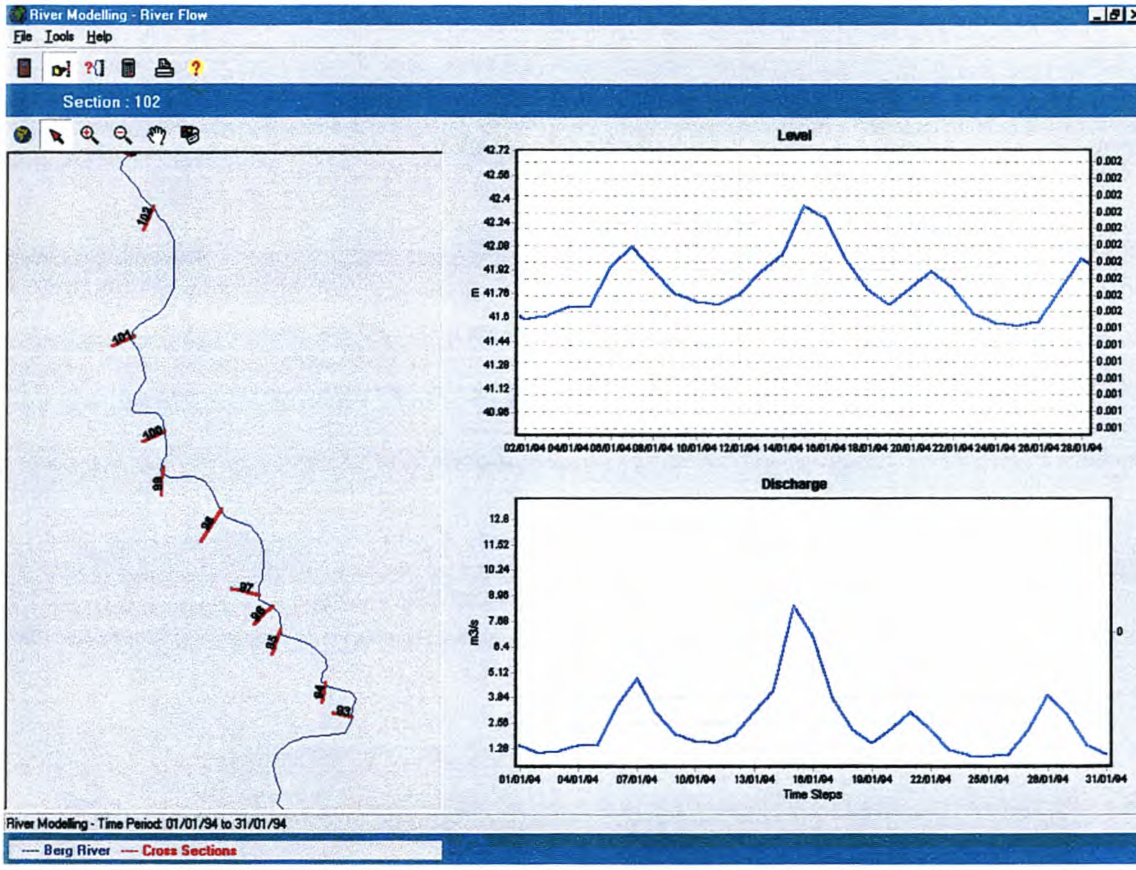

Figure 7.9: Time Series Results Screen for January 1994

The toolbar on this screen offers various options and these are described below.

- *Times Series Tool*: Time series graphs, for a selected time period, are displayed by clicking on the relevant cross section on the interactive map. For the flow option, water level and discharge are displayed and for the water quality option, graphs are displayed for Dissolved Oxygen, Phosphorus, TDS and Temperature.

- *Comparison Tool*: The user may select up to four different cross sections on the interactive map for which they wish results to be compared.

- *Statistics*: A new screen displays box and whisker plots for each cross section and tabulated percentile values that may be exported to a database file for further analysis. The Curves tool on this screen offers the functionality to display the duration frequency curves for each cross section.

- *Violations*: This option is only available for the water quality results and counts the number of water quality "target" violations. A new screen displays a table showing, for each cross section, the start and end dates of the violation period and the number of actual violations within the time frame.

The **Spatial Simulation Results** screen allows the user to animate the results of the DUFLOW simulation through time. The spatial graphs show the water level and discharge or constituent load and concentration at all the cross sections for a particular time step. The progress through the time steps may be speeded up or slowed down using the slider bar and paused, resumed or aborted using the relevant buttons.

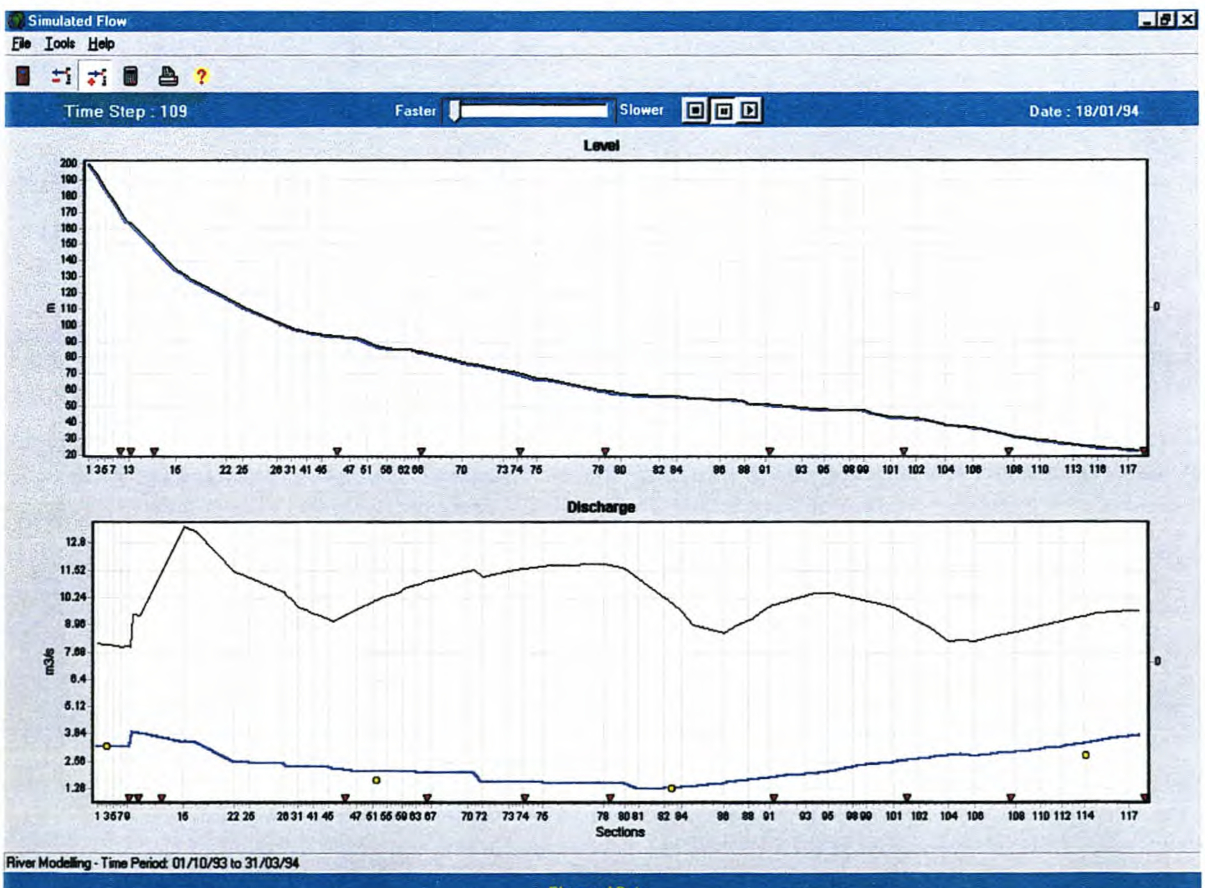

Figure 7.10: Spatial Animation Results Screen for 18 January 1994

The toolbar on this screen offers the user various display options and these are listed below:

- *Abstraction Points*: The locations of the various abstractions are indicated on the spatial graphs using red triangles.

- *Inflow Points*: The location of the various tributary inflows and return flows are indicated on the spatial graphs using green inverted triangles.

- *Statistics*: A new screen displays box-and-whisker plots for each cross section and tabulated percentile data that may be exported to a database file for further analysis. The Curves tool on this screen offers the functionality to display the duration curves for each cross section.

- *Violations*: This option is only available for the water quality results. A new screen displays a table showing, for each cross section, the start and end dates of the violation period and the number of actual violations within the time frame.

NB: Each of the River Model Results screens has printing facilities for hardcopy reproductions.

7.2.6 Reservoir Model Results Screens

The bathymetric input requirements of CE-QUAL-W2 require that the reservoir be divided into segments along the reservoir length and layers across the profile, effectively describing the reservoir in term of "cells". The reservoir simulated in this project, Skuifraam Dam, was divided into 10 segments and 30 layers. The first and last segments and layers are considered "boundary" cells and are as such, not included in the output (Kamish, 2000).

The **Profile Animation** screen presents a map depicting the reservoir and the demarcated finite difference segments used for the reservoir modelling. There are four graph boxes for the concentration results of the modelled constituents (Temperature, Phosphorus, TDS and Dissolved Oxygen). The coloured blocks represent the constituent concentration in each active reservoir cell and the black blocks represent the inactive cells or reservoir bed.

The results are animated by running through the time steps. The variations in each constituent concentration may be observed through the length and depth of the reservoir, simultaneously. A snap shot of the animation is shown in Figure 7.11.

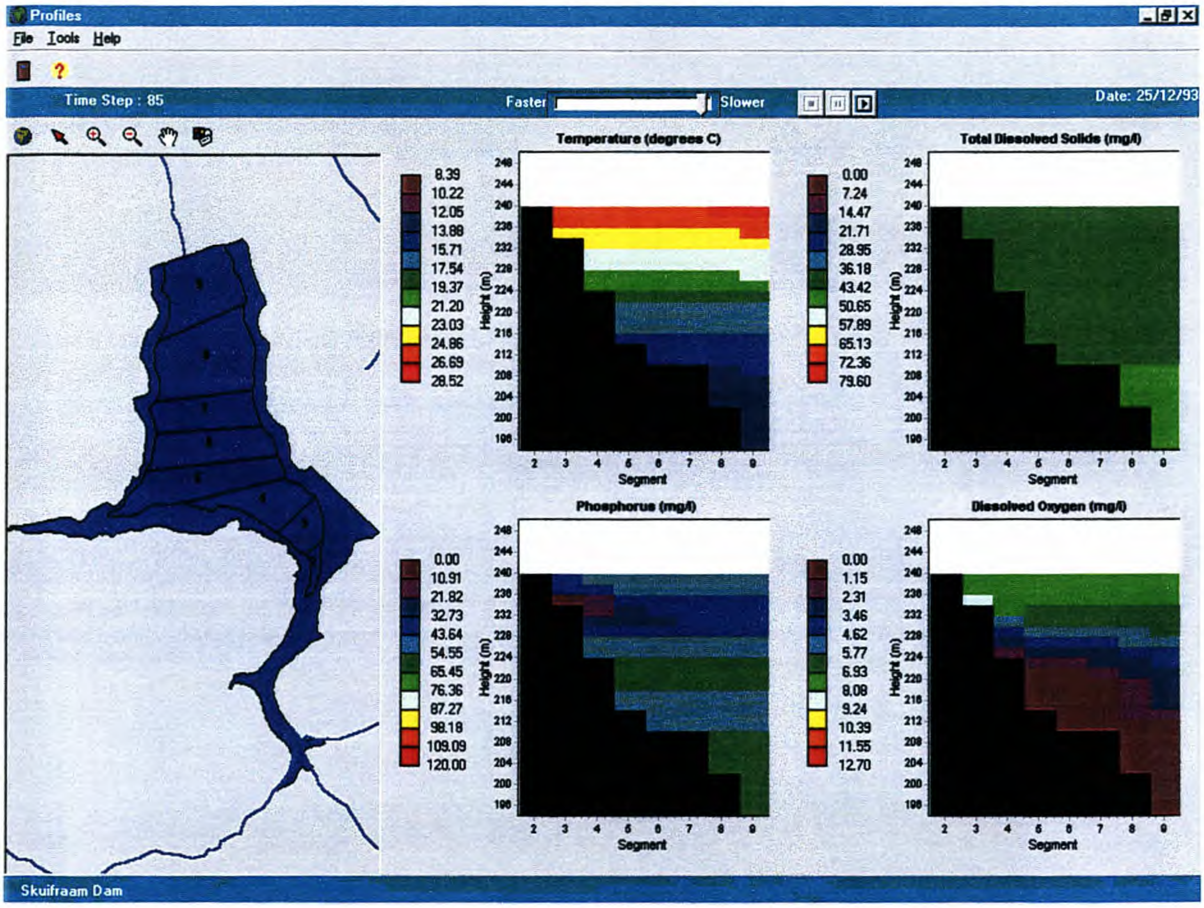

Figure 7.11: Profile Animation Results Screen for 25 December 1993

On the **Horizontal Simulation** screen, a grid is presented, depicting the cell configuration of the reservoir (Skuifraam Dam). The cells containing the characters '****' are the inactive cells and the numbered grid cells represent the active reservoir cells. There are also four graph boxes for the modelled constituents, Temperature, Phosphorus, TDS and Dissolved Oxygen. For each time step in the model simulation run, the concentration of the constituents, at a specified depth, for the length of the reservoir, are plotted. The longitudinal variations in constituent concentration between the inlet and the dam wall can be noted.

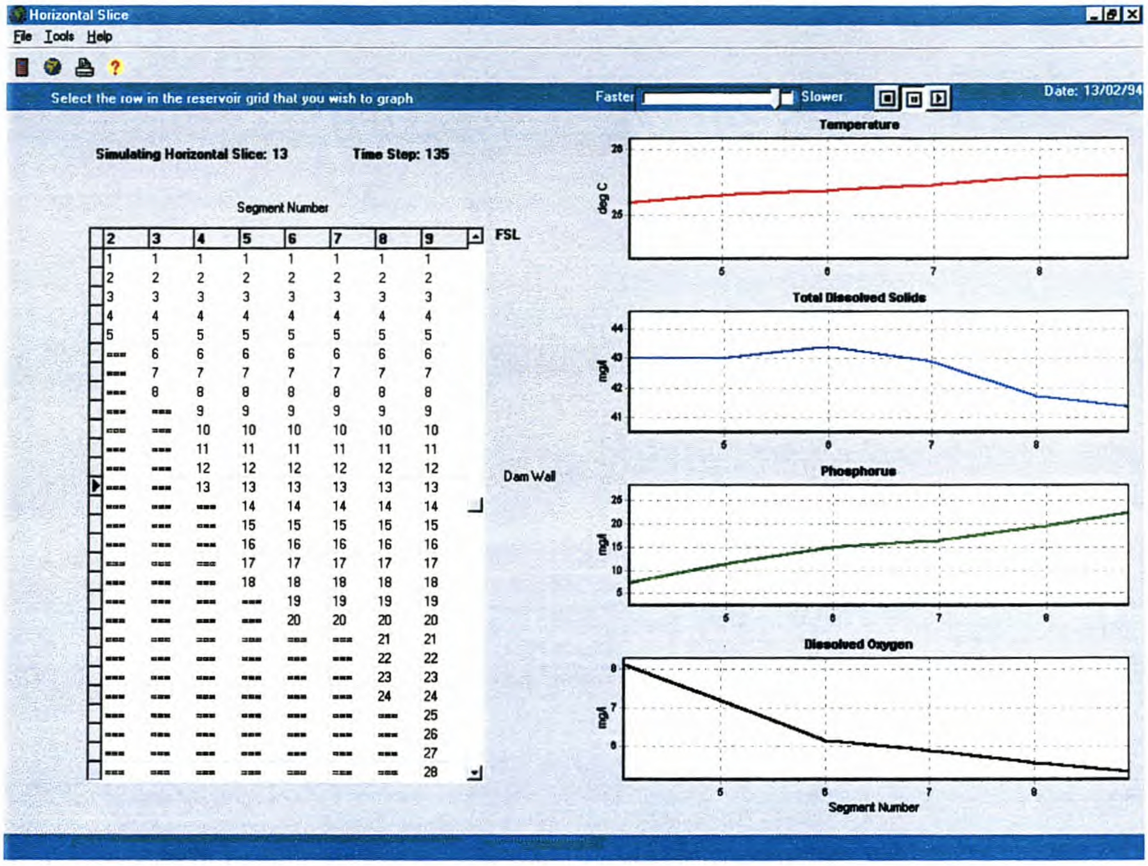

Figure 7.12: Horizontal Simulation Results Screen for 13 February 1994

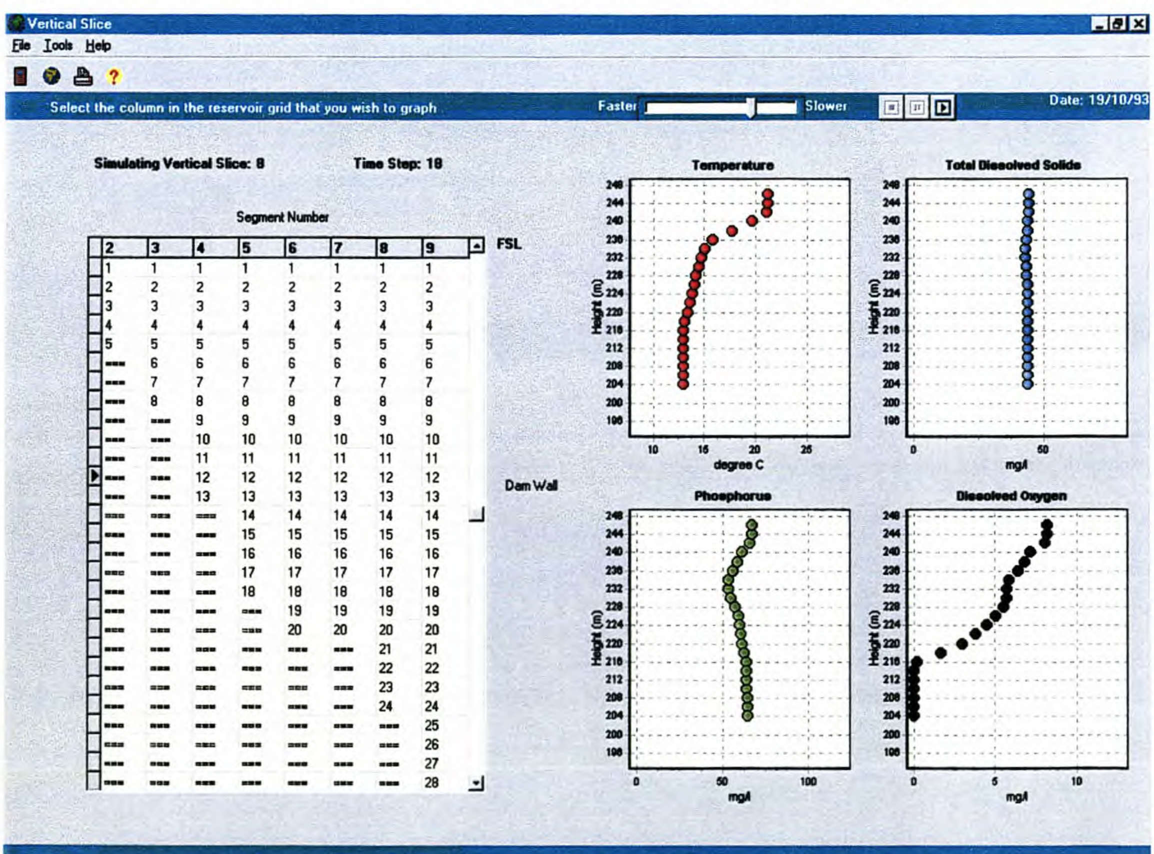

Figure 7.13: Vertical Simulation Results Screen for 19 October 1993

The same grid depicting the cell configuration of the reservoir is shown on the **Vertical Simulation** screen. The four graph boxes display the concentration of the modelled constituents listed above. For each time step in the model simulation run, the concentration profile of the constituents, for a specified vertical slice, for the depth of the reservoir, are plotted. The variations in constituent concentration (stratification) between the reservoir surface and bed can be clearly seen in Figure 7.13.

Again, on the **Time Series** screen there is a reservoir grid and four graph boxes depicting the concentrations of the modelled constituents. The time series, for the full simulation period, for a cell in the reservoir, are displayed by clicking on that cell in the grid (see Figure 7.14).

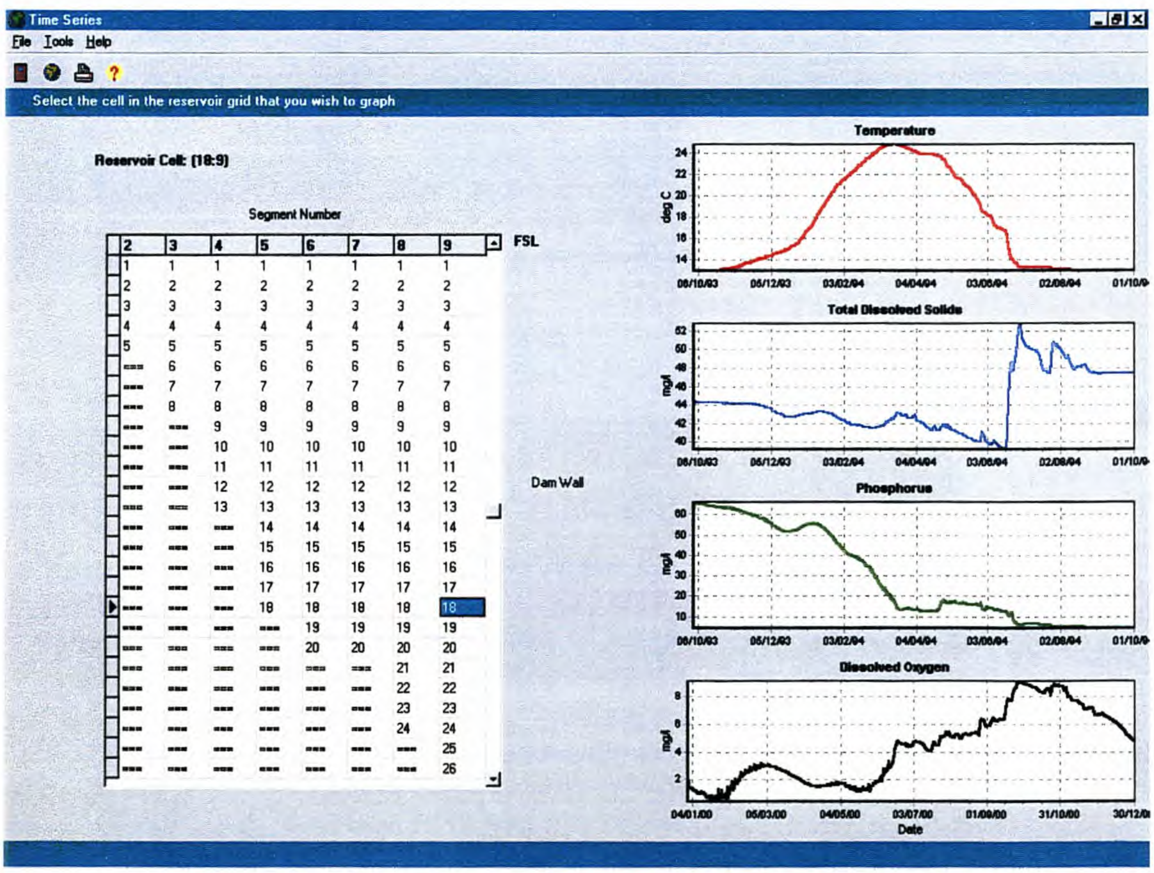

Figure 7.14: Time Series Results Screen for the period October 1993 to September 1994

The above three screens have facilities to print hardcopies of the graphs and view a map of the reservoir.

7.2.7 Help Facilities

Intuitive On-line Help facilities have been created for each screen and there are key words and a contents page to assist in locating the required advice or description.

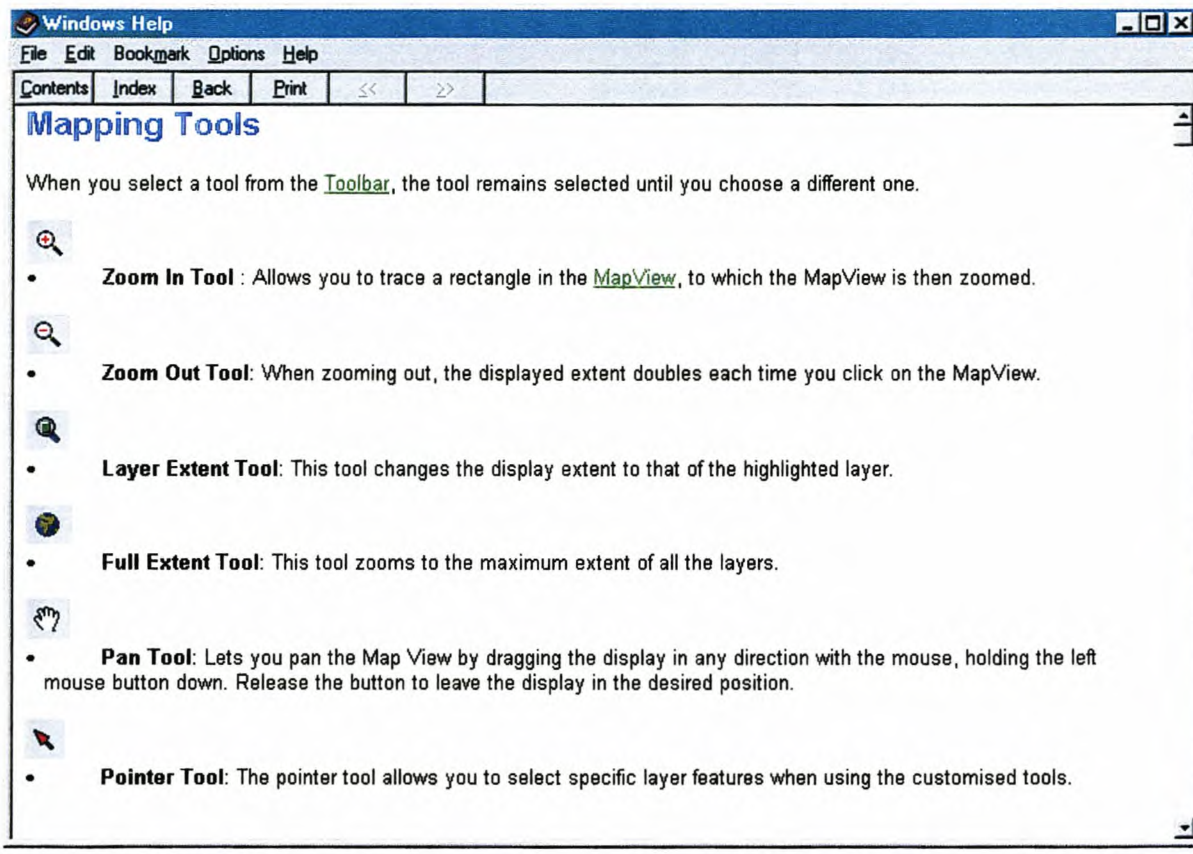

Figure 7.15: WQIS On-line Help Facility

7.3 DISCUSSION

The functionality and analysis offered by this information system is fairly comprehensive but by no means covers all the requirements of every river manager or water resource analyst. However, the development environment and design of the system are sufficiently flexible to allow the inclusion of other simulation models and analysis options to ensure that the WQIS fulfils its role as a decision support and information tool for a broad spectrum of users.

Chapter Eight

EVALUATION OF SIMULATION MODEL INTEGRATION

All too often, the integration of simulation models may sound viable in theory, but the practical implementation of many of the components, although possible, may not be cost or time effective. A good understanding of the numerous model characteristics needs to be achieved before integration is attempted. These include:

- the optimal application of the model (medium to long-term historical or trend analysis, or short term operational management), which determines,
- the frequency of simulation runs,
- the sensitivity or robustness of the simulation models,
- the consistency, nature and size of the model output,
- necessary input modifications for future runs,
- the analysis and display features required from the information system into which the models are integrated.

All these aspects affect the way the information is converted, stored, accessed, updated and displayed. Once all these aspects have been investigated thoroughly, the format and design of the relevant interfaces can proceed.

The simulation models initially chosen for integration into the information system are reviewed critically to assess their suitability for integration based on attributes such as project timing, operation, operating platform, pre- and post-processing and portability.

8.1 RIVER MODEL

The selection, setup and testing of DUFLOW formed a component of a concurrent WRC project (Nitsche, 2000).

8.1.1 Project Timing

The information system development and river simulation projects were run concurrently. As a result, the simulation model setup, input and output were being continually modified. Many of these modifications required adjustments to the interface between DUFLOW and the information system, some of which involved fairly extensive code modifications. Had the simulation exercise been nearing completion, allowing for a clear understanding of the final interface requirements, many of the re-coding exercises would have been unnecessary.

8.1.2 Model Purpose and Operation

The management questions or decisions for which DUFLOW is appropriate should also be carefully considered. A model such as DUFLOW is usually set up infrequently, using numerous years of historical data, and not updated daily or even weekly for use in operational management. An aspect that confirms this point is the fact that a simulation run of just a year takes a number of hours to complete, which is unacceptable if near real-time analysis is required. Therefore DUFLOW is more suited to simulating medium to long-term, historical conditions, the results of which can be used for statistical and trend analysis useful for future long-term planning. Some of these constraints can be overcome by predefining short-term scenarios and limiting the input adjustments made by the user. These are discussed further in Chapter 9.

8.1.3 Pre-processing – Input Files

Originally it was thought that updating the input data would be a simple exercise of reading the output data from the reservoir model and converting it to the relevant format required as input for the river model. However, after further investigation, it was discovered that, to run DUFLOW for current conditions, a number of input parameters and data needed to be updated each time a new model run was required. The observed inflows from tributaries, return flows and the various abstractions volumes, would need to have time frames and time steps corresponding to the release flows (reservoir release) that drive the simulation run.

As previously stated, DUFLOW should ideally be used for medium-term planning for which a model run may be required, at most, once a month. If this is the case, the development time required to integrate DUFLOW into the interface environment is not proportional to its ultimate utilisation. It would be far simpler to read the output into a spreadsheet format and from there, produce graphs and coverages in a standard GIS package such as ArcExplorer or ARCVIEW.

8.1.4 Post-processing – Output Files

DUFLOW output is written to flat text files that vary in size (up to 50MB for a Water Quality file) depending on the time step, number of cross sections, variables and length of run. These files must always be read sequentially, which is time consuming and format specific. Much of the code required to read flat files needs to be hardwired and is often specific to the current set of run parameters. To produce code that is generic and has the ability to read the resultant output of any permutation of parameters is time consuming and duplicates much of the post-processing already supplied within DUFLOW itself.

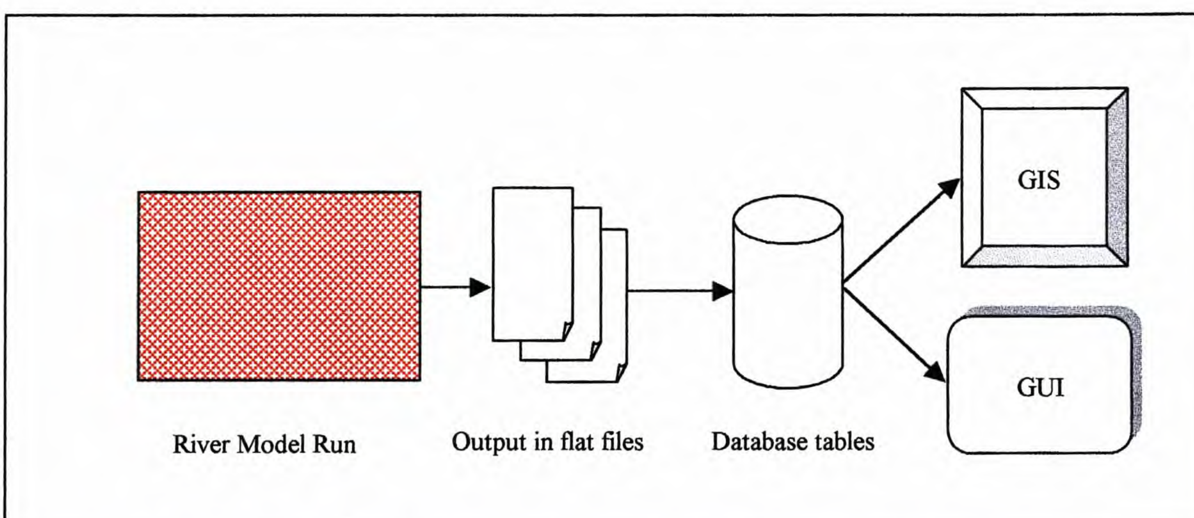

Figure 8.1: River Model Output

To avoid repeated accessing of these output files, their contents are read in once after each model simulation run and stored in a database tables (Figure 8.1). The number and size of these database tables, however, are also dependent on the run parameters and the size of the output file. Although the information is stored in database tables, reading in this information in such volumes is still time consuming.

8.1.5 Software Platform Compatibility

DUFLOW operates on a Windows95 platform which is compatible with the WQIS environment and therefore the launching and operation of DUFLOW from within WQIS is suitable and seamless. Once the command to launch DUFLOW has been given, WQIS opens DUFLOW and the current working file, and then remains idle until DUFLOW is closed.

8.1.6 Portability

DUFLOW is distributed under licence and therefore not portable unless a new copy of DUFLOW is purchased for each installation (STOWA/EDS, 1998). This constraint could possibly be overcome by publishing the WQIS on the Internet at a later stage. However, the cost of DUFLOW is less than 10% of its competitors such as ISIS and MIKE 11.

8.2 RESERVOIR MODEL

As part of the current WRC project, CE-QUAL-W2 was selected to perform the reservoir analysis of the future, Skuifraam Dam (Kamish, 2000).

8.2.1 Project Timing

The reservoir modelling exercise was initiated late into the project, due to resource and data constraints. Therefore, no attempt was made to design the required interfaces between the reservoir model and the information system until a complete results set had been produced. Consequently, a clear understanding of the interface requirements was achieved before the coding process began. The coding proceeded smoothly, requiring no significant changes due to modifications in the output files, as was experienced for the river model.

8.2.2 Model Purpose and Operation

Reservoir simulation usually involves the long-term or seasonal analysis of the physical and chemical processes occurring in the reservoir. Due to the volume and nature/lag effect of a reservoir, short-term scenario analysis would not produce significant variations in constituent concentrations from day to day, except possibly following a flood event. Identifying seasonal changes in the reservoir is vital when determining the operating rules of a reservoir, e.g. positioning/operating the off-take valves to minimise the water quality effects of the reservoir releases on downstream users.

The CE-QUAL-W2 model requires a significant amount of detailed input data and therefore the set-up time for the model tends to be quite lengthy. However, once the basic input files have been finalised, the general set-up is unlikely to change and therefore the set-up time is justified. The model may then be run with various start conditions (reservoir water level, start date, off take depth etc) without much extra effort. The model running time is usually under an hour, but this depends on the model configuration, i.e. the number of calculation cells defining the reservoir and the time period of the simulation.

8.2.3 Pre-processing – Input Files

Due to the pre-processing constraints of the river model, as discussed in the earlier sections, it was unnecessary to re-run the reservoir model for scenario analysis and therefore no pre-processing facilities were required. In future versions of the WQIS, to improve the functionality, a customised Windows based pre-processor could be developed to manipulate the input files and launch the model.

8.2.4 Post-processing – Output Files

The flat text output created by the CE-QUAL-W2 model must be read sequentially, in a format specific manner. However, this process is much shorter than reading the river output, as the reservoir output files are significantly smaller in size (between 5 and 10MB) depending on the number of time steps, constituents modelled and the reservoir dimensions. As a result, repeated access of the output files does not cause any processing delays and therefore the results are not stored in database tables. The output format is well suited to the display requirements of WQIS and therefore very little data manipulation was required to produce informative graphic results.

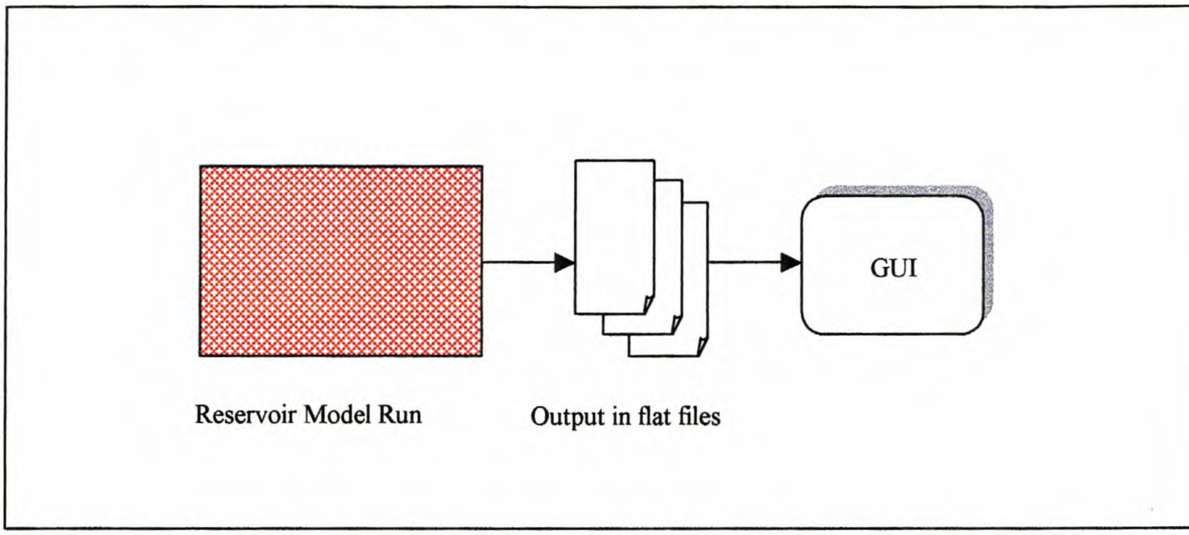

Figure 8.2: Reservoir Model Output

8.2.5 Software Platform Compatibility

CE-QUAL-W2 is a DOS based model with flat text, input and output files and is therefore not compatible with the WQIS environment. Therefore, only the output files produced by CE-QUAL-W2 are used as input to the WQIS. The post-processing option described above could, to a large extent, overcome the incompatibility.

8.2.6 Portability

CE_QUAL_W2 is available free of charge and may be downloaded from the Internet, thereby offering no portability problems. There are several pre- and post-processors for CE-QUAL-W2 commercially available, but these tools do not provide the customised functionality required by the WQIS and would reduce its portability.

8.3 DISCUSSION

The increasing use of spatial methods in simulation models for creating input and displaying output will eventually eliminate many of the integration and incompatibility problems currently experienced when integrating various simulation models into an information system.

In the future, hopefully, most models will construct their input information from a standardised set of GIS layers or an object-oriented network diagram. This will preclude the need for the development of multiple pre- and post-processors thereby ensuring that the Information System is generic and flexible, i.e. there are no limitations on the type (operational or long-term) and as all the required information will be stored in a similar format the set-up mechanisms will be comparable. However, there will still be certain constraints such as the volumes of information required and stored, and the time taken for a simulation run.

Chapter Nine

SCENARIO ANALYSIS USING DUFLOW

Irrigated areas are expanding, and there is no guarantee that future saline return flows will not render certain river stretches unusable as a means of supply. The RSE-BR catchment, chosen as a case study for this project, is no exception and is becoming increasingly susceptible to water quality issues that need urgent solutions.

The river simulation model, DUFLOW, accepted for inclusion in the WQIS, is effectively used for medium-term trend analysis and planning over a period of a few months or years. This information is useful for seasonal comparisons and an overview of conditions in the river system. However, if near real-time results are required for short-term operational decisions, a method for scenario analysis was required.

9.1 POTENTIAL SCENARIO ANALYSIS REQUIREMENTS

Following the interviews with the various water managers described in Chapter 4, it became clear that short-term water quality remediation was a high priority management issue in the Berg River catchment. In particular, managers expected the information system to provide decision support information on point and non-point pollutant spill remedies and irrigation releases, such as:

- the extent and magnitude of the spill,
- when to make releases,
- what volume to release,
- release period, and
- possible downstream effects.

The answers to these questions are typically required within hours and therefore a model with a short set-up and calculation time is necessary to perform the simulation and produce valuable decision support information. The scenario set-up is adequate to provide answers to a range of operational management issues as discussed in the following sections.

9.2 DUFLOW SCENARIO CONFIGURATION

In order to model river quality hazards and remedies effectively, DUFLOW needed to be configured to shorten the model run time and to facilitate easy methods for the user to stipulate water quality hazards and remedial measures.

For this purpose, a pre-processor or **Scenario Manager** was developed as part of the information system to allow the user to stipulate various spill and consequent freshening release characteristics, as well as the month in which they occur. The water quality and quantity characteristics may be set for separate model runs to simulate their individual impacts, or simultaneously to assess the remedial effect of the freshening releases on the spill event.

The following characteristics of the spill event are required:

- location,
- constituent,
- start and end day,
- peak concentration and
- hydrograph shape (Figure 9.1)

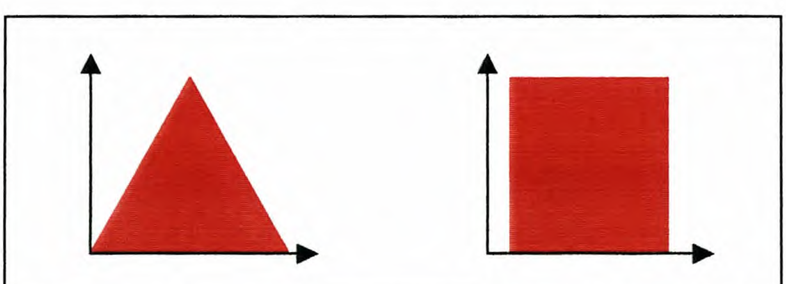

Figure 9.1: Spill Hydrograph Shapes

For the freshening release, the following characteristics are required:

- location,
- start and end day and
- peak volume.

The release hydrograph shape is set to increase uniformly from zero to the required peak value half way between the start and end day (Figure 9.2).

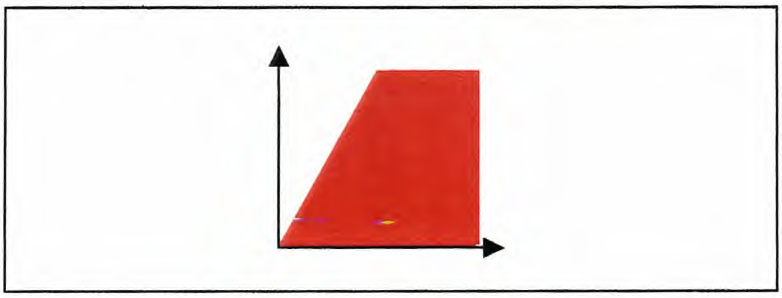

Figure 9.2: Release Hydrograph Shape

To shorten the model run time the DUFLOW model was configured to run for one month only and the user may select the appropriate month, depending on the time of year in which the spill occurs, using the scenario manager. The user may also set water quality limits that vary upstream and downstream of a specified target location. Once these characteristics have been set, the DUFLOW input files are updated to reflect the changes. DUFLOW is then re-run to simulate the adjusted quality and flow values. The application of the various scenario options are discussed in the following sections.

9.3 SCENARIO ANALYSIS OPTIONS

9.3.1 Release Management

Releases from Voëlvlei and the future Skuifraam reservoirs are required for purposes such as irrigation, spill hazard freshening and for the maintenance of the environmental flows and water quality required by all river users and the protected estuarine areas. These releases should be managed effectively, in order to limit the wastage and damage caused by unnecessarily large volumes.

To test the effects of a particular release volume or duration, the **Scenario Manager** for DUFLOW can be used to set the month in which the release is made, the duration of the release and the peak volume (the hydrograph shape is discussed above). The results of the subsequent model run may then be displayed in the information system, enabling the water manager to assess the water levels and velocities in sensitive river reaches. This process may have to be iterated a number of times, with different release distributions, to achieve the most appropriate release pattern.

9.3.2 Point Source Spill Management

Once the water manager has been alerted to a spill from a point source, such as a sewage treatment plant, or industrial site, the **Scenario Manager** can be used to enter the spill type, concentration, location and duration. The DUFLOW model is then run to determine the extent and severity of the spill and its possible effects on downstream users.

Freshening releases can then be tested on a trial-and-error basis in a similar manner to the method described above in Section 9.2.1. In this way, the most effective freshening release, with acceptable impacts on downstream users, can be determined.

9.3.3 Non-Point Source Management

DUFLOW does not cater for non-point source spills explicitly and therefore a method was devised to model the effects of diffuse contaminants, such as irrigation return flows and groundwater seepage, on water quality.

In this case, a spill concentration should be entered in the vicinity of the non-point source spill and then variable upstream and downstream quality limits should be set to ascertain compliance above and below the spill reach. The calculated contaminant loads may also be monitored. The above options are discussed in more detail in the parallel WRC study by Nitsche (2000).

9.3.4 Comparative and Predictive Modelling

A further use of the **Scenario Manager** would be to test the impacts of possible changes in the flow regime or effluent discharges into the river, such as:

- Altered or increased irrigation releases due to extended cultivation,
- Higher effluent discharge from sewage treatment plants due to upgrading and increased capacity,

- Increased non-point source pollution due to seepage from poor sanitation facilities in new, informal or semi-formal settlements adjacent to the river,
- Releases for flood management
- Water quality monitoring and enforcement
- Comparison of the effects of various changes to river flow and quality depending on the season in which they occur.

9.4 POSSIBLE ADDITIONAL OPERATIONAL MANAGEMENT OPTIONS

Consequent to the multiple users, managers and scientists involved in managing a river successfully, there will naturally be a demand for any number of scenario analysis options. However, no one information system will ever satisfy every user's individual requirements, but will hopefully be generic enough to be applied, and provide meaningful decision support for as many situations as possible. The information system described in this project is by no means comprehensive or complete. Numerous additional scenario options have been discussed and were considered to be worthy of inclusion into the model. Two of these options are discussed below, but their implementation was considered beyond the scope of this research.

9.4.1 Linking River and Reservoir Scenario Analysis

The first option would be to develop a method of using the output of reservoir scenario analysis as the input to the river scenario analysis. In this way, the effects of the internal reservoir processes, such as stratification, on the water quality and temperature of reservoir releases can be assessed. These releases can then be routed through the river model to determine the impacts of remedial and routine releases.

9.4.2 DISA Salinity Model Reverse Routing

DISA was originally developed to predict the impact of irrigation development on riverflow and salinity using readily available data from river systems with significant irrigation (DWAF, 1990). The model is described in terms of five general use sub-models, the abstraction, inflow, farm dam, canal and river routing nodes.

As a further development, the DISA model was refined for the Berg River (Ninham Shand, 2000), to refine the management of releases by improving the scheduling of abstractions and matching these abstractions to releases. The model now takes into account the time required for water to flow from the release point to abstraction points (i.e. the hydraulic characteristics of the river channel), the current natural flow in the river, and flow inputs (tributaries and point return flows) and abstractions (irrigators) en route.

The model is quasi-hydrodynamic, with the capacity to cope with the simulation of salinity as the only water quality constituent. It operates on a half-hourly time step for a weekly cycle during the irrigation season and is capable of providing flow and salinity decision support. The required inputs are:

- Requested abstraction volumes
- Current river flow
- Current tributary inflows and return flows (quality and quantity).

The model outputs are:

- The magnitude and timing of releases from the upstream source (dam or transfer)
- The abstraction times at each abstraction point
- Graphical representations of release hydrographs and salinity variation at points of interest.

In configuring the model, a modular approach was followed, allowing for a flexible means of configuring the system as a series of linked nodes. Six different types of nodes were allowed for:

- **Release nodes** are used to define release patterns at the source. In addition, this type of node can be used to define the desired outflow hydrograph at the downstream end of the system.
- **Abstraction nodes** are used to model major abstractions such as municipal, industrial and irrigation board pumping schemes. Provision is made for maximum abstraction capacities and minimum riverflow requirements for abstraction to take place.

- **Routing nodes** make use of the defined river channel geometry to route releases down the river on a sub-daily time step. Provision is made for "diffuse" abstractions along the routing reach, representing individual irrigation abstraction points operating on an ad hoc basis. The timing and magnitude of these abstractions represent the only major unknown quantity in the model, and will be determined by calibration against flows recorded at Observation Nodes in the main river channel (see below).
- **Observation nodes** provide a feed-back mechanism which is used to synchronise the simulated flows in the river with flows observed at one or more points along the river. If an observed flow on a given day is lower than the flow simulated by the model at the observation node, the diffuse abstractions upstream of the observation node are increased uniformly until simulated flows match what is being observed.
- **Inflow Nodes** simulate point inflows from tributaries and major effluent discharge points.
- **Reservoir Nodes** model impoundments as mixed tanks, using a daily mass balance.

The model operates on a "real-time" basis during the irrigation season, and can be updated on a daily basis if required. Release planning is carried out with a 14 day time frame, moving ahead one day at a time:

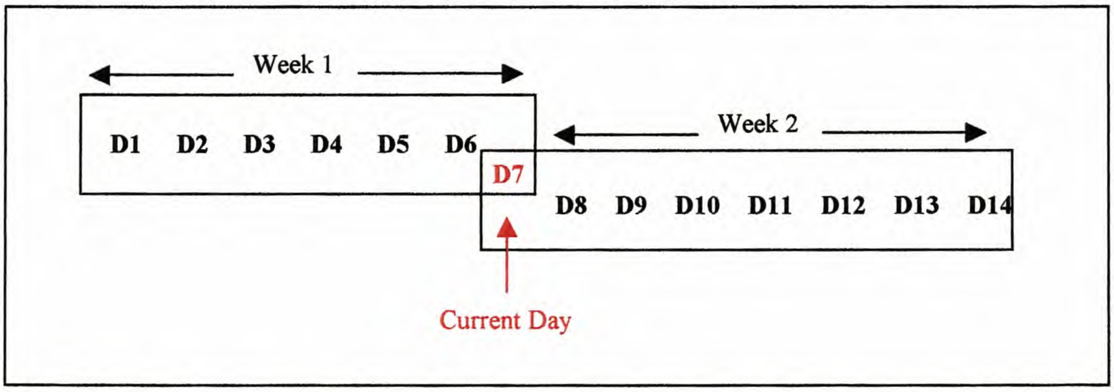

Figure 9.3: DISA Scheduling

- Days 1 to 6 represent the preceding 6 days,
- Day 7 represents the real-time current day, and
- Days 8 to 14 represent the coming week for which releases are planned.

On any given day, release planning can be carried out as follows:

- **Data Input:** Input of tributary inflows, current major abstraction rates, current release rates, and flows observed at the observation points for the current day (Day 7). At present, this is a manual process, but should eventually be replaced by an automated telemetry hook-up.
- **Synchronizing the System:** This step is completely automated and involves the estimation of diffuse abstractions in order to match observed flows. The synchronization spans the period (within days 1 to 6) since the previous synchronization. On completion, simulated model flows in the main river channel match observed flows for the preceding six days, and for the current day.
- **Release Adjustment Planning:** Release adjustment planning is carried out for the coming week (days 8 to 14) by specifying a desired outflow hydrograph at the downstream end of the system. If any release volumes have been requested by the large abstractors (pumping schemes / municipalities), these requirements are specified at the relevant abstraction nodes. At this stage, the model performs reverse routing, commencing at the downstream end of the system with the desired outflow hydrograph, and produces a required release hydrograph at the upstream end of the system.
- **Defining the Final Release Hydrograph:** The required release hydrograph produced by release adjustment planning is highly variable but can now be used as a "backdrop" to design a practical stepped release pattern. This simplified release can now be routed downstream, and the resultant outflow hydrograph at the downstream end of the system should be checked for unnecessary spillage. If required, minor adjustments to the design release can be made.

9.5 DISCUSSION

Clearly, there are many operational tools that would merit inclusion in an information system such as the WQIS. These options need to be well researched, and integrated only if they provide meaningful results to a range of river managers and water resource analysts.

Chapter Ten

CONCLUSIONS AND RECOMMENDATIONS

10.1 OVERVIEW

The aim of the research reported in this document was to develop an effective water quality decision support information system. To fulfil the aims of this project, complex communication and design challenges had to be dealt with effectively to produce an information system that satisfies the requirements of the intended users. Two crucial concepts that were featured were "interactive" and "integrated".

As part of the interactive communication process between the developer and users a questionnaire was distributed to potential users and those with valuable knowledge in the relevant fields. A prototype was then developed based on decisions made regarding software, methods of integration and technical feedback from the questionnaires. The prototype was then demonstrated at a series of interviews and demonstrations where further feedback was recorded and further software adjustments were made.

For this project, a number of the basic system components had already been outlined in the project proposal. The components and level of their integration required to appropriately meet user needs was agreed upon as part of the interactive development process.

The functionality and analysis offered by the WQIS is fairly comprehensive, but by no means covers all the requirements of every river water resource manager or user. However, the development environment and design of the system are sufficiently flexible to allow the inclusion of other simulation models and analysis options to ensure that the WQIS fulfils its role as a decision support and information tool for a broad spectrum of users.

Future research and system developments needs were highlighted in some of the interviews and the Steering Committee meeting for this project. Some of these are discussed in the following section.

10.2 FUTURE RESEARCH AND DEVELOPMENT

One of the main concerns expressed about the WQIS was, how to prevent this information system becoming just "another" system that is used for one project or application and then shelved. Therefore, in the research and development of the WQIS, numerous steps (listed below) were taken to avoid this occurrence.

- The system was developed interactively with the users to create a feeling of ownership and buy-in.
- Modelling capabilities were offered that produced meaningful results for a range of managers in the water management environment.
- The system design is simple and intuitive and offers comprehensive on-line help to cater for all levels of computer literacy.
- The system may be transferred to other river systems provided certain data naming and format conventions are followed.
- The information system is sufficiently generic to allow the inclusion of additional simulation and analysis tools.
- The WQIS may be used as an educational facility for catchment orientation, GIS exposure and map creation.

These precautions may, however, not be sufficient to ensure the continued use and applicability of the information system. The format of the input and output of this system needs to be compatible with that of the main water regulatory organisation, DWAF. In this way the input information of the system may be updated easily and the results may be distributed and used in other studies. DWAF is currently developing a data storage system based on the WDM principles (Lumb *et al*. 1988), for the purpose of standardising the format of their water resources data and any future information systems should be required to conform to this standard. However, the WDM development is not complete and therefore no standards are available as yet. For this reason, the WQIS was developed with its own database, but created sufficiently flexible to ensure that future conversions to WDM format proceed smoothly.

Concern was also expressed that the water quality constituents modelled in the WQIS were not adequate to describe the quality of the Berg River water used for irrigation and the subsequent irrigation return flows and leaching. However, due to the paucity of measured data, the modelling of more specific water quality indexes (such as the Sodium Absorption Ratio rather than TDS) would require an extensive and lengthy gauging and data collection exercise. In the interests of improved modelling and decision support, any improvement in measured water quality and flow data is always encouraged and should be considered at the outset of any modelling or simulation project.

10.3 CONCLUDING REMARKS

One of the achievements of this research has been the creation of an Integrated Water Quality Information System for use in water resource operational and planning decision support. In addition, however, the interaction with water managers has developed a clearer understanding of the day to day operational needs of these managers and which tools would best fulfil their requirements. Greater insight has been gained concerning the type of analysis and simulation tools which are suitable for integration into an information system and the benefits of using existing models rather developing new tools from scratch.

If the considerable interest and discussion stimulated by the development of this system is an indication of the need for effective decision support, then the WQIS could form the building block of an efficient, workable tool to be used in a wide range of future water resource applications.

Chapter Eleven

REFERENCES

Ambrose, R.B., Wool, T.A. and Martin, J.L. 1993. The Water Quality Analysis Simulation Program WASP5. Part A: Model Documentation. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia, USA.

Barandela, R. 1997. Geographic Information Systems and Environmental Assessment: Difficulties and Opportunities. ITC Journal, 1:74-78.

Bath, A.J. 1989. Phosphate transport in the Berg River, Western Cape. Technical Report of the Department of Water Affairs and Forestry, Pretoria. TR 143.

Bennett, D.A. 1997. A Framework for the Integration of Geographical Information Systems and Modelbase Management. International Journal of Geographical Information Science, 11(4): 337-357.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C. 1997. Hydrological Simulation Program--Fortran: User's manual for version 11: U.S. Environmental Protection Agency, National Exposure Research Laboratory, Athens, Georgia, EPA/600/R-97/080.

BKS and SSO, 1998. "Water Quality Calibration Model". Vaal River System Analysis. Report No. P C000/00/7086 Volume A. Directorate of Planning, Department of Water Affairs and Forestry, Pretoria.

Borland, 1997. User's Guide - Delphi 3. Scotts Valley, CA, USA.

Brown, L. and Barnwell, T.O. 1992. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia. EPA/600/3-87/007.

Centre for Water Research, 1992. DYRESM 1D User's Manual, Version 6.75.2 DW. University of Western Australia, Nedlands, WA.

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. Paper presented at the 6th SA National Hydrological Symposium, 523-530.

Cole, T.M. and Buckak, E.M. 1995. "CE-QUAL-W2: A two-dimensional, laterally averaged, Hydrodynamic and Water Quality Model, Version2.0", Instruction Report EL- 95-, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dearnley, P.A. and Mayhew, P.J. 1983. In favour of systems prototypes and their integration into the systems development cycle. The Computer Journal, Vol 26, No 1, 36-42.

Dent, M.C. 1993. Building Community in Hydrological Science: A Potential Path to Successful Integrated Environmental Management. Paper presented at the 6th SA National Hydrological Symposium, 289-296.

Department of Water Affairs and Forestry, 1990. Development of a Daily Hydrosalinity Model (DISA). Prepared by H Beuster, A Görgens and A Greyling of Ninham Shand as part of the Breede River Study. DWAF Report No. H 000/00/0790.

Department of Water Affairs and Forestry, 1990b. List of Hydrological Gauging Stations, Vol 1. Hydrological Information. Publication No. 15.

Department of Water Affairs and Forestry, 1993. Hydrology of the Berg River Basin. Prepared by R R Berg of Ninham Shand in association with BKS Inc. as part of the Western Cape System Analysis. DWAF Report No. P G000/00/2491.

Department of Water Affairs and Forestry, 1994. Integrated System Analysis. Prepared by K de Smidt of Ninham Shand in association with BKS Inc. as part of the Western Cape System Analysis. DWAF Report No. P G000/00/5093.

Department of Water Affairs and Forestry, 1996. South African Water Quality Guidelines. Volumes 1-8.

Department of Water Affairs and Forestry, 1997. Main Report. Prepared by CA Carter and PR Little of Ninham Shand as part of the Skuifraam Feasibility Study. DWAF Report No. P G100/00/0596.

DHI, 1992. Mike11 Version 3.01. A Microcomputer based Modelling System for Rivers and Channels: Reference Manual. Danish Hydraulic Institute Software.

Donigian, A.S., Jr., Imhoff, J.C., Bicknell, Brian, Kittle, J.L., Jr. 1984. Application guide for Hydrological Simulation Program--Fortran (HSPF): U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia. EPA-600/3-84-065, 177.

Environmental Laboratory, 1995. CE-QUAL-RIV1: A Dynamic One-Dimensional (Longitudunal) Water Quality Model for Streams: User Manual. Instruction Report E-95, U.S. Army Engineer Waterways Experiment Station, Vickburg, MS, USA.

ESRI, 1996a. Using ARCVIEW GIS. Redlands, CA, USA.

ESRI, 1996b. MapObjects GIS and Mapping Components – Programmer's Reference. Redlands, CA, USA.

ESRI, 1996c. MapObjects LT – Programmer's Reference. Redlands, CA, USA.

ESRI, 1996d. ArcExplorer – Users' Guide. Redlands, CA, USA.

Görgens, A.G.H. and Moolman, J.H. 1998. Water Quality Information Systems for Integrated Water Resource Management: The Riviersonderend-Berg River System. Project proposal submitted to the Water Research Council.

HR Wallingford, 1997. ISIS Flow: User's Manual. Halcrow/HR Wallingford, UK.

Hydrologic Engineering Center, 1978. WQRRS User's Manual. CPD-8. Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, USA.

Jewitt, G.P.W. 1998. Resolution of Scale in an Integrated Catchment Information System for the Rivers of the Kruger National Park. Unpublished PHD thesis, University of Stellenbosch.

Kamish, W. 2000. Assessment of a Hydrodynamic Water Quality Model, CE-QUAL-W2, for a Winter Rainfall Reservoir. Unpublished report to the WRC Steering Committee.

Karimi, H.A. and Houston, B.H. 1996. Evaluating Strategies for Integrating Environmental Models with GIS: Current Trends and Future Needs. Computers, Environment and Urban Systems, 20(6): 413-425.

Kittle, J.L., Jr., Lumb, A.M., Hummel, P.R., Duda, P.B., Gray, M.H. 1998. A tool for the generation and analysis of model simulation scenarios for watersheds (GenScn). U.S. Geological Survey Water- Resources Investigations Report 98-4134, 152.

Lahlou, M., L. Shoemaker, S. Choudhury, R. Elmer, A. Hu, H. Manguerra, A. Parker 1999. Better Assessment Science Integrating Point and Nonpoint Sources, BASINS Version 2.0 User's Manual. EPA 823/B-98-006. Environmental Protection Agency, Office of Water, Washington, DC.

Lilburne, L., Benwell, G. and Buick, R. 1997. GIS, Expert Systems and Interoperability. Transactions in GIS, 2(3): 233-243.

Lumb, A.M., Carsel, R.F., and Kittle, J.L., Jr., 1988. Data management for water-quality modelling development and use: Proceedings of the International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology.

Midgley, D.C., Pitman, W.V. and Middleton, B.J., 1994. Surface Water Resources of South Africa 1990. WRC Report Series 298/94.

Mingins, P. 1996. The Future of GIS. Proceedings of the Institute of Civil Engineers – Geographic Information Systems, 114 : 44-50.

Nitsche, N. 2000. Assessment of a Hydrodynamic Water Quality Model, DUFLOW, for a Winter Rainfall River. Unpublished Masters thesis, University of Stellenbosch.

Ninham Shand, 2000. Development of an Irrigation Release Planning Model for the Berg River. Unpublished development work for DWAF.

O'Bree, M. 1999. Personal Communication. Cape Metropolitan Council.

Rob, P. and Coronel, C., 1993. Database Systems: Design Implementation and Management. California: Wadsworth.

Schoolmaster, F.A. and Marr, P.G. 1992. Geographic Information Systems as a Tool in Water Use Data Management. Water Resources Bulletin, 28(2): 331-336.

Shepherd, A. 1997. Interactive Implementation: Promoting Acceptance of Expert Systems. Computers, Environment and Urban Systems, 21(5): 317-333.

South Africa, Republic, 1998. National Water Act. Act no. 36 of 1998. Government Printer.

STOWA/EDS 1998. Duflow for Windows. Version 3.0. EDS, Leidschendam, The Netherlands.

Tate, G. 1990. Prototyping: helping to build the right software. Information and Software Technolgy, Vol 32, No 4, 237-244.

Turban, E., 1993. Decision Support and Expert Systems: Management Support Systems. New York: Macmillan.

Ubbels, A.A. and Verhallen, A.J.M. 2000. Collaborative Planning in Integrated Water Resources Management: The Use of Decision Support Tools.

Van Rensburg, J.D.J and Dent, D.C. 1997. Development of a water quality and quantity modelling system, which will provide a common currency for communication between researchers in the Kruger National Park Rivers Research Programme. WRC Report No 654/1/97.

Wells, S.A. 2000. "CE-QUAL-W2 Version 3: Hydrodynamic and Water Quality River Basin Modelling," Proceedings, HydroInformatics 2000, IAHR, DROM_EM5.

Wijers, B.E.W., 1993. The Application of GIS in Integrated Water Resources Management. Paper presented at the 6th SA National Hydrological Symposium, 403-409.

ADDITIONAL SOURCES

Anon. Think Evolution not Revolution for Effective GIS Implementation. GIS World 10(4): 48-51.

Barnes, A.K. 1997. Managers and their Technological Perceptions: Will GIS meet their Perceptions? Geomatics Information Magazine, 11(12): 72-74.

Burrough, P.A. 1992. Development of Intelligent Geographical Information Systems. International Journal of Geographical Information Systems, 6(1) : 1-11.

Chou, H.C. and Ding Y. 1992. Methodology of Integrating Spatial Analysis/Modelling and GIS. Paper presented at the 5th International Symposium on Handling Spatial Data.

Ferrier, G. and Wadge, G. 1997. An Integrated GIS and Knowledge-Based System as an Aid for the Geological Analysis of Sedimentary Basins. International Journal of Geographical Information Science, 11(3): 281-297.

Hendriks, P.H.J. 1998. Information Strategies for Geographical Information Systems. International Journal of Geographical Information Science, 12(2): 621-639.

Johnson, L.E. and Dyke, S. 1997. Real-World GIS Implementation. GIS World, 10(2): 54-57.

Kemp, K 1992. Spatial Models for Environmental Modelling with GIS. Paper presented at the 5th International Symposium on Handling Spatial Data.

Lanfear, K.J. 1989. Geographic Information Systems and Water Resources Applications. Water Resources Bulletin, 25(3): v-vi.

Little, P.R., Olivier, J.J. and Howard, G. 1993. The Use of Geographic Information Systems in a Water Resources analysis of the Western Cape. Paper presented at the 15th Annual Symposium of the South African Institute of Civil Engineers.

Marjanovic, P. 1999. The Role of Information Technology in Water Management with Emphasis on GIS – Current Technology Trends, Main Success Factors, Problems and Misconceptions. Proceedings of the 21st SA Institution of Civil Engineering, Division of Information Technology.

Mather, C. 1997. Geographic Information Systems, Mapping and Development Practice. Science, Technology and Development, 15(2-3): 291-302.

Pryjomko, R. and Rabley, P. 1998. Mapping the Future. Urban Age – The Global Magazine, 18-19.

Ray, C.F. 1996. GIS in a Major Water Utility. Proceedings of the Institute of Civil Engineers – Geographic Information Systems, 114 : 23-29.

Thomas, M. 1996. Implementing GIS across a Business. Proceedings of the Institute of Civil Engineers – Geographic Information Systems, 114: 12.

Wolff-Piggott, B.B., Görgens, A.H.M. and Zietsman, H.L. 1993. Enhancing Decision-Support Software: The Interfacing of a Hydro-Salinity Model and a Geographic Information System. Paper presented at the 6th SA National Hydrological Symposium, 515-522.

APPENDIX A

UNIVERSITEIT VAN STELLENBOSCH
UNIVERSITY OF STELLENBOSCH

1999-06-28 8276/10/65 : JT/gw

Dear Sir

INTERACTIVE WATER QUALITY INFORMATION SYSTEM

A Water Research Commission study titled, *Water Quality Information Systems for Integrated Water Resource Management : The Riviersonderend-Berg River System* is being undertaken by the Department of Civil Engineering, University of Stellenbosch. As part of this study, an interactive water quality information system (WQIS) is being developed for water resource and quality management. An extract from the project proposal is included for your information.

The processes of monitoring, modelling and managing the water quality of a catchment system, including all its unique complexities and interrelationships, requires an innovative tool or set of tools to help water managers with their decision making. This process also requires a comprehensive set of relevant data. These data bases are becoming increasingly available due to the efforts of several agencies involved in monitoring environmental conditions. Following naturally, is the development of numerous methods for analysing and modelling the real world using these data stores. Many of these tools require a fair degree of technical expertise and training to operate correctly and their output may have to be translated/converted to meaningful information for decision making using a further set of analytical and graphical display tools.

A more promising technique for management may be to wrap all these functions into a single system and not to focus entirely on satisfying new technical modelling requirements by producing yet another modelling system. Therefore, this project aims to integrate/couple existing models into a consistent, user friendly GIS environment which satisfies as many of the technical user's or manage's (and later educational) information and modelling needs. This tool will be an integrated water quality information system (WQIS).

It is envisaged that, initially, the information system will comprise the following components:

- river model,
- reservoir model,
- Graphical Information System (GIS) to analyse and store spatial data,
- one or more databases linking the input and output from above three components, and

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- a user friendly Graphical User Interface (GUI) which will seamlessly interact with all the components and provide the means to analyse and display data and the results of scenario testing
- later the system will hopefully be expanded to include catchment washoff capabilities.

The key to producing a valuable, workable tool is the word, "interactive". This interaction should not be neglected until after the final product is handed over and technology transfer to end-user is already in progress. The entire product development process should involve consultation and interaction between the developer, users (managers) in all relevant fields and those with experience in using or previously developing similar information systems.

As part of this interactive process, questionnaires have been distributed to a number of knowledgeable persons who could add valuable input and have experience in any of the following project related fields : water quality, water resources, model/software development, model/software user.

It would be greatly appreciated if you would complete (where questions are relevant) the enclosed questionnaire and return it to:

Jean Tukker
Department of Civil Engineering
University of Stellenbosch
Private Bag X5018
Stellenbosch
7599

If you would prefer to receive or reply to the questionnaire electronically, please send your requests to **jtukker@shands.co.za**.

Thank you in advance for you time and valuable input.

Regards

MRS JEAN TUKKER

PROF AHM GÖRGENS

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/gw

WATER QUALITY INFORMATION SYSTEMS FOR INTEGRATED WATER RESOURCE MANAGEMENT : THE RIVIERSONDEREND-BERG RIVER SYSTEM

Extract from the project proposal

Method

The objectives of this project require a multi-disciplinary research effort, combining farm-scale field work, intensive in-stream and in-reservoir sampling, development of data base and graphical user interface software, GIS applications, simulation modelling, and advocacy and educational outreach activities.

Task 1 : Farm-scale fieldwork: The objective of the plot-scale fieldwork will be to assess over three irrigation seasons the respective salt mobilisation rates and irrigation return flow processes in two sets of irrigation fields on Malmesbury Shale-derived soils, where the one set represents newly developed irrigation and the other set long-established irrigation. Each set will consist of at least two different irrigation treatments, typical of the local practices. Irrigation application will be flow-metered and resultant return flows will be gauged and sampled through artificial drain outflows. These drains will be installed at the interface of the soil and the weathered shale layer above the bedrock. To maximise information from the experiment, nutrient levels (phosphates and nitrates) in the drain outflow will also be measured. Soil water content will be monitored using a neutron probe. Soil water salinity will be measured using soil water extractors. Groundwater observation holes will be drilled and, if possible, existing boreholes will be converted to allow monitoring of groundwater level and salinity changes. Estimates of potential evapotranspiration will be made by measuring a set of meteorological variables using an existing automatic recording weather station, strategically placed relative to the field sites. At the end of each season, the data will be analysed statistically and interpreted to provide input to the other tasks described below.

Task 2 : Develop generic methods for spatial salinity risk assessment by expert interpretation, using soil maps, GIS techniques, salinity data from monitored tributaries, the findings of the farm-scale studies described above and, especially, the vast data base of soil chemical analyses historically performed for individual farmers across the whole Berg River catchment. These methods will be demonstrated by identifying zones along the Berg River and its primary tributaries where irrigation may increase downstream salinities significantly.

Task 3 : Assess eutrophication hazards in the Riviersonderend-Berg River (RSE-BR) system by determining the nutrient sources and nutrient balance of the main stem Berg River and its primary on- and off-channel impoundments through at a 24-month period. This will be done through intensive sampling and flow/water quality data analysis at selected flow-gauging stations, water quality profiling of impoundments and periodic monitoring of major effluent discharges. This work will be preceded and overlapped by a source identification exercise, consisting of current land use mapping and effluent location inspections, mapping and documentation.

Task 4 : Develop an interactive water quality information system (WQIS), using existing catchment information systems such as AQCES and ICIS as examples : Inter alia, it will provide interactive access to historical water quality data and flow time series as well as water qulaity data collected under this project, spatially linked to catchment coverages of physiography, monitoring sites, soils, landuse, infrastructure and climate.

Task 5 : Configure and appropriate water quality simulation model of the main stem river system and the relevant impoundments that is integrated with the WQIS and demonstrate its use by scenario analyses in support of both planning and operational decision making. Currently, water quality aspects of large scale water resources planning in South Africa are supported by a systems model, WRPM, which operates at a monthly resolution and caters for salinity only, not for eutrophication. The RSE-BR system is relatively small, so the total transmission time of releases through the system is expected to be less than one week. A monthly resolution is therefore too coarse for detailed planning and for operational analyses of the RSE-BR system. Investigations are afoot as part of the Vaal River System Analysis Update study by DWAF to incorporate nutrient transport in WRPM under assumption of steady flow through the month. This assumption is not expected to be applicable to the RSE-BR system. Due to relatively high gradients and shallow soils most Berg River tributaries show fast responses to rainfall, causing highly unsteady flow during winter throughout most of the system. Phosphate transport studies in the 1980's showed that remobilsation and transport during such flood flows were crucial components of the overall balance.

WATER QUALITY INFORMATION SYSTEMS FOR INTEGRATED WATER RESOURCE MANAGEMENT : THE RIVIERSONDEREND-BERG RIVER SYSTEM

Questionnaire

Aim

The purpose of this questionnaire is firstly to prime the relevant parties about what they want from this system and secondly for the developer to assimilate important information on the following:

- Level of technical expertise of the users
- Data inputs required
- Data outputs required
- Preferred methods of results display (i.e graphing capabilities)
- Types of analysis required

In addition to the questionnaire, a prototype or "first attempt" system is being developed which should provide a base for further discussion and input to the development process. This prototype will be demonstrated after the questionnaires have been distributed for comment. Using the responses received through the demonstration and questionnaires a product that incorporates as many of the recommendations as possible, will be developed in a process of iterative consultation and development.

Basic Outline

The system is required to include a few necessary components to meet the information and modelling/predictive objectives of the study. The development environment will be predominantly GIS based but will not require the user to have advanced knowledge of such packages. From this GIS "window" the user will be able to launch the reservoir and river models (catchment model), do analysis and display results. If there is a need, a number of pre-determined, general scenarios could be compiled and made available for decision making at a managerial level.

The exact format of the system's various components will be decided using the responses to this questionnaire.

QUESTIONS

Please respond in full to as many (or those relevant to your field) questions as possible.

Name : ______________________________

Organisation : ______________________________

Position : ______________________________

Field : ______________________________

A. WATER QUALITY RIVER MODEL

DUFLOW has been selected as the streamflow water quality model. The DUFLOW water quantity and quality component allows the user to perform unsteady flow computations in networks of open water courses. It is also useful in simulating the transportation of substances in free surface flow and more complex water quality processes (user manual).

1. What information would you find useful from a streamflow water quality modelling exercise? Why?

   ____

   ____

   ____

2. What time-step of water quality model output results would be most useful to you? Why?

   Hourly : ______________________________

   Daily : ______________________________

   Monthly : ______________________________

   Other : ______________________________

3. What output results would interest you? Give reasons.

   Time Series ______________________________

   Statistical Characteristics ______________________________

   Concentrations ______________________________

   Loads ______________________________

   Other ______________________________

4. What type(s) of analysis should be performed on the results?

   ____

   ____

5. How would you prefer these results to be displayed?

   a) On maps showing eg. rivers, monitoring points, landuse

      ____

   b) Longitudinal sections showing eg. flow, concentration levels/routing

      ____

   c) Cross sections showing eg. flow level and concentration

      ____

   d) Line graphs showing eg. time series, box-whisker plots

      ____

6. Would a set of pre-determined, general streamflow water quality scenarios be useful OR would you prefer to create your own scenarios using DUFLOW? Why?

   ____

   ____

   ____

B. WATER QUALITY RESERVOIR MODEL

1. What information would you find useful from a reservoir water quality modelling exercise? Why?

   ____

   ____

   ____

2. What time-step of reservoir water quality model output results would be most useful to you? Why?

   Hourly : ______________________________________

   Daily : _______________________________________

   Monthly : _____________________________________

   Other : _______________________________________

3. What output results would interest you? Give reasons.

   Time Series ______________________________

   Statistical Characteristics ______________________________

   Concentrations ______________________________

   Other ______________________________

4. What type(s) of analysis should be performed on the results?

   ____

   ____

5. How would you prefer these results to be displayed?

   a) Longitudinal sections showing eg. concentrations, routing

      ____

   b) Line graphs showing eg. time series, box-whisker plots

      ____

6. Would a set of pre-determined, general reservoir water quality scenarios be useful OR would you prefer to create your own scenarios using the chosen model? Why?

____

____

____

C. SOILS INFORMATION

The soil information will primarily be displayed spatially as a background to the modelled scenarios as part of the salinity hazard mapping exercise (see Task 2 of the proposal extract).

1. What other information could be incorporated in these coverages eg. sampling sites, landuse, depth?

____

____

2. How should this information be displayed?
   a) Pop-up tables on interrogation of a map____________________________
   b) General soils information guidelines ____________________________

D. GENERAL

1. For a river system, would the proposed Information System fulfill your technical planning and operational decision making requirements? If not, why?

____

____

____

____

2. Do you think models/ information systems are an asset to water resource planning and decision making? Why?

____

____

____

3. Would an information system with predictive capabilities, such as the one described above, help you to perform your particular function? How?

____

____

____

4. Indicate the type of role you would like Information Systems to play in their application to Water Resources to support your job.

____

____

____

____

____

____

5. How could the internet best be used to encourage the use of water quality information systems such as this and/or to publish the results of real-time scenario runs?

____

____

____

E. COMPUTING SKILLS

1. Level of Computing Expertise :

☐ Expert ☐ Competent ☐ Fairly Capable ☐ Novice

2. Level of GIS Expertise :

☐ Expert ☐ Competent ☐ Fairly Capable ☐ Novice

Which GIS Packages are you familiar with? ______________________________

3. Do you use simulation models :

☐ Continually ☐ Often ☐ Occasionally ☐ Never

4. Identify the kind of tools (computerised or not) you would usually apply to water resource investigations:
   - For modelling different scenarios ______________________________
   - For analysis ______________________________
   - To display results ______________________________

WQIS ADDRESS LIST

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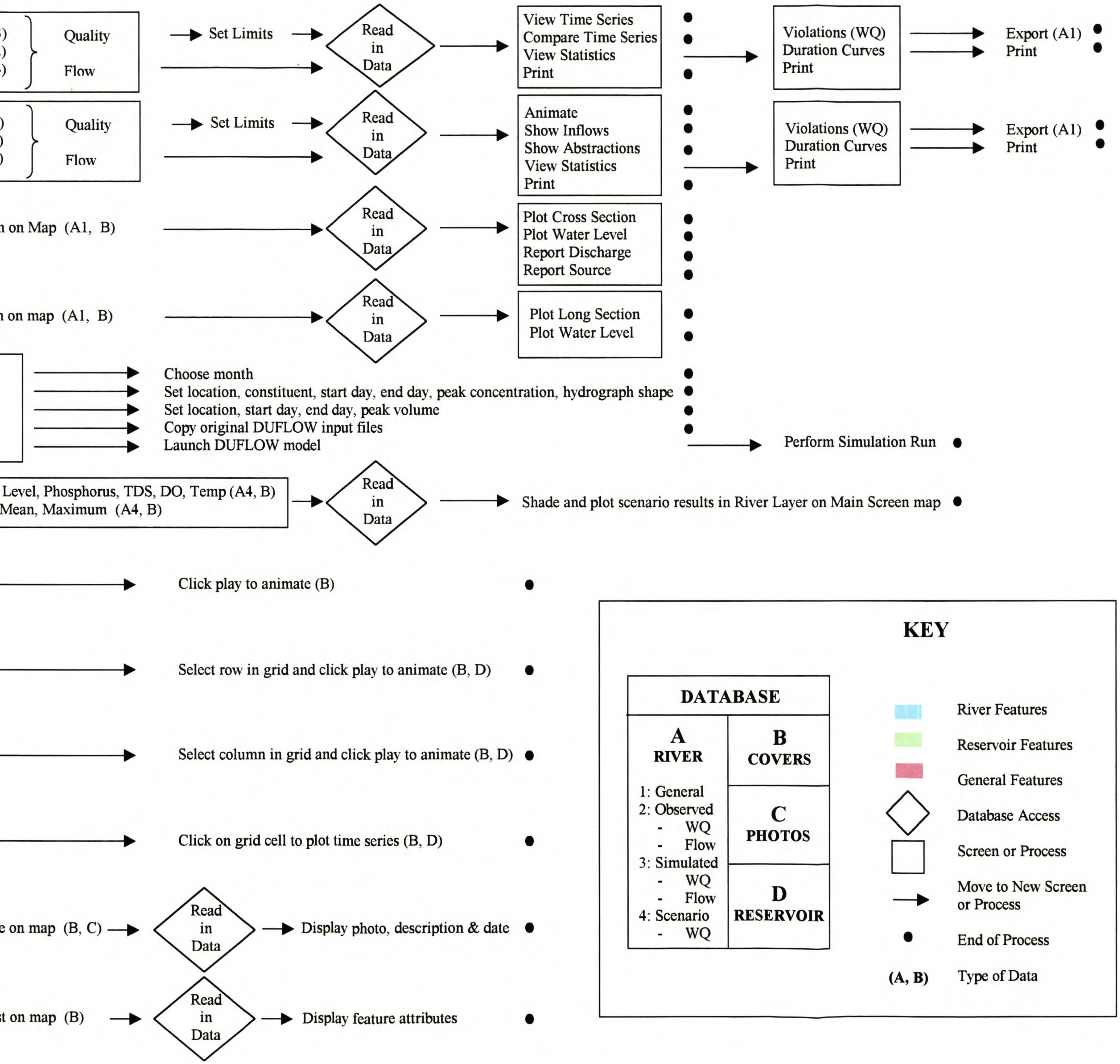
APPENDIX B


Quality
Flow
Set Limits
Read in Data
View Time Series
Compare Time Series
View Statistics
Print
Violations (WQ)
Duration Curves
Print
Export (A1)
Print
Quality
Flow
Set Limits
Read in Data
Animate
Show Inflows
Show Abstractions
View Statistics
Print
Violations (WQ)
Duration Curves
Print
Export (A1)
Print
n on Map (A1, B)
Read in Data
Plot Cross Section
Plot Water Level
Report Discharge
Report Source
n on map (A1, B)
Read in Data
Plot Long Section
Plot Water Level
Choose month
Set location, constituent, start day, end day, peak concentration, hydrograph shape
Set location, start day, end day, peak volume
Copy original DUFLOW input files
Launch DUFLOW model
Perform Simulation Run
Level, Phosphorus, TDS, DO, Temp (A4, B)
Mean, Maximum (A4, B)
Read in Data
Shade and plot scenario results in River Layer on Main Screen map
Click play to animate (B)
Select row in grid and click play to animate (B, D)
Select column in grid and click play to animate (B, D)
Click on grid cell to plot time series (B, D)
e on map (B, C)
Read in Data
Display photo, description & date
t on map (B)
Read in Data
Display feature attributes
KEY
DATABASE
A
RIVER
1: General
2: Observed
- WQ
- Flow
3: Simulated
- WQ
- Flow
4: Scenario
- WQ
B
COVERS
C
PHOTOS
D
RESERVOIR
River Features
Reservoir Features
General Features
Database Access
Screen or Process
Move to New Screen or Process
End of Process
(A, B)
Type of Data

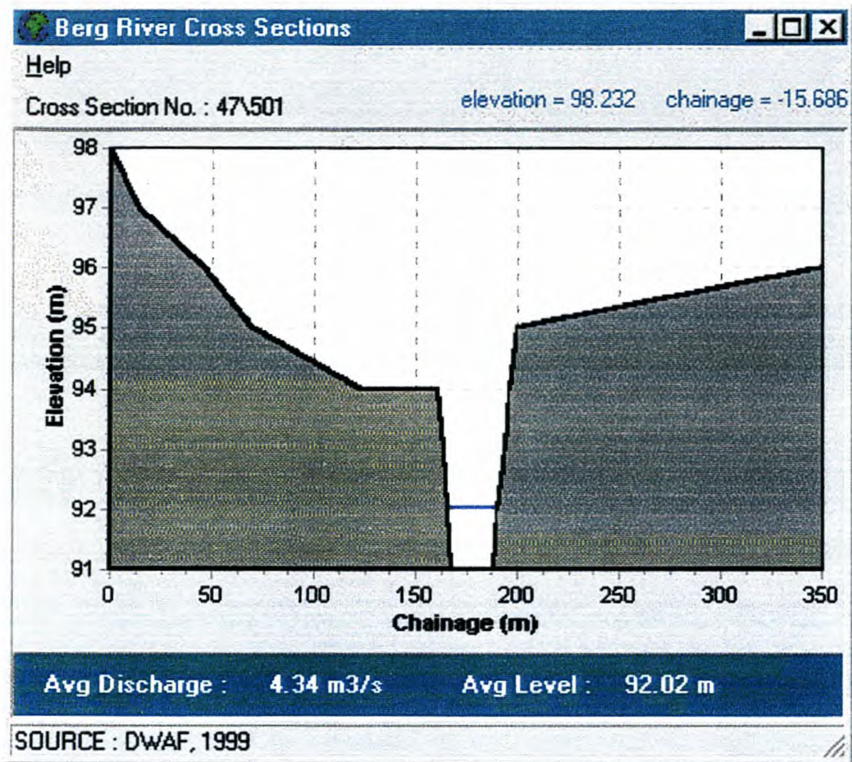


Figure B.2: Final Cross Sections Screen

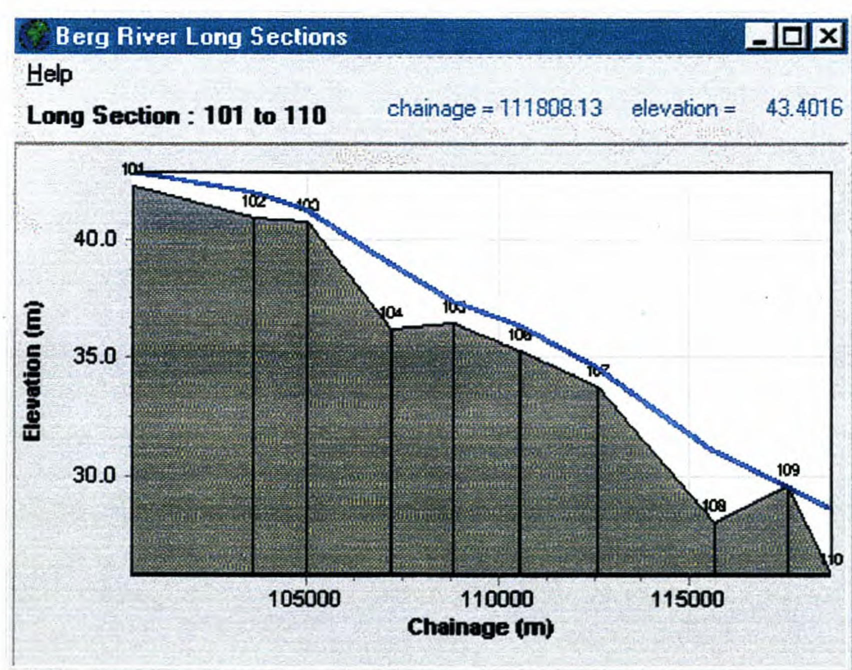


Figure B.3: Final Long Section Screen

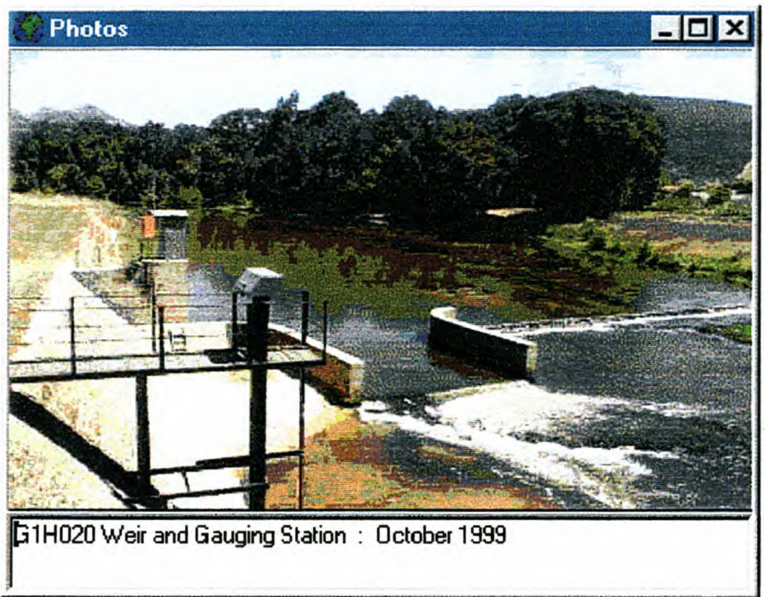


Figure B.4: Photographs

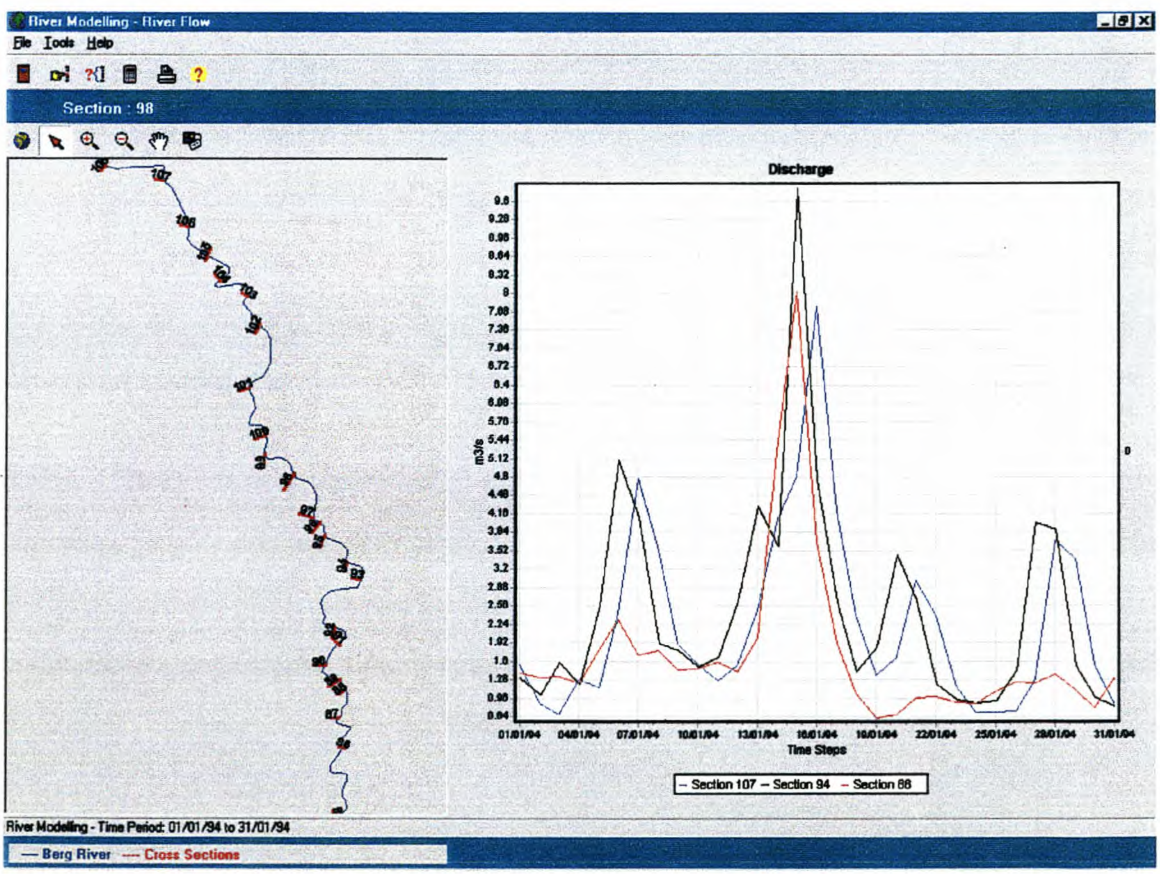


Figure B.5: River Results - Cross Section Comparison

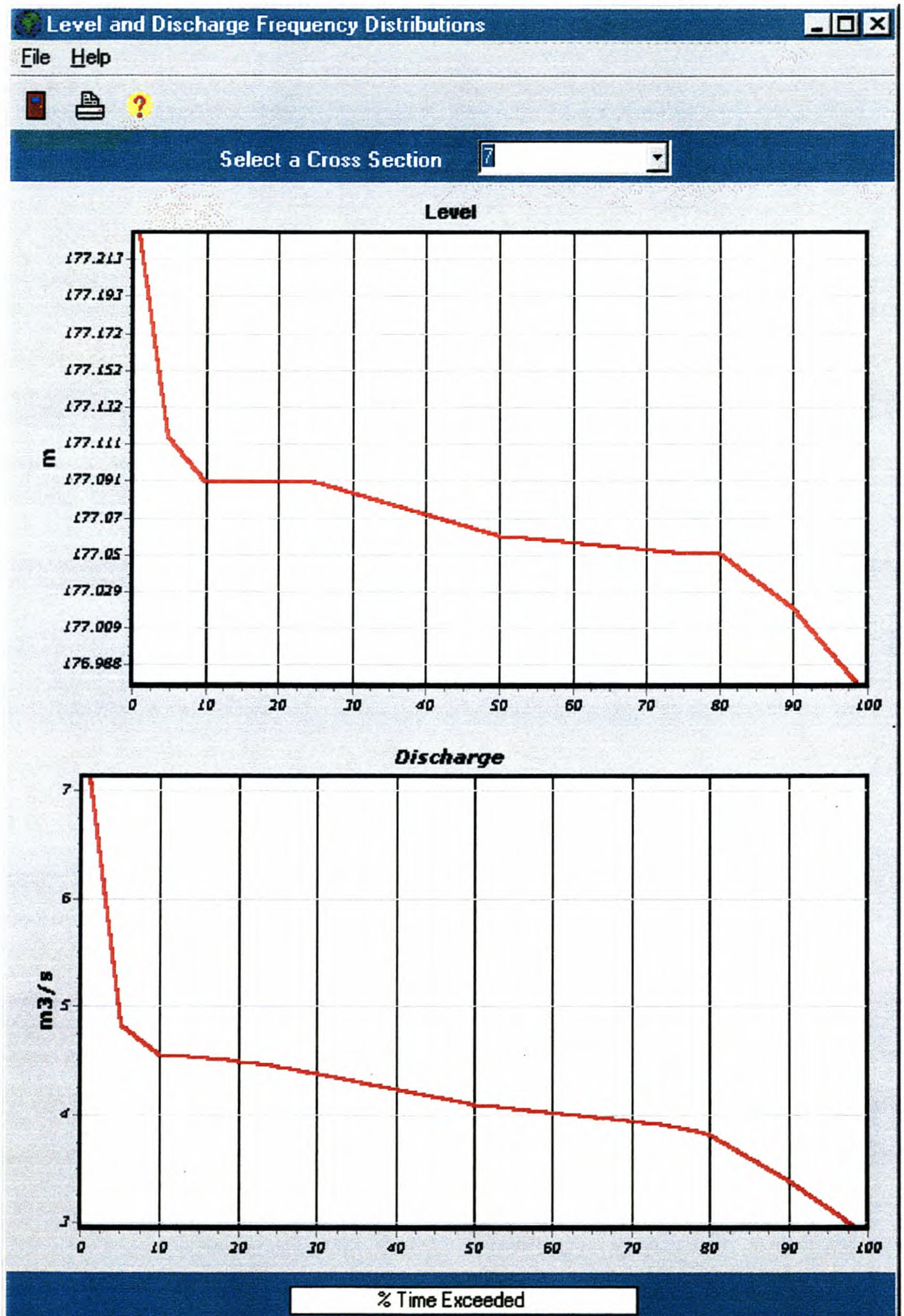


Figure B.6: River Results - Duration Curves

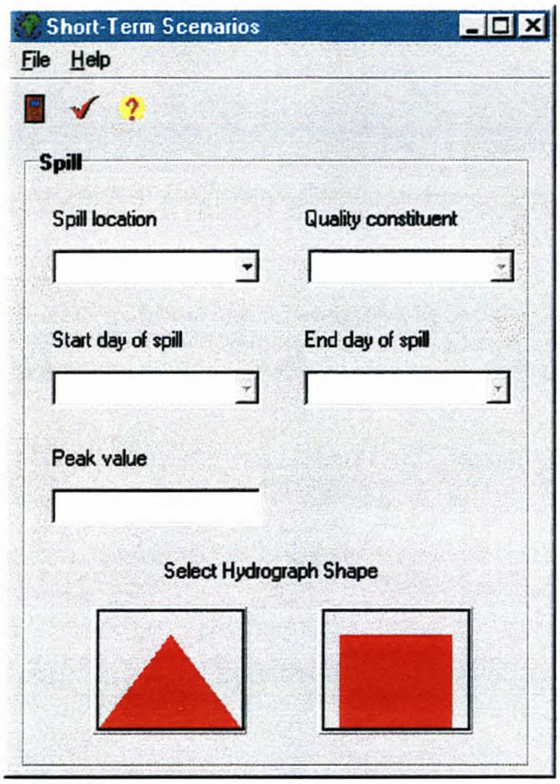


Figure B.7: Scenario Analysis - Spills

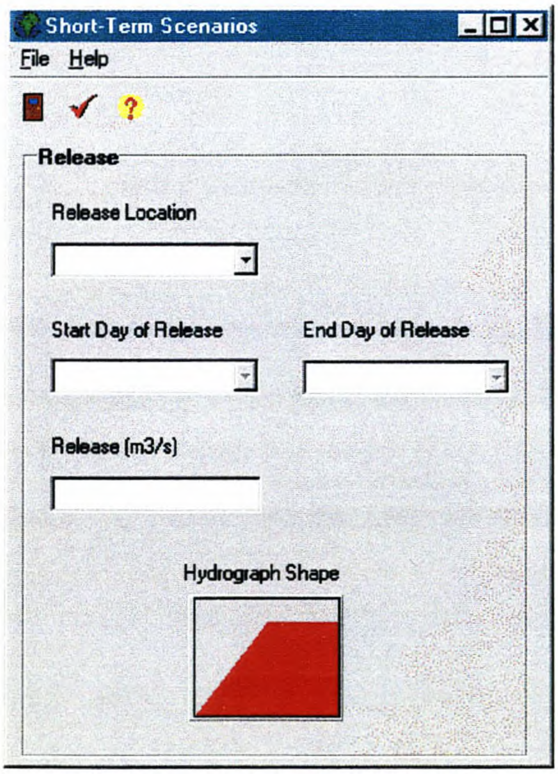


Figure B.8: Scenario Analysis - Releases

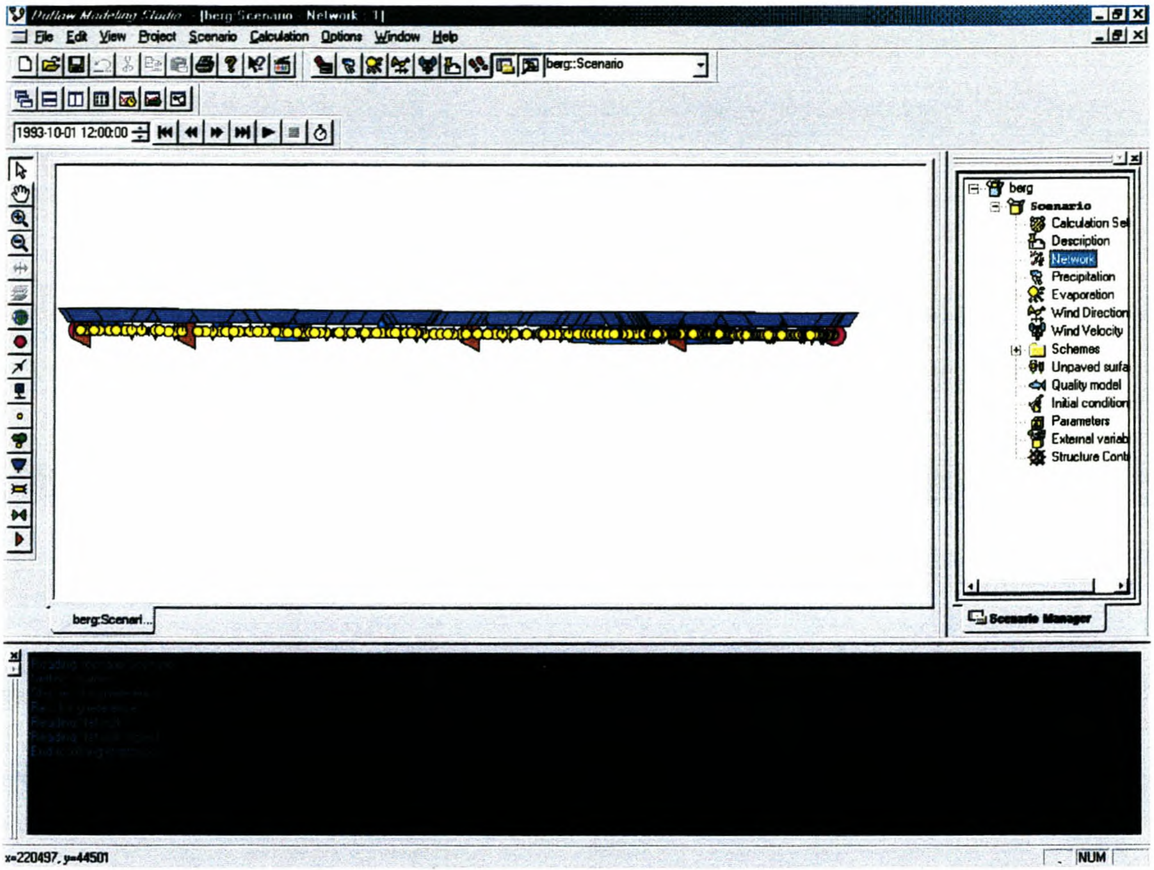


Figure B.9: DUFLOW Modelling Studio