An Information Base for a Decision Support System for Management of the Mhlathuze River

by

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Abstract

Effective integrated catchment management is dependant on suitable information describing the physical, social and economic conditions in the catchment. It also depends on knowledge of the processes controlling the environmental systems in the catchment.

This thesis describes the development of an information base (IB) for a computer-based decision support system (DSS) to support the effective management of the Mhlathuze River system. The IB has been developed to contain most of the available data, which are analysed and processed by models, for utilization by catchment managers.

The DSS and accompanying IB was developed during the formulation and implementation of the new Water Act (1998) in South Africa. It attempts to support the implementation of this Water Act, which stipulates the integrated management of water resources on a catchment basis.

The database was designed to contain all hydrologically relevant data and information on the Mhlathuze River catchment. Extensive data collection has identified information on rainfall, evaporation, flow measurements, the soil type map of the area, 1:50 000 topographical maps and 1:500 000 maps, 1991 census data, lithology and groundwater, national, regional and local boundaries, pollution and water quality monitoring points, water consumption and details of water users, etc. The database is still growing with the identification and collection of more data and the creation of additional information about the Mhlathuze River catchment from various models.

A structure was developed in the IB to give access to the megabytes of information on the database in a structured manner. The operating environment of Arcview 3 (running on Windows 95) was used to develop a user - database interaction system. The Windows concept of interactive icons was used to customise the user interface by incorporating buttons and tools to the IB. Scripts, written in Avenue, were attached to these buttons and tools, to add to the functionality of the IB.

A Digital Elevation Model (DEM) was developed from 100-metre elevation contours which originated from 1:500 000 maps. These were supplemented by digitized contours from the

1:50000 maps. The DEM has a horizontal resolution of 125 metre by 125 metre per cell, and covers the whole extent of the Mhlathuze River catchment, stretching 120 km in the east-west direction, and 60 km in the north-south direction.

A land use model for the catchment was developed from satellite imagery (7 bands from the Landsat TM satellite). Two different techniques, involving supervised and unsupervised classification methods were applied to identify the land cover classes. The supervised classification method used the maximum likelihood technique, while the unsupervised classification method applied a cluster analysis technique of classification.

For the hydrological run-off modelling of the Mhlathuze River system, the HYdrological Modelling System (HYMAS), utilising the Variable Time Interval (VTI) model, was chosen to simulate short duration hydrological events in a distributed manner. The model was used in an Instream Flow Requirements (IFR) study to identify the ecological reserve of the river. Information derived from the DEM and land use model were used during the hydrological simulations. Output from the simulations was compared to the few observed flow measurements which are available for the catchment.

Uittreksel

(Abstract in Afrikaans)

Effektiewe geïntegreerde opvangebiedbestuur is kardinaal afhanklik van geskikte informasie van die fisiese, sosiale en ekonomiese toestande in 'n opvangebied. Kennis van die prossesse wat die omgewing beïnvloed, is ook belangrik.

Hierdie tesis beskryf 'n Informasiebasis (IB) van 'n rekenaargebasseerde Besluitnemingondersteuning Stelsel (BS) wat ontwikkel is om die effektiewe bestuur van die Mhlathuze rivier te ondersteun. Die IB is ontwerp om meeste van die beskikbare data te bevat, en dit dan te analiseer en te prosseseer vir gebruik tydens opvanggebiedbestuur.

Die BS en gepaardgaande IB is ontwikkel gedurende die ontwikkeling en implementering van die nuwe Waterwet (1998) in Suid-Afrika. Dit poog om die implementering van die Waterwet, wat geïntegreerde bestuur van waterbronne per opvangebied stipuleer, aan te moedig.

'n Databasis is ontwerp om al die hidrologies verwante data en informasie van die Mhlathuze opvangebied te bevat. Informasie wat geïdentifiseer is deur intensiewe data insameling sluit in: reënval; verdamping; waterafloop; grondtipes; 1:50 000 topografiese kaarte en 1:500 000 kaarte; 1991 sensus data; litologie en grondwater; nasionale, internasionale en provinsiale grense; moniteringspunte vir besoedeling en waterkwaliteit; watergebruike, inligting oor water gebruikers; ens. Die databasis groei steeds met die identifikasie en insameling van meer data, asook die samestelling van informasie omtrent die Mhlathuzerivier deur middel van verskillende modelle.

'n Struktuur is ontwikkel om toegang te verleen na die groot hoeveelhede informasie wat bevat is in die databasis. 'n Gebruikers-databasis interaksiestelsel is ontwikkel met behulp van Arcview 3 sagteware (wat loop op Windows 95). Die Windows konsep van interaktiewe ikone is gebruik om die Arcview omgewing te manipuleer. Knoppies is aangebring in die IB en programmetjies, geskryf in Avenue, is agteraan hierdie knoppies geheg, wat die funksies van die IB uitbrei.

'n Digitale Elevasie Model (DEM) is ontwikkel vanaf 100-meter hoogtekontoere, wat verkry is vanaf 1:500 000 kaarte. Hierdie kontoere is aangevul met versyferde kontoere vanaf 1:50 000 kaarte. Die model, met 'n horisontale resolusie van 125 meter by 125 meter per sel, sluit die hele opvangebied in, en strek oor 120 km oos-wes, en 60 km noord-suid.

'n Grondebruikmodel van die opvangebied is saamgestel vanaf satellietbeelde (7 bande van die Landsat TM satelliet). Twee verskillende metodes ('n gekontroleerde en 'n ongekontroleerde metode) is gebruik om die verskillende grondgebruike in die opvangebied te bepaal. Die gekontroleerde klassifikasiemetode het die maksimum waarskynlikheid metode aangewend, terwyl die ongekontroleerde metode het die trosanalise tegniek gebruik het.

Vir die hidrologiese afloopmodel van die Mhlathuzerivier, is HYMAS (HYdrological Modeling and Application System) se VTI (Variable Time Interval) model gekies om kortstondige hidrologiese voorvalle op 'n verspreide skaal te simuleer. Die model is aangewend om die ekologiese reserwe die rivier se stroomvloei vereistes te bepaal. Informasie wat afgelei is van die DEM, sowel as van die grondgebruikmodel, is toegepas tydens die ontwikkeling van die hidrologiese model. Uitvoere van die model is vergelyk met beperkte waargenome afloopdata van die opvangebied.

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Statement of originality

The author of the dissertation hereby declares that the research done and reported in this dissertation is original work done by herself, and was not copied from any other source, unless referenced clearly.

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1 Introduction

Life on earth is dependant on light and water for survival. In a catchment, where human beings live together with nature, the developments that lead to improvements of the people's living standard (as expressed by industrial development) often impact on the natural ecosystem. These effects are critical when it impacts on the water supply that is essential for the ecological well being of the catchment. If the environmental flux is not kept within natural ranges, within which ecological systems are sustained, the situation can deteriorate to the point where there is insufficient water supply (in quantity and quality) to sustain both humans and ecological needs.

Integrated catchment management (ICM) involves balancing of the water needs of the inhabitants of a catchment (represented by the anthropogenetic developments in a catchment) and the ecological water needs (which are described in the National Environmental Act, 1998). The human demands on the water resources of a catchment are as socially complex as those that describe the environmental water needs. In order to maintain the resources of a catchment in a sustainable manner, it is necessary to be cognizant of the socioeconomic conditions, as well as the physical environmental conditions. This thesis, however, concentrates entirely on the physical features of the catchment, but recognizes the extreme importance of the social and economic constraints.

In order to effectively manage a catchment, it is necessary to develop an understanding of the significant processes and interactions that control the catchment features. This knowledge is derived from data and information that must form the underlying basis of ICM. Data that are usually collected in a catchment, are diverse, and usually collected for very specific purposes, that were not necessarily intended for integrated catchment management. However, for effective management of a river's catchment, there is a need to collect this data, capture it into a system that is suitable for analysis and dissemination. Generally, in most catchments, the captured data is insufficient for catchment management and it needs to be supplemented by information derived from other resources such as models that incorporate the physical features and processes in the catchment.

The Water Act (1997) and the National Environmental Management Act (1998) have established new control measures and structures for environmental management. These management structures are critically dependent on monitoring, recording, assessing, generating and disseminating relevant information on natural resources for their effective functioning. These Acts require that environmental management must be integrated, acknowledging that all elements of the environment are linked, and they must pursue the selection of the best practicable environmental option, taking into account the effects of decisions on all aspects of the environment and all people in the environment. These new Acts place a very heavy burden on information requirements and on the expected dissemination of the information to stakeholders. These laws advocate a risk-averse and cautious approach to environmental management, which takes into account the limits of current knowledge about the consequences of decisions and actions.

The legislation and recognized guidelines require management structures of a region, to make decisions on the basis of best available information for the region. These recent developments in regional management structures are also supported by International Standards (ISO14001) that are placing a heavy burden on managers to make informed decisions. Consequently, there is a great need to provide and disseminate relevant information for decision makers at the catchment scale. It is essential that the information achieves credibility with the relative stakeholders, who must be fully informed of all the assumptions and techniques employed in information generation.

This project was initiated to develop an information system for conducting relevant Environmental Impact Assessments (EIA) of proposed developments in the Zululand region. However, the development of the Information Base (IB) has been extended to support the development of a Decision Support System (DSS) that is intended to cater for greater needs in integrated catchment management. The DSS is being developed around a regional database supported by relevant tools to provide information which support the various management options in the catchment.

1.1 Background

The legal requirements to water resource management in South Africa have been changed dramatically by the Water Act of 1998. Requirements include integrated catchment management, as well as the formation of Water Management Areas managed by Catchment Management Agencies. Several reports have been published on suggested routes to be taken by water resource managers to implement the requirements of the 1998 Water Act. For an example, see Görgens (1998).

The development of the IB in this project has been directed at the Mhlathuze River catchment which is situated in the northern part of KwaZulu/Natal in South Africa (Figure 1.1). It discharges into the Indian ocean through the Mhlathuze estuary at Richards Bay. In this 4000-km^2 catchment, the growing water demands, which include irrigation for formal and subsistence farming, as well as industrial and municipal water, have already exceeded supply (DWAF, 1997). This implies that the social process of water allocation negotiation is crucial and has begun.

The main water sources of the Mhlathuze River catchment, which are used to meet the growing demands of the region, are:

- the Mhlathuze River
- the Goedertrouw Dam (full capacity: 320 million cubic metres)
- Coastal lakes:
    - Lake Chubu (full capacity: 10.5 x 10^6 m^3)
    - Lake Nhlabane (full capacity: 40 x 10^6 m^3)
    - Lake Mzingazi (full capacity: 55000 m^3)
    - Lake Nsezi (full capacity: 834 000 m^3)
- Off-channel lakes:
    - Lake Mangeza
    - Lake Mpangeni
- Mfuli River
- Nseleni River (which flows into Lake Nsezi)
- Mhlatuzana River
- the Thukela River Catchment Water Transfer Scheme (DWAF, 1994)
- the Mfolozi River inter-basin transfer scheme.

Figure 1.1 indicates the positions of the main river courses with their catchment boundaries, and the main lakes in relation to the larger towns in the area.

The dry spell of 1993 to 1995 caused the level of the Goedertrouw Dam to be drawn down to the critical low level of less than 20% in September 1995 despite the implementation of severe water restrictions. This situation confirmed earlier concerns of the Department of Water Affairs and Forestry (DWAF) about the consistency of adequate water supply to the growing demand in the Mhlathuze catchment (DWAF, 1990). The development of an emergency water transfer scheme was initiated during the dry spell to transfer water from the Thukela River basin into the catchment of the Goedertrouw Dam.

The foundation for integrated catchment management in the Mhlathuze River basin was laid by the Drought Management Committee for the Mhlathuze water resources which was formed during the dry period of 1995. This committee ceased operation after the drought was broken by the exceptionally good rain season in 1995/96. After the proclamation of the Water Act in 1998, the DWAF and Mhlathuze Water initiated a study on the Mhlathuze water resources, consisting of two parts:

1. Mhlathuze: Operating Rules and Future Phasing Structure, and
2. Mhlathuze: System Environmental Study.

Part of the initiatives taken during these two studies was the formation of the Mhlathuze Stakeholders Committee in 1998. The objectives of this committee were to:

- set a vision for the water resources of the Mhlathuze Catchment,
- recommend the ecological management class of the water resources in the Mhlathuze Catchment,
- provide recommendations for the ecological reserve of the Mhlathuze Catchment.

These initiatives have not been finalised, but they are expected to recommend significant reduction in water allocation in order to comply with the Water Act (1997) and to meet estimated future requirements.

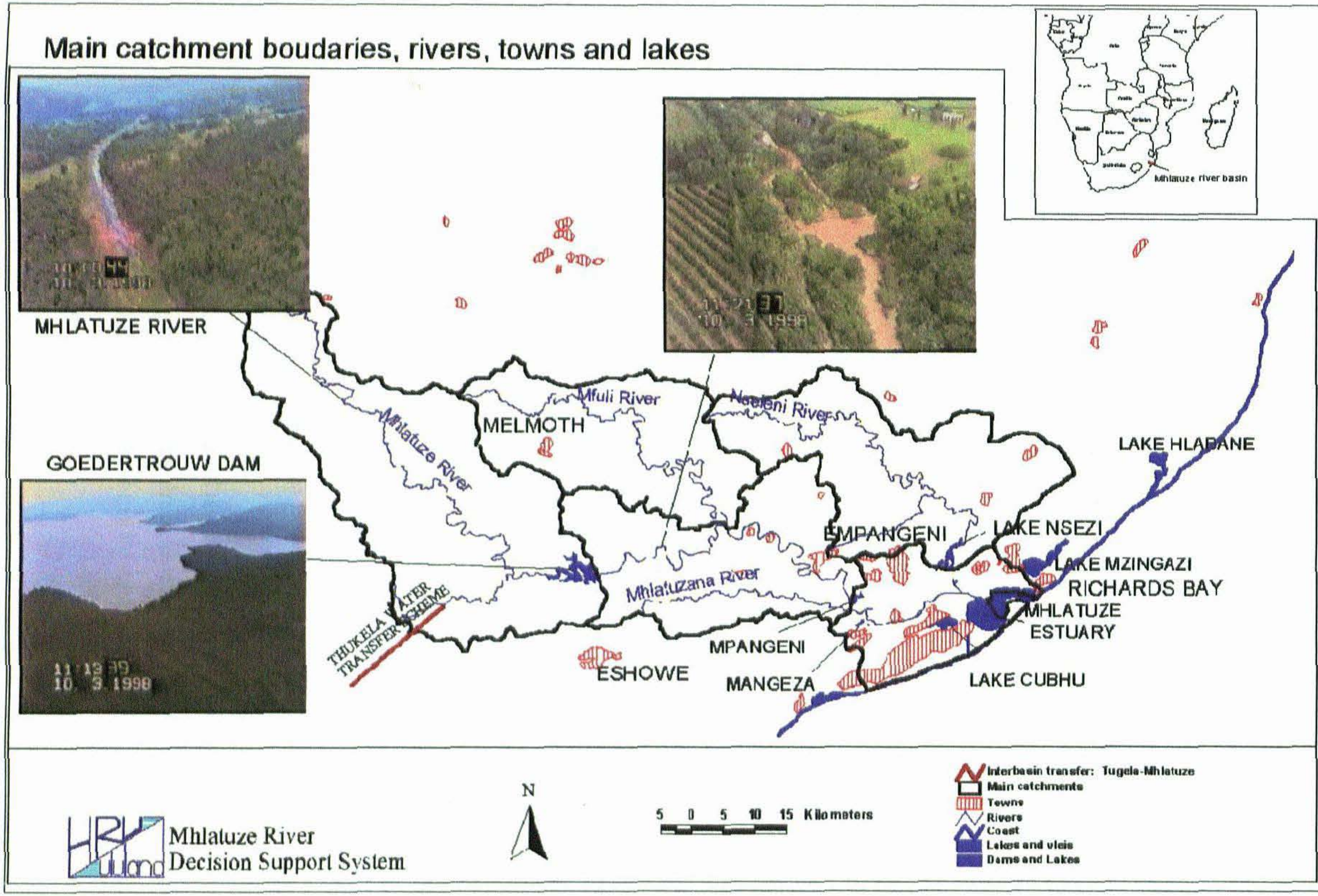

Figure 1.1: Main river courses with their catchment boundaries and bigger towns in the area.

1.2 Aims and Objectives

The primary aim of this project is to develop an Information Base (IB) which will ultimately form part of a Decision Support System (DSS), as a tool towards achieving informed management decisions of the Mhlathuze catchment. The IB is designed to incorporate a database containing relevant information for water resource management, to adopt methodologies for integrating information storage and retrieval, and to develop a structured system that will provide a tool for assisting in the planning and management of the water resources of this rapidly developing region of Zululand, in a sustainable manner.

To achieve the aims of the project, several objectives have been stipulated:

- The *collection of data* relevant to the water resources of the Mhlathuze River catchment.

- The development of an *integrated spatial and sequential database*, which also includes graphical information and digital reports, all accessible from one GIS-based user platform.

- *Analysis of the data to create physical information* of the catchment characteristics to support decision making, in particular
  - the development of a *Land Use Model* for the catchment from satellite imagery
  - the development of a *Digital Elevation Model* (DEM) of the Mhlathuze River catchment.

- Identification and incorporation of models to create required additional information for catchment management, in particular the implementation of a *hydrological model for the simulation of the surface run-off* of the catchment water resources, making use of the information contained in the database, the DEM and Land Use Model.

- The *integration of the above-mentioned database and models* into one system, giving user access through a GIS platform, from where the vast scope of water-related information of the Mhlathuze catchment can be made accessible to stakeholders of the water resources.

2 Description of a Catchment Management Decision Support System

There are numerous Decision Support Systems (DSS) being developed worldwide. The DSS concept has been applied to many facets of life where computer-aided graphical interface has been used to display a user friendly picture of the assumed or simulated effects of changes to a system. Applying the DSS concept to the management of water resources in a catchment has great potential.

The concept of Decision Support applied to management of water resources and supported by computerised systems has been described extensively by Fedra (1995) who suggest that the key to useful computer-based decision support is *integration*. He goes on to explain that "integration recognizes that in any given software system for real-world applications, several sources of information or data bases, more than one problem representation or model, and finally a multifaceted and problem-oriented user interface, ought to be combined in a common framework to provide a realistic and useful information base."

Decision support is a broad concept (Fedra, 1995) which involves the investigation of alternative solutions to possible problems and constraints, and ranking of these solutions. To come to the optimal solution (or simply a possible solution), it might prove necessary to add additional constraints or relax other constraints. Consequently, a DSS that aids in decision making, will also aid in problem identification. It will evaluate management decisions by revealing assumed effects of changes in the catchment.

Görgens (1998) advocates that "integrated water resource management is simultaneously a *philosophy*, a *process* and an *implementation strategy* to achieve equitable access to and sustainable usage of water resources by all stakeholders at catchment, regional, national and international levels, while maintaining the characteristics and integrity of water resources at the catchment scale within agreed limits."

2.1 Desired attributes of a DSS for Integrated Catchment Management

Different issues are addressed by different models within a catchment management DSS. Each DSS (and each model within each DSS) are moulded to fit the needs of a specific situation, the resources available for the development of the DSS and the catchment that is under consideration.

However, a similar design style occurs in most DSS's that are shaped around catchment management. Most catchment management DSS's have the following common attributes:

- aid in decision making at a certain management level (e.g. a technical level, or a strategic planning level, etc.);
- integrate computer technologies for the benefit of the decision maker;
- incorporate a database of sequential and GIS related data, and include images and digital documents;
- have more than one model embedded in the DSS for simulating different forces at work in the catchment, but mostly concentrate on one specific problem or application area;
- provide a Graphical User Interface (GUI) platform to display the input to and output from the models linked to the DSS;
- link different software packages (to some degree) in an attempt to unify the output from different simulation packages to provide information in support of management decisions;
- sometimes incorporate economic and social models;
- have recognized the need to incorporate an Artificial Intelligence component.

The development of a catchment DSS can be conceptualized as a simple integrated graphical user interface of a database, which transforms data into information, by one (or more than one) acceptable simulation model and graphical output module, that can be used for displaying the effects of changes in the catchment. It conceivably can grow into a system of interlinked databases from different computer systems with interlinked models (incorporating many of the possible issues at stake in the catchment) in a computerised environment where all models incorporate aspects of the output from other models in the system (on a real time basis). From the output of this 'unified model' the effects of changes can be displayed graphically with maps, graphs, tables, animated pictures, etc. It could also include a component of artificial intelligence. Systems of this nature are still under development and are unlikely to be generally available for the immediate future.

A search of the Internet identified many DSS's that are in various stages of development for some aspect of catchment management. These include:

1. DESERT: DEcision Support system for the Evaluation of River basin sTrategies. *(Http://www.iiasa.ac.at/Research/WAT/docs/desert.html)*
2. SMART PLACES: a geographic decision support system which assists communities in assessing the implication and opportunities of alternative development plans. *(http://www.Smartplaces.com)*
3. WATERSHEDSS: This model transfers water quality and land treatment information to watershed managers in order to assist them in making appropriate land management decisions, and assists and evaluates sources, impacts and potential management options for control of non-point source pollution. *(http://h2osparc.wq.ncsu.edu/)*
4. Integrated Catchment Information System (ICIS): the software is part of a DSS which includes a comprehensive data base of scientific information on the rivers in the Kruger National Park (South Africa), as well as several models simulating different aspects of the water resources, with integrated graphical output displays. *(http://www.ccwr.ac.za/icis/)*
5. WaterWare: A water resource management system. It is an integrated, model-based information and decision support system for water resources management and has been developed through a series of applications to different river systems. *(http://www.ess.co.at/WATERWARE/)*
6. MMS: The Modular Modelling System address the problems of model selection, application, and analysis. The framework for MMS has three major components: pre-processing (input, analyse, and preparation of spatial and time-series data), modelling (simulation and analysis tasks), and post-processing (display and analyse model results,

and pass results to management models or other types of software). (*http://wwwbrr.cr.usgs.gov/mms/*)

7. The Colorado's Decision Support Systems: This comprehensive study on the Colorado River catchment (situated in the US) addresses management and decision support issues. Projects under the main study include database development, modelling, system integration and user involvement. (*http://crdss.state.co.us/*)
8. BASINS: Better Assessment Science Integrating Point and Non-Point Sources, which integrates a GIS, national watershed data, and state-of-the-art environmental assessment and modelling tools into one convenient package. (*http://www.epa.gov/ost/basins/*).

Each river's catchment has its own unique characteristics and constraints, and provides unique opportunities, determined by its administrative, socioeconomic, land use and environmental resource character (Görgens, 1998). Each catchment needs its own tailor-made DSS, depending on the level of knowledge, degree of expectation and development and socioeconomic conditions which vary considerably within and between catchments. While catchment DSS's must share commonalities in decision support functions, they will all have unique requirements for specific catchments.

2.2 The conceptual model of a DSS: Integrating GIS and hydrological modelling for catchment management

A Geographical Information System (GIS) is in essence a tool for the display, manipulation and analysis of spatial features (vectors, points, polygons and raster images). The simpler versions of GIS specialise in vector analysis, while more complex GIS's also include raster image analysis. The latter bring better functionality to the desktop of the researcher, but also require more expensive computer hardware. With the ever increasing rate of computer functionality (in both hardware and software realms) available on the market, the vector-based GIS's are integrating more and more raster functions (Kelbe, Snyman and Germishuyse, 1999).

The spatially distributed features of a catchment have generally been described by models that have been used extensively to support management of catchments. The relationship between the management of a catchment and GIS needs to be viewed from the point of the decision maker. Effects of changes in a catchment (due to either specific decisions or more naturally occurring changes) can be visualized through maps, graphs and graphics, that display the effects of changes on the water resources. This provides catchment managers with the broader picture instead of hard (but more accurate) data in tabular form (Fedra, 1994). Adding a GIS component to a catchment management Decision Support System is to provide interactive support for visual presentation of spatial information and to support spatial modelling and analysis of relevant data. The spatial modelling and analytical capabilities of the GIS also provide support for a hydrological model in the Catchment Management DSS where representation of processes requires spatial integration.

The linkage between a hydrological simulations and a Geographical Information System is logical, but the implementations of this link are still in the development phase for the Mhlathuze River catchment. This is due to the spatial characteristics of a catchment that are lumped together when representative values for parameters are used in most hydrological models. "Maps of parameters" displaying the spatial values of parameters (as well as the variability of the parameters) in the hydrological model (e.g. the slopes of a catchment which were derived from a digital elevation model) can provide a better picture, but are still lumped together during the runtime of the model.

Frequently, the linkage between GIS and the hydrological model are found to be one of "working alongside" rather than "integration", which speaks of a level of closer cooperation. "Linkage with GIS is frequently found, but in the majority of cases, GIS and environmental models are not really integrated, they are just used together. GIS is frequently used as pre-processors to prepare spatially distributed input data, and as post-processors to display and possibly further analyse model results." (Fedra, 1994).

2.3 Catchment Management in South Africa

Integrated catchment management in South Africa is conceived by Görgens (1998) to be simultaneously a philosophy, a process and a strategy to achieve a sustainable balance between utilization and protection of water resources in a catchment. Catchment Management must recognize the need for mutual dependence of water, land use and aquatic ecology management through a consensus by relevant stakeholders, communities and organs of state. This should be achieved through four different levels of catchment management, which have their origin at the simple entry level of surface water and groundwater management. This should include both the water quality and quantity. On the other end of the scale, the "ideal" level of catchment management will include the consideration of water, land and other environmental resources, as well as the social and economic conditions in the catchment. This is driven by the principle that the development of the human society can be sustained if and only if water and other natural resources are wisely managed.

In South Africa, this concept of the "ideal" catchment management strategy has gained widespread support, but actual implementation is still in the early stages of development.

It is recognized that the role of a DSS in catchment management will be determined by its functionality in the framework of a catchment management strategy. In a catchment management strategy, the **VISION AND FOCUS** should be clarified and used as part of the guidelines for implementation of the Catchment Management Process. The guidelines for the vision and focus are quoted from Görgens (1998):

Guideline 1:

> *A catchment management initiative should take cognisance of the values of, and the pressures on, the society which is dependent upon the water resources in that catchment.*

Guideline 2:

> *Every catchment has a unique character and resources, which requires the development of a locally appropriate vision of the catchment's future and a locally appropriate process to ensure sustainable management.*

Guideline 3:

Initially, the focus of catchment management should be limited to a few existing or perceived water-related issues on which "sufficient consensus" has been achieved, with other issues being included once experience and success is achieved.

Guideline 4:

Catchment management should address all components of water resources and all elements of the hydrological cycle which may relate to each issue.

Guideline 5:

Building vision and developing a focus for the catchment management process requires systematic planning and the allocation and application of considerable resources, which have to be planned and budgeted for.

Similar guidelines are listed by Görgens (1998) for the implementation of Catchment Management, regarding the following issues:

- Scale of Catchment Management
- Integrated Management Process
- Stakeholder and public participation
- Initiation
- Catchment Management Structure
- Financing
- Assessment
- Planning
- Catchment Management Strategy/Plan
- Implementation
- Administration

- Review
- The way forward: towards Integrated Catchment Management

Regarding the last issue on the above-mentioned list, i.e. the way forward, it is suggested that the catchment management structure should attempt to increase integration of spatial and environmental resource planning, as ongoing steps towards "ideal" integrated catchment management in the decision process.

2.4 Conceptual model of the IB of the Mhlathuze River catchment

The IB under development in this study is aimed at application in the Mhlathuze River catchment. It was originally intended as a support tool for Environmental Impact Assessments (EIA). This was extended to include integrated catchment management for Strategic Environmental Assessments (SEA) and Catchment Management Agencies (CMA's).

The *conceptual model of the system* being developed, consists of the following components, each providing information through appropriate software:

- a database with the relevant scientific information for the DSS (including sequential data, maps, reports and images in digital format)
- a graphical user interface, which provides access to the digital data
- numerical models, which provide relevant information for the evaluation of scenarios of water management decisions, including surface water and groundwater modelling
- a platform for the evaluation of model outputs from different scenarios via statistical analysis and graphical display.

2.4.1 The catchment

The *catchment* under investigation is the Mhlathuze River (Figure 1.1), which is linked to other catchments via two inter-catchment water transfer schemes. Water transfers will be taken into consideration in the Mhlathuze River if water shortage arises, but no consideration is given to the transfer effects in the donor catchments.

The *water features* covered in this investigation are the surface water resources of the Mhlathuze catchment, as well as some of the groundwater features. The groundwater component along the coastal plain is considered to be part of the catchment and has been incorporated into the system by Kelbe and Germishuyse (1998). The water quality component can be included at a later stage and is not considered in this dissertation.

2.4.2 The database

Fedra (1995) points out that the data and background information of a river catchment can be brought together in one single system which overcomes "technical problems such as different units of measurement, different map projections, hard to trace paper files and missing documentation." The Mhlathuze IB overcomes this by putting all water resource related information (including sequential data, digital maps, digital reports, and images) onto one user platform from where it can be accessed easily.

The database provides the digital data through appropriate computer software. The input of data into the correct format for reading by the water resource models needs to be done seamlessly by a user friendly "expert system" which is programmed to retrieve information from the database and prepare the data for reading by the models. Preparation of data by this expert system requires a number of tools to extract and filter, reformat and convert, interpolate and extrapolate, adapt and often interpret the original data (Fedra, 1995). Most of this work needs to be done manually in the Mhlathuze River DSS, but with ongoing development a customised expert system can be developed.

A workshop was attended during which the attendants attempted to set national standards for time series data in South Africa. At this workshop no single standard was identified, but it was agreed that current research could conform to one of two data file formats. They are the Watershed Database Management (WDM) file format from the United States Geological Surveys (USGS), or the commercial DBF file format used in most relational database systems. However, the Mhlathuze IB currently maintains the use of the source data format, with limited transformation necessary where it is for the application of some of the expert tools.

The Mhlathuze IB has collected a vast array of data which supports the numerical models for creating the necessary information for management decisions. The difficulty is to determine the information needs and priority of these needs for effective catchment management. Before negotiations commence over water allocations, the needs are latent. The process of interaction between stakeholders advisors will clarify information needs, develop trust in the information and prioritise the information (Mark Dent, pers. comm., 2000).

2.4.3 The graphical user interface

The user interface is the place where the visualization of information in the IB takes place. It offers one platform from where both data and information can be retrieved and presented to the users. "Visualization provides the bandwidth necessary to communicate and understand large amounts of highly structured information, and permits the development of an intuitive understanding of processes and interdependencies, of spatial and temporal patterns, and complex systems in general. Also, many of the problem components in real-world planning or in a management situation, such as risk or reliability, are rather abstract: a graphical representation of such concepts makes them tangible objects that can literally be manipulated and understood intuitively." (Fedra, 1995)

In the Mhlathuze River IB the ESRI software, Arcview 3, has been chosen, as the Graphical User Interface (GUI). The version chosen was designed to operate on a PC Windows platform. Its principal function is to display and manipulate digital vector-based maps, but it is not restricted to this function. It provides add-on tools (called extensions) for image display and manipulation, as well as functions for the acquisition to the digital database and for handling data of different kinds such as tables, reports, images, etc. An Internet Map Server (IMS) for general user access across the Internet to the DSS's functionality, is being implemented as part of the IB.

Although some of the sequential data were included in the database in its original format, the GIS related data were restructured to Arcview shapefiles, which makes it possible to access all spatially related information from the Mhlathuze IB's GUI.

2.4.4 Models

Fedra (1995) expresses the possibility for including rules in an expert system, and at the same time use embedded rule-based component in models which can provide a repertoire of building blocks for interactive software systems that link policy level information with the underlying data. The development of this features of an IB can be done in the environment of Avenue, which is the application development language for Arcview.

The creation of relevant information from the available or generated data requires appropriate tools in the form of numerical models. These models must be viewed as a sequence of assumptions in order to play a role in the bargaining process over water allocation. However, all these tools (or models) require data to drive their exogenous variables and to derive estimates of their endogenous variables and parameters. The IB is being created to determine these requirements and to either source the additional data and capture it in a suitable format or to obtain (create) suitable methods (models) to generate the required information. Consequently, there is a need to determine the suite of methods and models which are required in the Mhlathuze IB to provide the information needs of the catchment authorities. This is an ongoing process which has identified some of the information requirements described above. Incorporated in the IB is the Variable Time Interval (VTI) model (Hughes, 1994) and the Modflow Program (Guiguer and Franz, 1996) that provide hydrological information for testing management options.

The VTI model is one of the models included in the HYdrological Management And Simulation (HYMAS) Program. It simulates the surface run-off from the catchment on a daily basis and includes the feature of a changing simulation time interval if the need arises during times of intensive changes in catchment processes. A more extensive description of this model is provided in Chapter 4.

The Modflow Program was used to simulate the groundwater component in the areas surrounding some of the coastal lakes. Germishuyse (1999) describes Modflow as a finite-difference model, with the model domain being divided into a grid of rows, columns and layers which form rectangular three-dimensional array of cells. Within each cell there is a node at which the head is calculated. For steady state simulations, the model domain is configured for one very long time period. For transient flow conditions, the parameters must be specified for each time interval (referred to as stress period).

Modflow is designed to simulate geohydrological flow conditions in saturated porous media and to determine the water balance of aquifer systems that include the effects of groundwater extraction. The groundwater flow patterns can be derived from the simulated elevation of the groundwater. These flow patterns indicate surface areas (e.g. industrial waste sites) that contribute to groundwater which flows directly into surface water resources such as dams or lakes. This model has been described in detail by Germishuyse (1999) and Kelbe and Germishuyse (1998) and has not been included in this thesis.

2.4.5 Interactive access for scientific application

Once the database has been established, and the simulation models have added the supplementary information to the databases which are not available from measurements, the users of the IB need a platform to obtain access to these different components of the information.

Evaluation of model outputs through visualisation exposes the user to the effects of changes to the current system. Interaction between the user and the system are essential, as "...interaction is a central feature of any effective man-machine system: a real-time dialogue, including explanation, allows the user to define and explore a problem incrementally in response to immediate answers from the system; fast and powerful systems with modern processor technology can offer the possibility to simulate dynamic processes with animated output, and they can provide a high degree of responsiveness that is essential to maintain a successful dialogue and direct control over the software." (Fedra, 1994).

The visualisation of model outputs in the Mhlathuze IB can be developed through Arcview's

Dialog Designer, which can be used to create a customised front-end for a man--machine interactive system using Windows concepts.

It is envisaged that the IB of the DSS can be used for *negotiation support* by stakeholders as an interactive tool during meetings such as the Stakeholders Committee meetings. As water shortage issues are addressed by stakeholders of water resources, insight can be provided at the meeting to the effect of suggested solutions to problems. Graphical display can provide insight into changes to water demands and rainfall scenarios (Mark Dent, pers. comm., 1999).

The IB is being developed in this study to form part of a DSS which conforms with the attributes of a catchment management DSS described in Section 2.1: *"Desired attributes of a DSS for Integrated Catchment Management."* However, it excludes the social and economic models and the process of negotiation which are important for a complete management tool. The system should undergo constant development as changes occur in the catchment and as different issues arise around water demands. It should be kept current with ever-increasing computer technology to keep the IB market related: not only does the database need updating on a regular basis, but the hydrological models should be constantly upgraded to incorporate new developments in the sphere of water resource modelling. Exciting new developments are taking place worldwide regarding the implementation of Artificial Intelligence in systems like these, but the implementation of these (and many other new) concepts lies outside the frame work of this dissertation. However, the IB was designed to provide opportunities for changes to the system for future development which can incorporate new trends in information technology and integrated catchment management systems.

3 Climate, Geology and Water Resources of the Mhlathuze River basin

The water resources of a region or catchment are associated with the storage components of the hydrological cycle and the transfers between these storage components. The sources and sinks controlling the resources are also an integral part of their function. Consequently it is important to evaluate all of the major water resources and the controlling features within a catchment. This chapter examines the level of knowledge about the climate, geology and the main water resources of the Mhlathuze River catchment.

3.1 Regional Climate and Rainfall

The climate of northern Zululand, where the Mhlathuze River catchment is situated, can be described as subtropical, with humid summers and moderately warm winters, with most of the annual rainfall occurring during the summer (September to March).

The general climate of Southern Africa has been described by Preston-Whyte and Tyson (1988). The climate of the region where the Mhlathuze catchment is situated, is affected by tropical systems during late summer (February to March) when exceptional heavy rainfall and high temperatures can occur. During winter (June to August) the influences of the middle latitude cyclones and frontal systems generally prevail to produce widespread rainfall. The intermediate season, particularly spring (September to November) have frequent thunderstorms that create intense, short duration storms that often occur in association with synoptic features (Kelbe, 1988).

3.1.1 Rainfall

Reliable long term rainfall records for the catchment are few and they are not evenly spread throughout the catchment (Figure 3.1). There are more rainfall records for the flat coastal zone, where there is a good infrastructure that provides observers accessibility to the area, even to rural areas. The opposite is true of the mountainous catchment areas upstream of the Goedertrouw Dam and in the catchment of the Mfuli River where there are some restrictions on the accessibility. In these areas there are few rainfall records of significant length. This should be kept in mind during interpretation of the rainfall maps, as well as catchment rainfall records generated for the simulation of the surface water run-off using simulation models. These distributed maps and catchment records are produced from the available point rainfall measurements. Sources of the rainfall records measured in the catchment are the SA Weather Bureau, SA Sugar Association and the Department of Agriculture. These reocrds were provided by the Computing Centre for Water Research (CCWR).

Mean annual rainfall and mean monthly rainfall maps have been incorporated in the IB from two sources. WR90 (Midgley, Pitman and Middleton, 1994) rainfall fields (Figure 3.2) were purchased to supplement the minute by minute grid rainfall (Dent, Lynch, and Schulze, 1989). Because these data sets have been created for different purposes and are used by various agencies in numerical models, they represent different spatial scales. An effort is being made by Fourie (HRU, personal communication) to create images of the mean rainfall fields at greater spatial resolution for modelling purposes.

The measured rainfall records indicate a mean annual rainfall of 700 mm along the western section of the catchment, which gradually increase to a value more than 1200 mm on the flat coastal zone in the east. See Figure 3.1. Taking into consideration that some of the rainfall originates from storms which move in a northern direction along the coast, it is clear that the mountains which form the southern catchment boundary of the Mhlathuze River catchment, creates a rainfall shadow area to the north of this catchment boundariy. The Nkwaleni Valley lies in the heart of this rainfall shadow area. This statement is confirmed by the mean annual measured rainfall of several rainfall stations in the valley, and rainfall stations in and around Eshowe, which

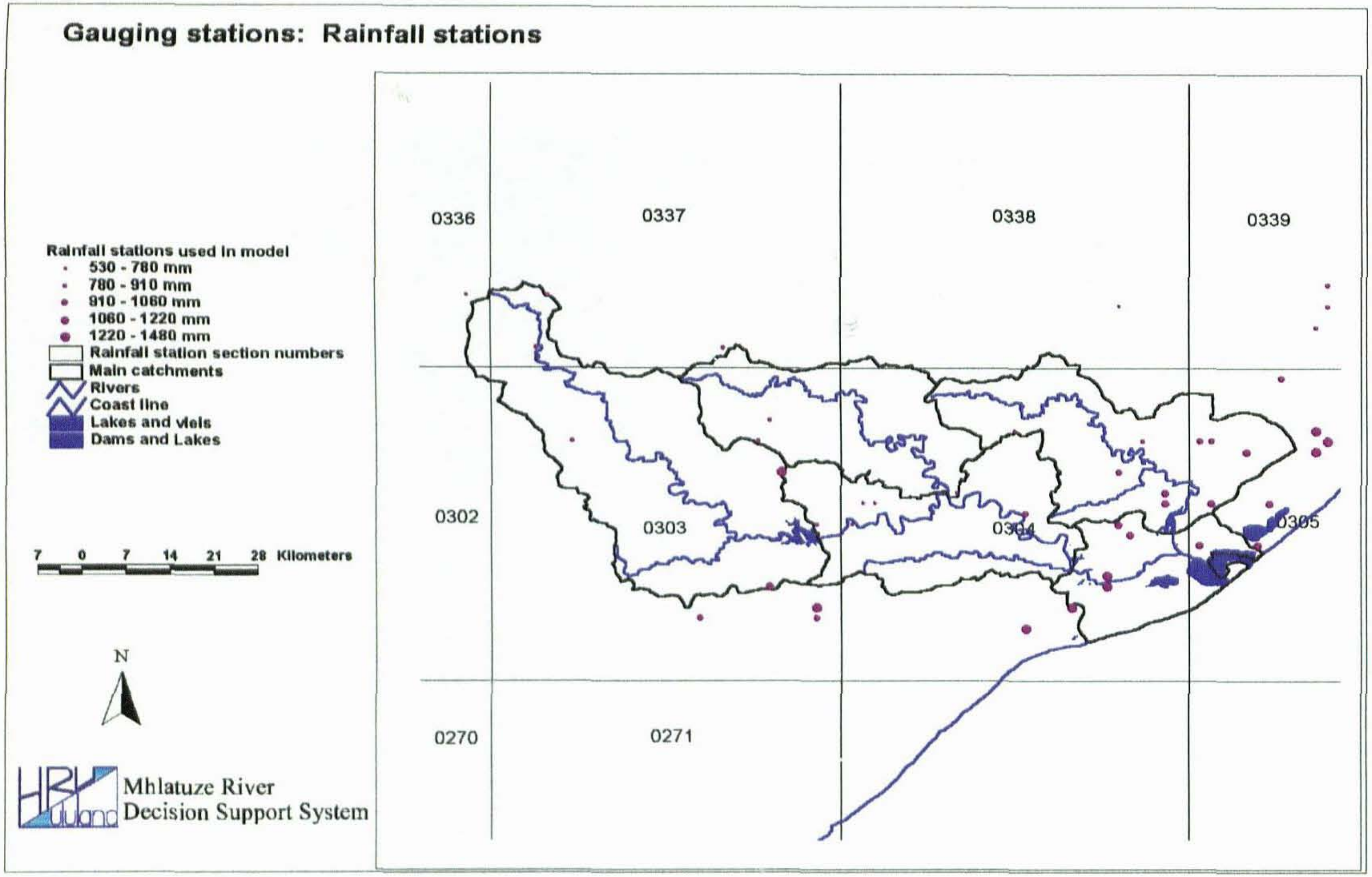

Figure 3.1: Position of the rainfall stations used in surface water simulations (source: Department of Agriculture, SA Sugar Association, SA Weather Bureau), as well as positions of evaporation stations in the area (source: DWAF). Weather Buro rainfall station blocks are also indicated by the numbered grid. The Mhlathuze catchment falls entirely in the blocks 303, 304 and 305.

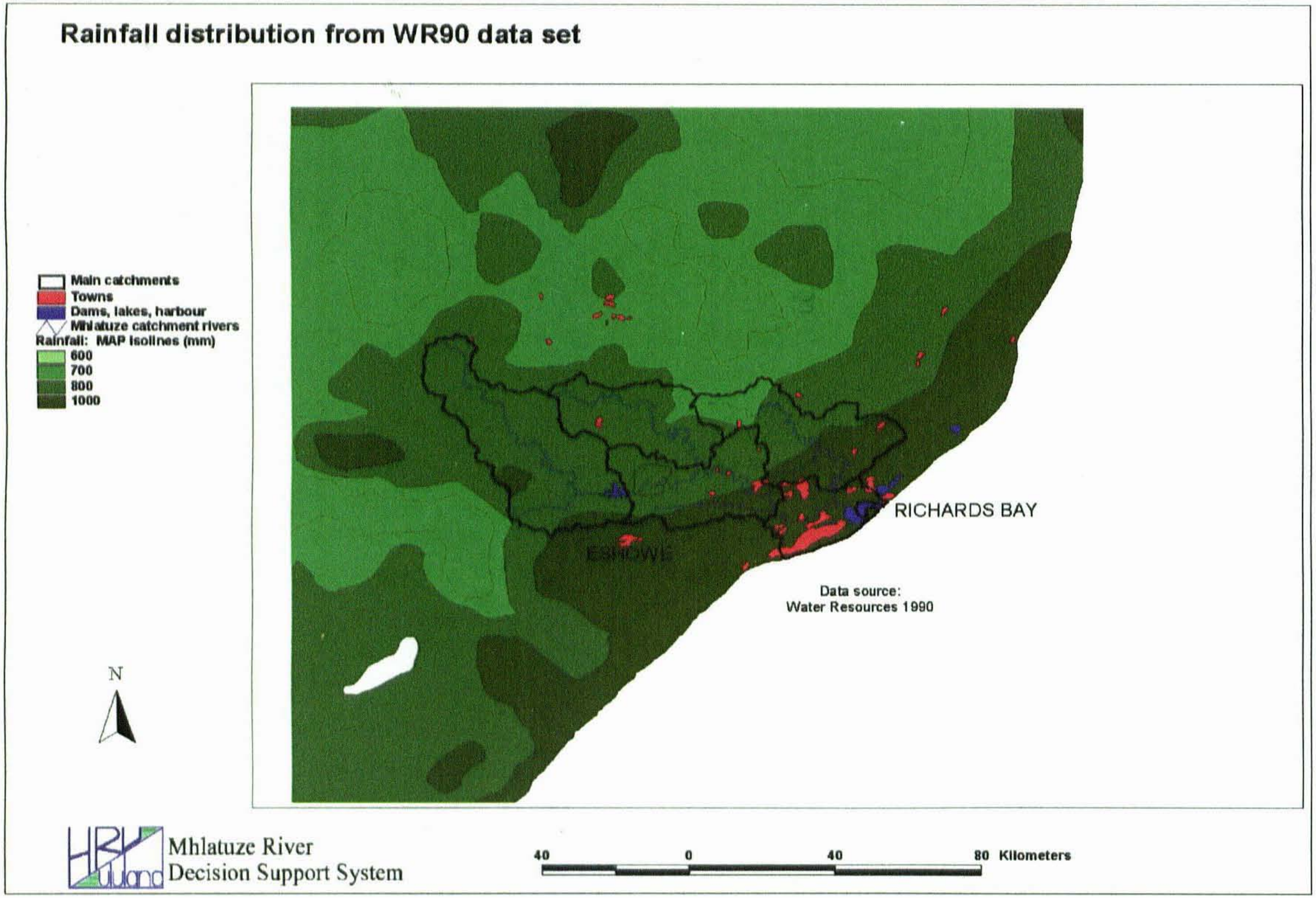

Figure 3.2: Spatial rainfall estimations from the WR90 data set.

is situated south of the catchment boundary. These stations are indicated in Figure 3.1. The Mhlathuze River catchment upstream from the Goedertrouw Dam does not have sufficient measured rainfall records to confirm this theory.

3.1.1.1 Spatial rainfall maps

The WR90 data set (Midgley *et al*, 1994) indicates an increase in rainfall from the flat coastal zone in the east to the mountainous inland catchment in the west. See Figure 3.2. The minute by minute rainfall grid (Dent *et al*, 1989), indicates a similar rainfall pattern, but also shows higher rainfall on areas which are both forested and high in altitude. However, the WR90 data set (Midgley *et al*, 1994) shows much less spatial structure when compared to the rainfall grid (Dent *et al*, 1989). The rainfall grid (Figure 3.3) has been created from the rainfall observation surface and an estimate of the MAP for each minute by minute grid was derived using *inter alia* the altitude, the latitude, the longitude, the distance from the sea and the distance from topographic barrier which would induce orographic rainfall, where appropriate. (Dent, *et al*, 1989). Fourie (HRU, pers. comms.) is currently seeking a linear relationship between the rainfall and topographical elevation to increase the spatial resolution of the available rainfall maps.

3.1.1.2 Temporal rainfall data

Rainfall records were obtained from the CCWR database for the catchment of the Mhlathuze River and surrounding area (Figure 3.1). The area bordered by longitude 30 degrees 30 min to 32 degree 30 minutes and latitude 28 degrees 15 minutes to 29 degrees 30 minutes provided almost two hundred stations which were of variable length of record and observation period.

Stations were discarded for the IB which had the following features:

1. All stations with a record length of less than five years.
2. Rainfall stations which were too far from catchment boundaries.
3. Rainfall stations which fell in a different rainfall regime from the nearest catchment boundary.

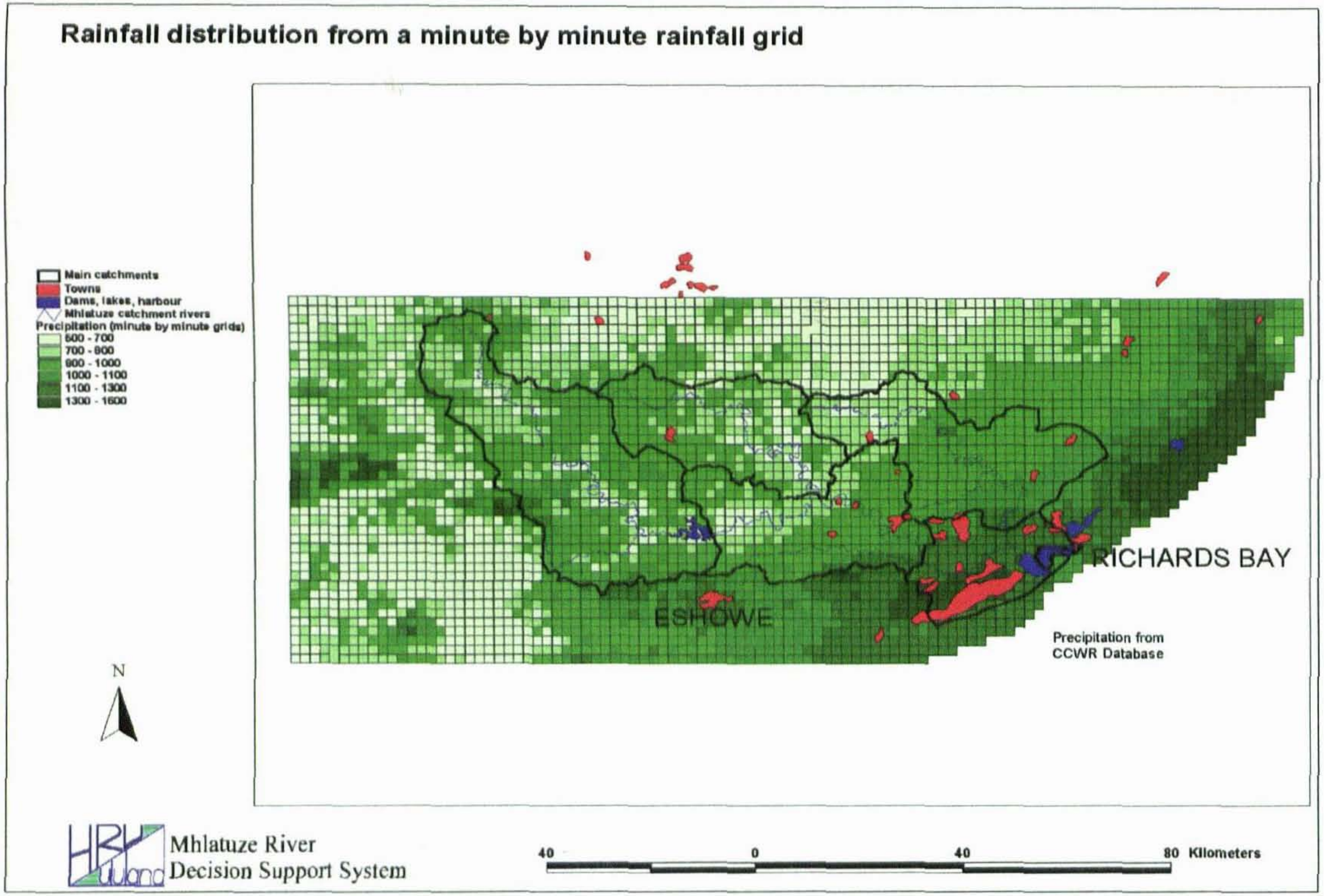

Figure 3.3: Rainfall grid, as estimated by Dent, Lynch and Schulze (1989) for the whole of South Africa, indicated here for the Mhlathuze River catchment.

This decision was based on the assumption that the rainfall to the north of the southern catchment boundaries are different (lower) than to south of it. Rainfall records measured south of the catchment were not used to estimate rainfall inside the catchment boundaries.

Alltogether 51 *rainfall stations were used for the whole study area, to derive rainfall series* for the different subcatchments used in the hydrological modeling. The positions of the stations used are indicated on Figure 3.1. An indication of the length of the record is portrayed by the size of the circle that indicates their positions. Reliable full records for the catchment are sparsely positioned for the western upstream catchment, and are generally restricted to the catchment boundaries, due to an undeveloped road network of the region upstream of the Goedertrouw Dam. Estimations of the catchment rainfall for the catchment areas of the Mfuli River and the Mhlathuze River upstream of the Goedertrouw Dam were problematic, because there were too few available rainfall records, they were of short lengths, and they were generally situated on the catchment boundaries. Figure 3.4 presents one of the rainfall records, which was extracted from the CCWR database and patched by Fourie (*1999, pers comms*). *This rainfall station is situated in the* middle of the catchment, about 2½ km from the DWAF weir W1H009.

3.1.2 Evaporation

Also incorporated into the IB are the mean annual and seasonal estimates of the WR90 evaporation (Midgley *et al*, 1994) portrayed in Figure 3.5. This is also at a very low spatial resolution for the scale of application in the IB.

Data for the evaporation stations in the W1 region were extracted from the DWAF databank. Table 3.1.1 gives a summary of the evaporation database. It lists the DWAF station number, the place name, the hydrological years of available data, the mean annual evaporation (MAE) for the Symons pan, the MAE for the A-pan and the station elevation, i.e. the metres above mean sea level for the position of the station.

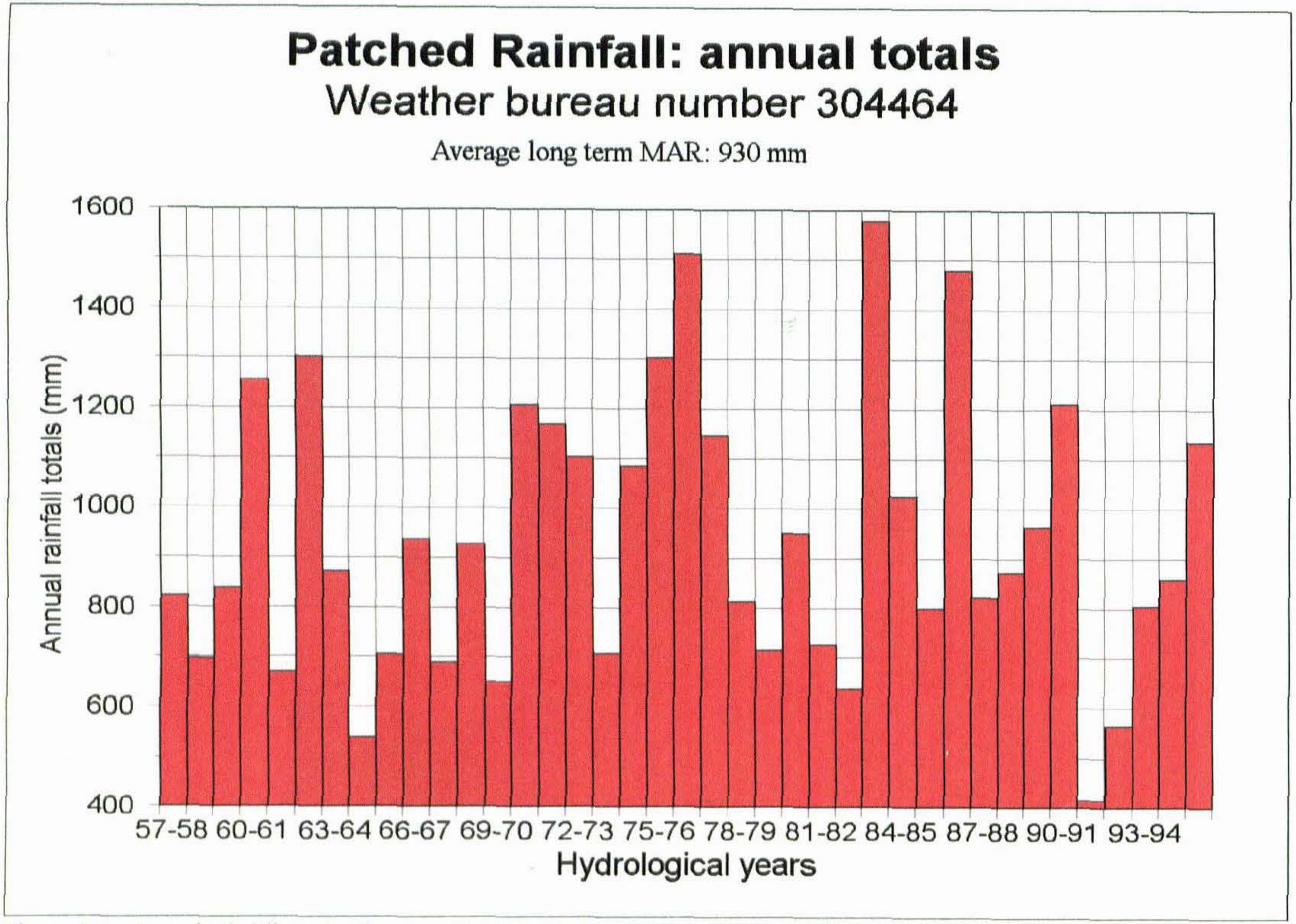

Figure 3.4: Annual rainfall totals of station 304464. Daily rainfall was extracted from the CCWR database and patched by Fourie (1999).

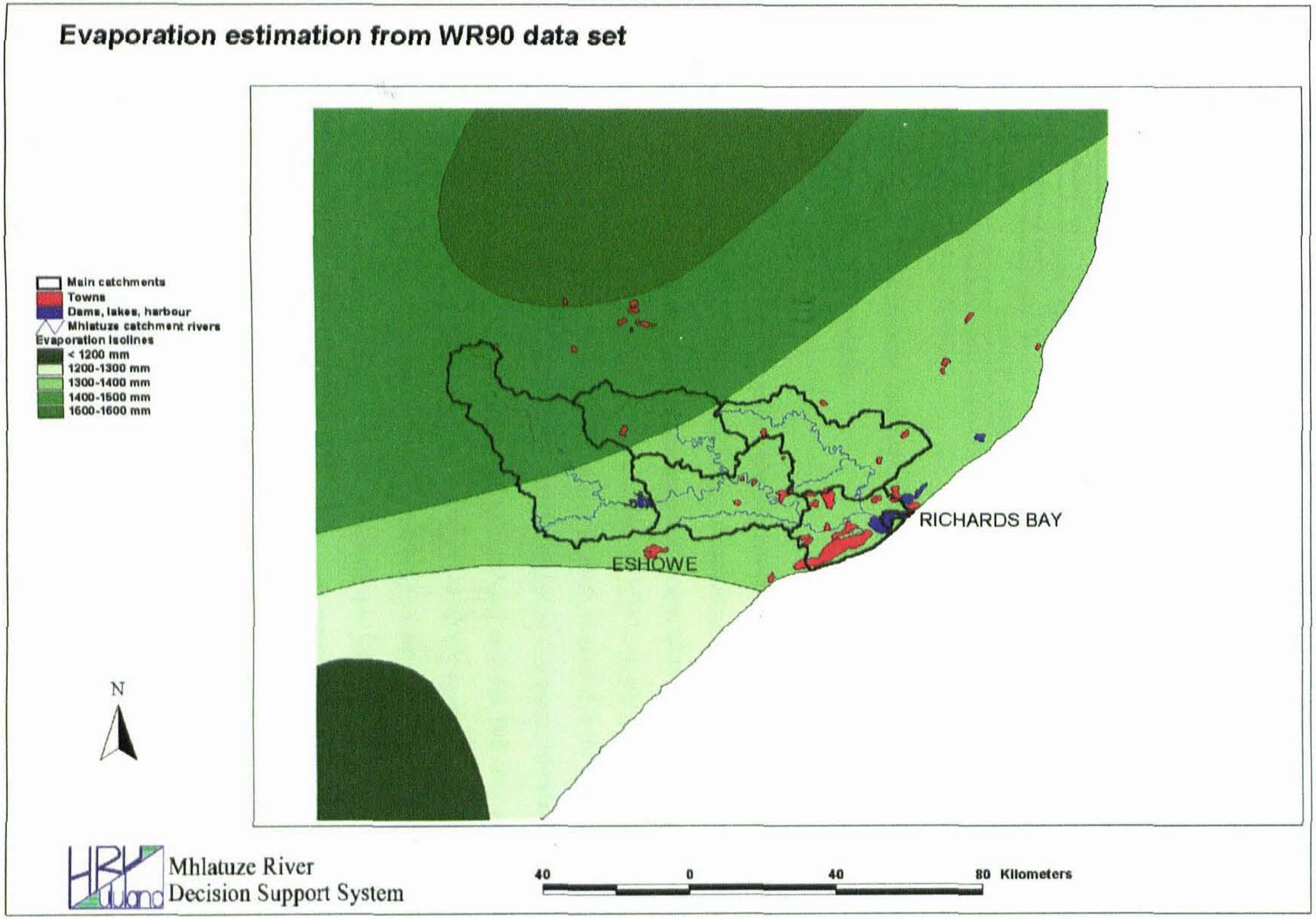

Figure 3.5: Spatial evaporation estimation from the WR90 data set.

Table 3.1.1: The evaporation database.

Station no	Place	Hydrological year	MAE(S) (mm)	MAE(A) (mm)	Elevation (mamsl)
W1E001	Mtunzini	1968/10 - 1997/09	1642	2080	61m
W1E003	Empangeni	1966/10 - 1978/09	(1527)*	1923	152m
W1E004	Amatikulu	1966/10 - 1978/09		1917	91m
W1E005	Esikhawini	1972/10 - 1987/09	1554	1773	17m
W1E009	Lake Mzingazi	1975/10 - 1997/09	1557		6m
W1E010	Eshowe Dam	1978/10 - 1996/09	1305	1513	490m
W1E011	Goedertrouw Dam	1982/10 - 1997/09	1740	1970	245m
W1E012	Melmoth	1984/10 - 1996/09	1280	1768	823m

* This value has been calculated from the measured A-pan value, using the equation for the MAE from A-pan to S-pan: MAE (S) = 130 + 0.726 x MAE (A-pan), according to Midgley *et al* (1994).

Monthly/annual average minimum and maximum values are calculated only where data for complete months/years are available.

There are five evaporation stations within the catchment, measuring data used to estimate the evaporation for hydrological model simulations. According to the evaporation maps from the WR90 data set (Midgley *et al*, 1994), the mean annual evaporation (Symons-pan) increases from 1200 mm per annum in the south of the catchment, to 1500 mm per annum to the north of the catchment (Figure 3.5). The individual evaporation records measured in the catchment contradict this general estimation. This can be attributed to the catchment's topography and humidity which play a role in the amount of evaporation that takes place, and the fact that not all available evaporation stations situated in the area, were used in the WR90 spatial evaporation estimation. The evaporation measured at Melmoth (W1E012, 900 metres above mean sea level) measures less evaporation than in the Nkwaleni valley at the Goedertrouw Dam (W1E011, 180 metres above mean sea level). For the water run-off simulations, representative evaporation stations were chosen for the estimation of evaporation in each main subcatchment.

3.2 Geology, Geomorphology and Soils of the Mhlathuze River basin

The geology, geomorphology and soils have a large bearing on the hydrology and the geohydrology of a region. These determine the river morphology, as well as the water storage and the run-off characteristics of a catchment. Consequently, it is important to describe the main features of these characteristics.

3.2.1 Geology (adapted from Rheeder, 1999)

Refer to Figure 3.6 for estimates of the Lithology (Martini & Associates, 1994).

The headwaters of the Mhlathuze River originate in the highveld region of KwaZulu/Natal, inland of the escarpment that forms part of the Drakensberg range. This high region is characterized by geological complexes that are distinctly different to the coastal section of the Mhlathuze catchment. The lower reaches of the river pass through the Zululand coastal plain where the underlying geology is mainly of more recent marine origin covered by very recent aeolian deposits. In the interior, the Basement Complexes comprises mainly granites and gneisses of two distinct units: the Kaapvaal Craton continental block and the Natal Metamorphic Province.

The Kaapvaal Craton was formed after the earth's primitive basaltic crust was intruded approximately 3000 million years ago by huge granitic plutons. Some of this primitive basaltic crust is preserved as the Nondweni Greenstone Belt in the Vryheid area just inland of the catchment. However, continental collision and subduction approximately 1000 million years ago produced the Natal Metamorphic Province that produced extensive mountain ranges along the southern margin of the Kaapvaal Craton. Erosion exposed the deep mountain roots of highly deformed granitic and gneissic rocks along the main river valleys.

A long period of erosion flattened the mountain belt to a stable platform onto which, a thick sequence of coarse-grained river sediments were deposited to form the maroon-coloured Natal Group Sandstones. At this time South Africa was part of the super-continent Gondwana, that was located near the south pole and covered by glaciers and ice.

As Gondwana drifted northwards to warmer latitudes, thick clay and silt beds were laid down in a large sea that occupied the Karoo basin to form the Ecca Group. A thick unit of shales of the

Pietermaritzburg Formation forms the base of the Ecca Group. Overlying the shale is a sequence of light grey sandstones called the Vryheid Formation. These sandstones were deposited along ancient sandy shorelines behind which lay vast swamplands that formed the coal deposits. This is followed by a thick succession of dark grey shales of the Volksrust Formation.

The red-, green- and purple-coloured mudstones and sandstones of the Beaufort Group (250 million years) characterise deposition in a steadily drying swampland. The equivalents of the Beaufort- and Stormberg Groups are represented as follows: Black shales and sandstones with thin coal seams comprises the lower- most Emakwezi Formation. This in turn is overlain by quartz-rich "glittering" sandstones of the Ntabene Formation, followed by red and purple mudstones of the Nyoka Formation. The overlying Clarens Formation comprises cream-coloured fine-grained sandstones. These sandstones originated in a desert environment and presently form the cliffs in the middle Drakensberg and Lebombo ranges.

180 million years ago, intrusions of magma crystallized to form dolerite sills and dykes. This initiated the Karoo volcanic episode that comprises vast outpourings of lava-flows that spread across much of Gondwana to form the Letaba Formation. Remnants of these once extensive lavas form the Lebombo mountains. The Karoo volcanic episode heralded the start of the Gondwana break-up and was accompanied by uplift, crustal extension and numerous faulting which produced a rift between KwaZulu-Natal and Antarctica and the birth of the Indian Ocean.

The first deposits formed in the newly opened Indian Ocean were silt and sandstone of Cretaceous age (145 – 165 million years ago). This was followed by extensive dune fields of calcareous sands, that developed parallel to the coast. These now form the Berea and Bluff Ridges. In most areas deep weathering of older dunes produced the dark red sands of the Berea Red Sand.

In recent times, eustatic sea-level changes due to ice ages caused deeply incised river valleys that was subsequently filled with estuarine sediment, forming the young unconsolidated muds and shelly sands underlying the extensive Zululand Coastal Plain.

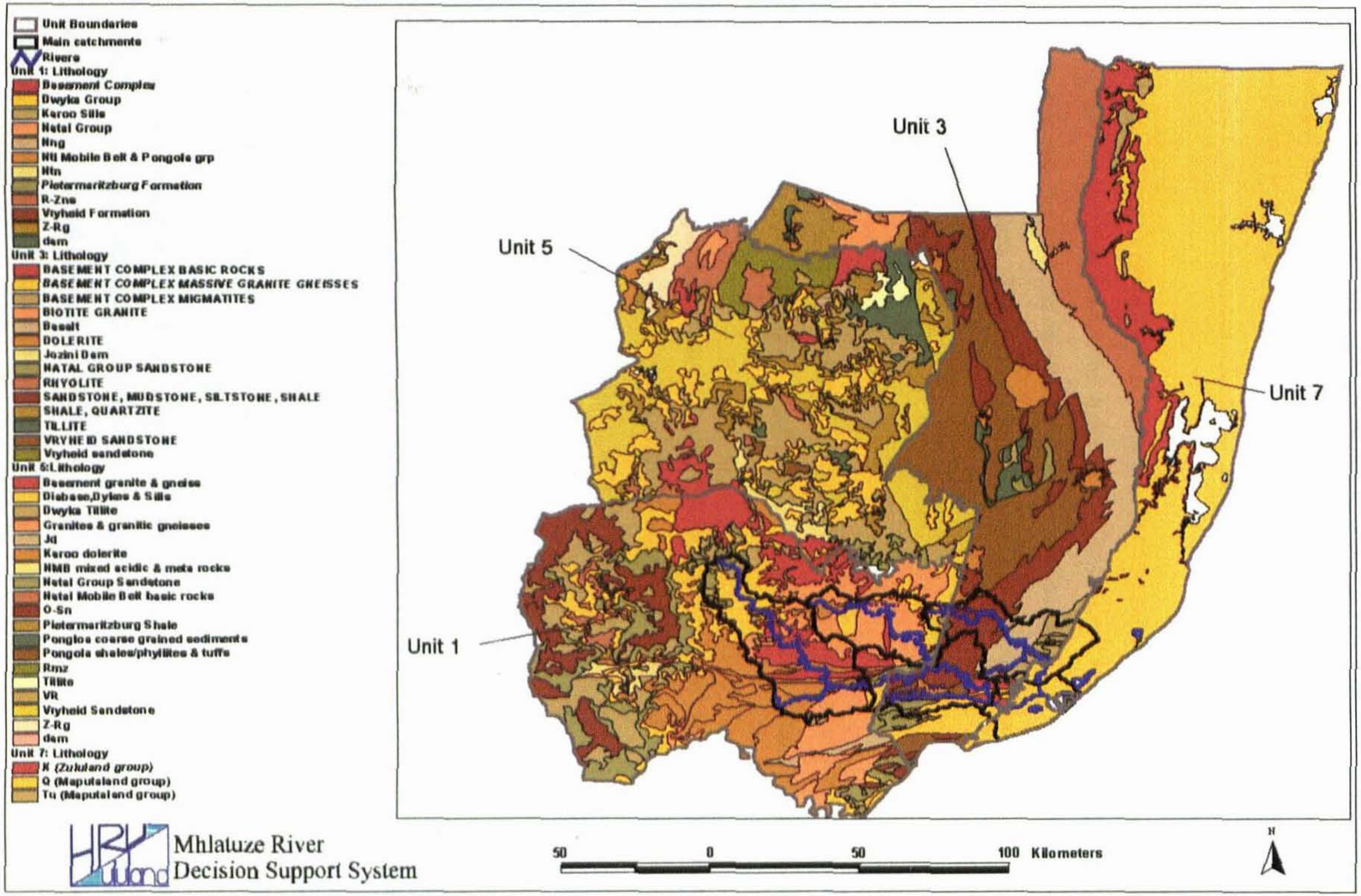

Figure 3.6: Estimations of the Lithology in and around the Mhlathuze catchment. (Source: Martini & Associates, 1994)

3.2.2 Geomorphology

The principal morphological features of the catchment can be discerned from the 100 metre contours on the 1:250 000 maps, which were obtained from the Department of Land Affairs, Chief Directorate Land and Information Surveys. The 100-metre contours are shown in Figure 3.7.

The catchment starts at elevation of more than 1600 metres above mean sea level in the western sections and slopes to sea level at the mouth of the Mhlathuze River. The river generally flows in a west to east direction and comprises of three main tributaries, that have been used to define five main subcatchments. These main subcatchments are the catchments of

- the Mfuli River,
- the Mhlatuzana River,
- the Nseleni River,
- the main course of the Mhlathuze River upstream from the Goedertrouw Dam and
- the main course of the Mhlathuze River downstream from the Goedertrouw Dam.

In order to support analytical methods and models for the creation of catchment information for the IB, the 100-metre contours have been used to develop a Digital Elevation Model (DEM). This model and its development are described in detail in Chapter 4.

3.2.3 Soils

Initially the general soil type estimations from the WR90 data set (Midgley *et al*, 1994) were used in the IB. The soils in the WR90 data set(displayed in Figure 3.8) indicates four different soil types, with SIRI codes 15, 17, 18 and 20. The characteristics of these four soil types are given in Table 3.2.1. Using the dominant series texture listed in Table 3.2.1, the soil textures of the catchment were classified into four broad categories, which are listed in Table 3.2.2.

The soil classification from the WR90 data set are taken from 1989 Revised Broad Homogeneous Natural Regions map (RBHNR) produced by Schulze and Lynch (1992). The source maps were created from 1:2 500 000 maps. Additional information was taken from 1:2 500 000 terrain morphological map of Southern Africa.

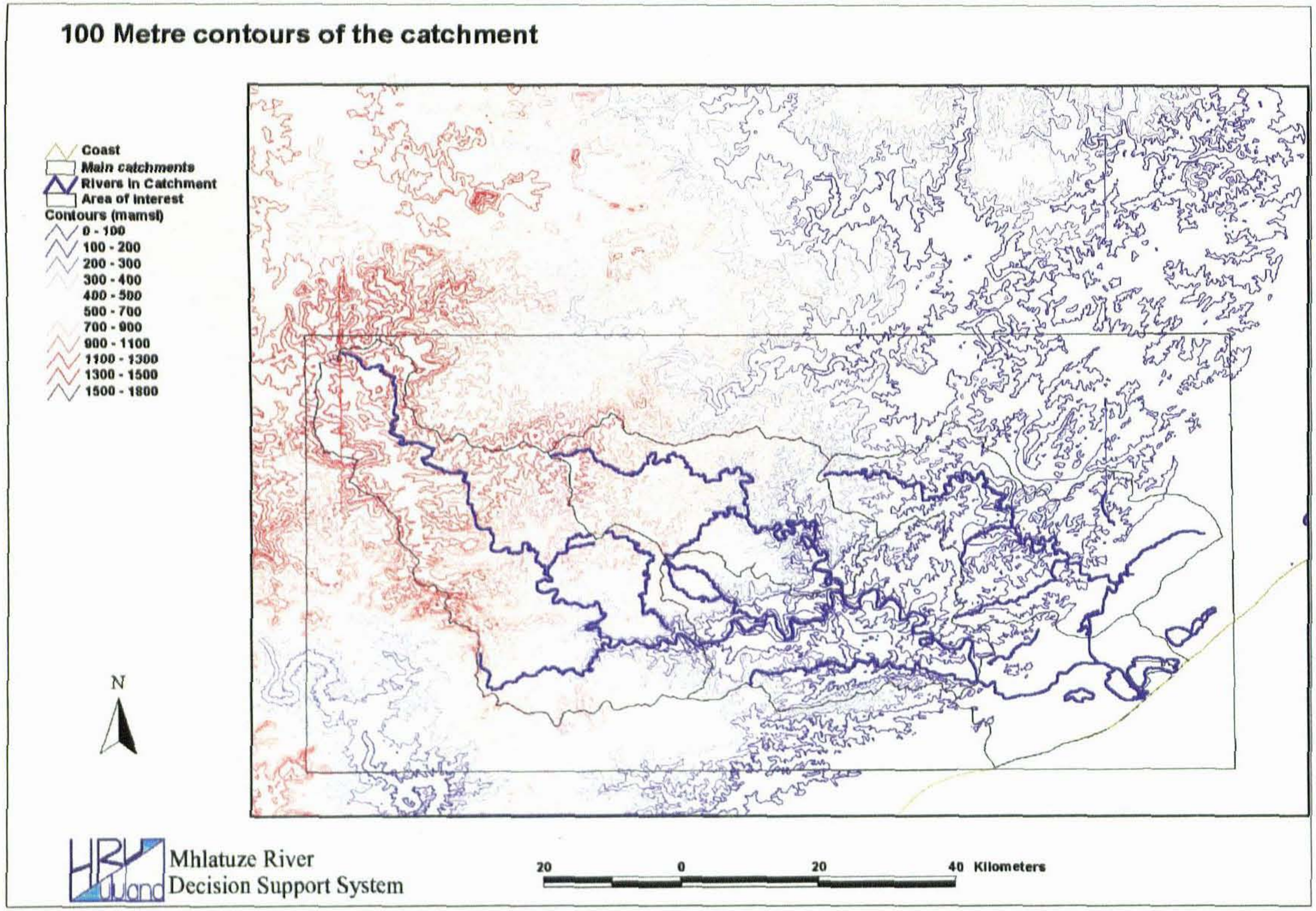

Figure 3.7: *100 Metre contours of the Mhlathuze catchment and surrounding areas, from the scale of 1:250 000.*

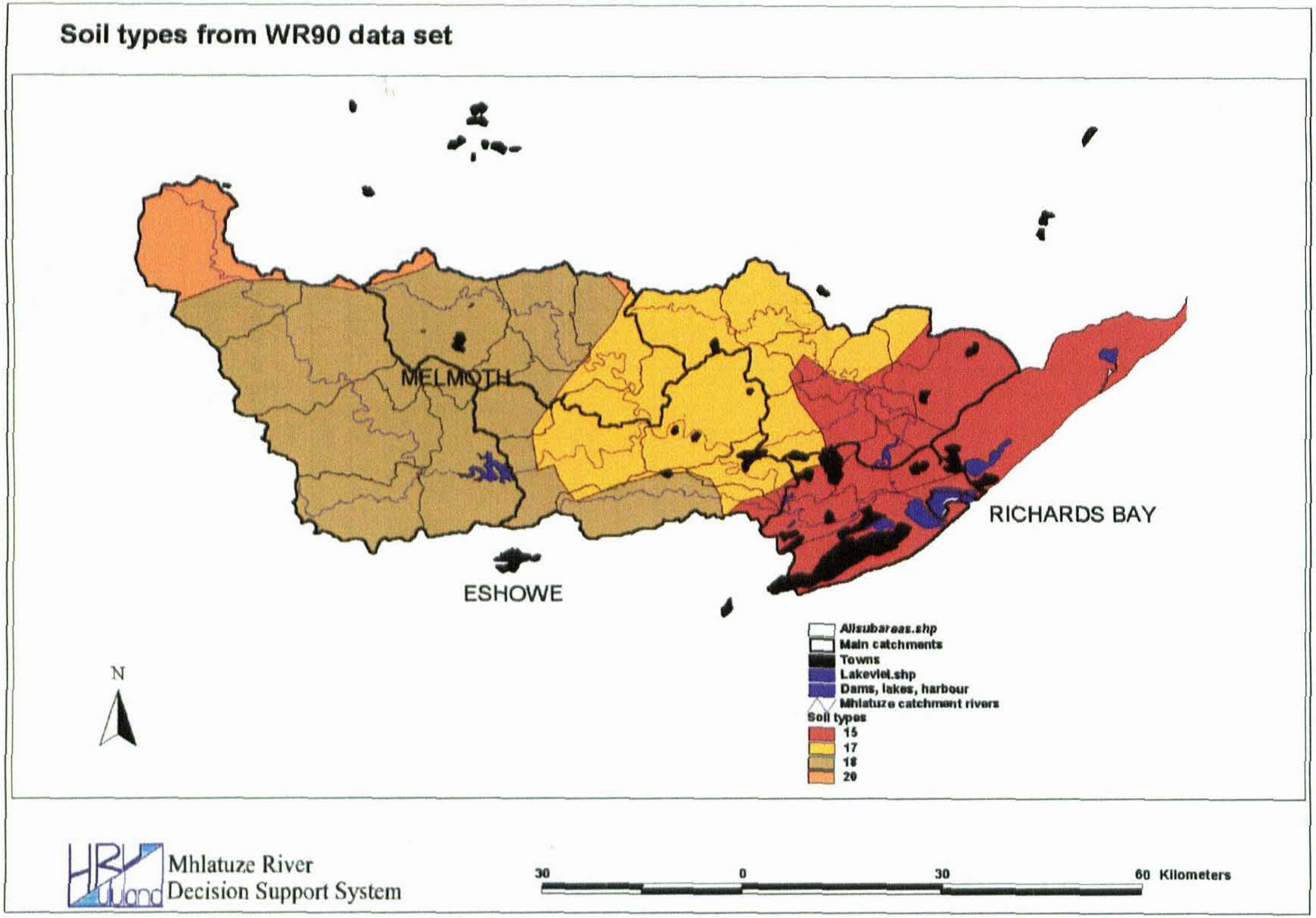

Figure 3.8: Soil type estimations from the WR90 data set. See table 3.2.1 for the related information of each soil type.

Table 3.2.1: Soil types of the catchment:

CODE*	AVERAGE SOIL DEPTH (mm)	DOMINANT SOIL TEXTURE	DOMINANT SOIL SERIES (DSS)
15	>1000 (100%)	Sa - 90% SaClLm - SaCl 10%	Fw10/Fw11 80% Cv30/Cv31 15% Du10/Oa47 5%
17	300-800 (70%) > 900 (20%)	SaLm - SaClLm 60% SaCl - Cl 30%	My21 30% Sd21 20% Ar40 20% Ms10/Ms20 20%
18	400-1000 (100%)	SaClLm - SaCl 100%	Hu26/Hu27 25% Sd11/Sd12 20% Gs16/Gs19 20% Ms10 15% No10 15%
20	150-450 (50%) 500-900 (45%)	SaLm - SaClLm 30% SaClLm - SaCl 65%	Ms20/Gs28 45% Hu16/Hu17 20% Sd20/Sd21 15% Cv16 10%

CODE	DOMINANT RELIEF OF REGION (mm)	NAME OF DOMINANT SOIL SERIES	PERCENTAGE OF DOMINANT SOIL SERIES
15	Flat (0-100)	Fw10/Fw11	80%
17	Undulating Steep (100-500)	My21	30%
18	Undulating (150-1200)	Hu26/Hu27	25%
20	Undulating Steep (200-900)	Ms20/Gs28	45%

CODE	DOMINANT SERIES TEXTURE (DST)	PERCENTAGE OF DST	LOWEST ELEVATION (mamsl)	HIGHEST ELEVATION (mamsl)	RANGE OF ELEVATION (m)
15	Sa	90%	0	100	100
17	SaLm-SaClLm	60%	100	500	400
18	SaClLm-SaCl	100%	150	1200	1050
20	SaClLm-SaCl	65%	200	900	700

* The first column (CODE) refer to Broad SIRI soil mapping units.

Table 3.2.2: Classified soil textures for descriptions provided:

Dominant series texture	Assigned soil texture
Sa (SIRI code 15)	sandy soils
SaLm-SaClLm (SIRI code 17)	sandy loams
SaClLm - SaCl (SIRI codes 18, 20)	clayey loams

Inspection of the Soil Type Map for Richards Bay (2830) reveals the many soil types found in the catchment. The accompanying memoir of the Soil Type Map lists the soil characteristics such as the stream bed minimum and maximum depths, the minimum and maximum depths of the valley sides, the minimum and maximum percentage of clay content of the A, E and B21 soil horizons, and descriptions of the soil texture.

The analysis of the soils as captured from soil profiles, is also listed in the memoir. The following information used from these soil profile analyses were taken from the B horizon (where available, or A horizon otherwise):

- the description of the soil found in the horizon,
- the percentage of course, medium and fine sand in the soil,
- the sand grade
- the percentage silt and percentage clay content
- the organic content

These values were averaged (area-weighted) for the soil profiles found in each of the subareas that were used in surface water modelling described later. These averaged estimates for lumped parameters again stressed the crudeness of lumped models for simulating surface water run-off.

3.2.4 Geomorphology of the rivers

Seventeen different river cross section measurements were undertaken by students from the Department of Hydrology during the course of 1998. The positions of these cross section measurements were chosen on the main course of the Mhlathuze River, at approximately 1-km intervals, from the position of weir W1H009, to the road bridge over the Mhlathuze River near Felixton.

A video was taken during a flight along the main river course of the Mhlathuze on 10 March 1998 as part of an Instream Flow Requirements study (DWAF, 1998) for the Mhlathuze River system. This was used to create a visual photography album of the river and lakes, which are available in the DSS through the GUI interface in Arcview.

Several field trips were conducted to most parts of the Mhlathuze River catchment and photographs were taken to supplement the images of the river course. These photographs and images (together with notes made during the field trips) were used to estimate river reach characteristics like Manning's n for the river reaches, Manning's n for the flood plains, the rivers' channel widths and channel depths (Ven Te Chow, 1988).

Field trips were conducted during June 1997, November 1997 and July 1999. Many of the upstream rivers were found to have stopped flowing on the field trips of July 1999. During November 1997 these river courses all had some measure of flowing water.

3.3 Water Resources

The water resources of the Mhlathuze River basin consist of the main river course of the Mhlathuze River, several tributaries to this main river, off-channel lakes and coastal lakes, the Goedertrouw Dam, groundwater resources and two inter-basin transfer schemes from the Thukela and Mfolozi catchments. All water bodies interact through rivers, canals, groundwater movement and water pipelines and pumps, which complicates the water resources' interaction. Together these water bodies form the Mhlathuze River System or Mhlathuze Water Resources (Mhlathuze Stakeholders Committee Meeting, 1998).

Little information is available on the abstractions from most of the water bodies in the catchment. However, lead agencies recognize that there is a legal requirement to acquire this information. Most of these have started a monitoring program for water abstractions from the different water resources in the catchment.

3.3.1 The River System

The main Mhlathuze River upstream from the Goedertrouw Dam has one tributary (the Mvuzane River) into which the Thukela Emergency Water Transfer Scheme (TEWTS) contributes water during times of water shortage in the catchment (Figure 1.1). The Mfuli River joins the Mhlathuze

River downstream from the Goedertrouw Dam. The Mhlatuzana River flows into a marshy low-lying area, which overflows into the Mhlathuze River. No flow measurements have been done for either of the Mfuli or Mhlatuzana Rivers. The Nseleni River flows into Lake Nsezi, which overflows through a well-vegetated river course that joins the Mhlathuze River at the Mhlathuze Estuary.

The catchments of Lake Mzingazi, Lake Chubu and Lake Nhlabane contribute to these lakes by small streams and groundwater movement (Kelbe and Germishuyse, 1998). There are several coastal lakes that are believed to be remnants of estuaries (Kelbe and Germishuyse, 1998). The main off-channel lakes are situated near Empangeni and consist of Lake Mangeza, Lake Mpangeni and some other smaller lakes.

3.3.2 Flow measurements

Daily and monthly flow data was extracted from the database of the DWAF database in Pretoria and Durban, and is incorporated into the IB. The positions of these flow measuring stations are indicated in Figure 3.9. A summary of the data related to each of the flow stations are provided in Table 3.3.1 (daily data) and Table 3.3.2 (monthly data). Also refer to Table 3.3.3 for a description of each weir's position and function.

For the purpose of catchment management, the measured flow records generally needs to be interpolated for missing periods and extrapolated to supply information of the quantity of water available in the catchment. The run-off simulation model included in the IB provides extra information on the availability of water run-off from the various subcatchments. The calibration of the simulation model relies heavily on the availability of measured stream flow records. Table 3.3.3 gives the details of daily flow measurements used for the calibration of daily surface water run-off simulations, described in Chapter 4.

There are two places where streamflow records have been measured in the catchment which are of suitable use for run-off simulation calibrations. The first is at the present site of the Goedertrouw Dam. Stream flow data, measured at the weir W1H006 before the dam's construction, is available for 10 years over the time period: 1964 to 1973, but even this record has long periods of missing data and is complicated by abstractions at the abstraction weir W1H027, which was situated above weir W1H006. Abstraction records from W1H027 indicate no seasonal pattern and show large variations, from little abstraction during wet periods, to as much as 2.1 m^3/s (Hughes and Smakhtin, 1999). Weir W1H006 was reopened after the construction of the Goedertrouw Dam as W1H028. It is still measuring flow records that are of value to establish parameter values for simulation of the historical scenario which includes water abstraction.

Table 3.3.1: Daily flow data details (Source: the DWAF):

WEIR	Begin Year	End Year	Nr of days of observed data	Average flow * (m^3/sec)	Maximum flow (m^3/sec)
W1H005-A01	1948/8/11	1997/2/28 (Ongoing)	17036	0.11	8.89
W1H006-A01	1964/9/7	1979/3/31	2385	4.4	270.9
W1H009-A01	1962/12/22	1991/4/30 (Ongoing)	8019	5.67	925.5
W1H026-A01	1948/8/12	1968/3/31	7170	0.01	0.1
W1H028-A01	1979/10/31	1996/9/30 (Ongoing)	5933	2.68	114.7
W1H029-A01	1982/12/2	1996/9/30 (Ongoing)	5049	0.13	0.33
W1H030-A01	1982/11/10	1997/2/2 (Ongoing)	5191	0.82	2.65
W1R001-A01	1981/11/1	1996/3/31 (Ongoing)	5296	0.66	488.4
W1H032-A01	1993/2/3	1997/3/24 (Ongoing)	1397	2.33	103
W1H032-M01	1993/3/1	1997/3/24 (Ongoing)	160	1.18	2.87

* The average flows were calculated for observed data only. Missing data was excluded from the calculations.

Table 3.3.2: Monthly flow data details (Source: the DWAF):

WEIR	Begin Month	End Month	Average flow ** (Million cubic metres/month)	Maximum flow (Million cubic metres/month)
W1H005	Dec. 1948	May 1996 (Ongoing)	0.25	5.41
W1H006	Oct 1964	Jan 1979	11.52	83.12
W1H009	Dec. 1963	March 1991 (Ongoing)	14.95	176.95
W1H026 *	Sept. 1948	Febr. 1968	0.04	0.17
W1H027 *	Sept. 1956	Nov. 1979	0.3	2.1
W1H028 *	Nov. 1979	Sept.1996 (Ongoing)	7.07	67.94
W1H029 *	Jan. 1983	Sept. 1996 (Ongoing)	0.35	0.74
W1H030	Dec. 1982	Jan. 1996 (Ongoing)	2.17	3.48
W1R001	Nov. 1981	March 19960 (Ongoing)	1.74	61.6

* These gauges were/are situated at the present Goedertrouw Dam site.

** The average flows were calculated for observed data only. Missing data was excluded from the calculations.

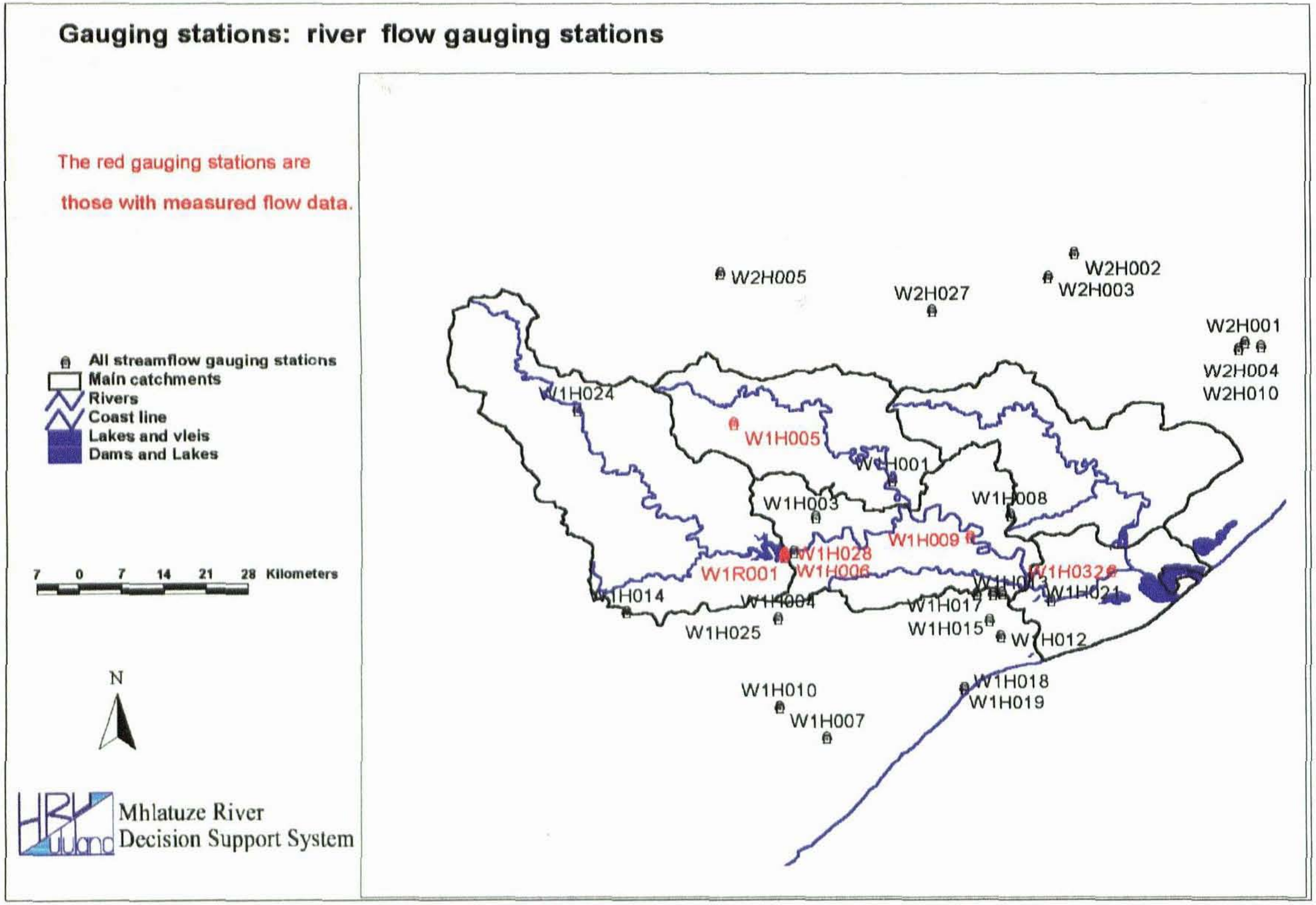

Figure 3.9: Positions of flow measuring stations.

Table 3.3.3: Flow gauges measuring daily data which were used in calibrations of surface water simulations:

WEIR	DESCRIPTION	BEGIN MONTH	END MONTH
W1H009	Flow in Mhlathuze River downstream from Heatonville irrigation pumps	Jan.1963	Ongoing measurements
W1H006	Flow on Mhlathuze at Goedertrouw Dam site, before Dam construction	Nov. 1964	March 1979
W1H027	Flow in New Venture irrigation canal upstream from W1H006, at Goedertrouw Dam site, before the dam's construction	Sept. 1956	Nov. 1979
W1H028	Flow in Mhlathuze River downstream from Goedertrouw Dam	Nov.1979	Ongoing measurements
W1H029	Flow in New Venture Irrigation canal, downstream from Goedertrouw Dam, upstream from W1H028	Dec.1982	Ongoing measurements
W1H030	Flow in Nkwaleni Irrigation canal, downstream from Goedertrouw Dam, upstream from W1H028.	Nov.1982	Ongoing measurements
W1H032-A01	Flow in Mhlathuze River at Mhlathuze Water pumps	Feb.1993	Ongoing measurements
W1H032-M01	Water pumped by Mhlathuze Water pumps	Mar. 1993	Ongoing measurements

The second flow gauge used during calibration of run-off simulations is situated below the confluence of the Mhlathuze and the Mfuli Rivers in the centre of the catchment at Riverview (W1H009). Flow records are available from 1963 until the present. This record is also subject to upstream abstraction, even during the early part of the record, which makes it difficult to establish natural conditions of the catchment.

Both the flow records measured at W1H006 and W1H009 contain errors associated with sedimentation of the weirs (personal communications, DWAF).

3.3.3 Dams

All of the larger farm dams are registered with the DWAF as these can affect the run-off of surface water, through abstraction and evaporation. These dams only have to be registered when the dam wall is higher than 5 metres, or if the dam capacity exceeds 50 000 m^3. These dams are situated within the boundaries of farms and are generally used for crop irrigation. The positions of these dams have been incorporated into the IB but no abstraction rates are available.

Goedertrouw Dam

The Department of Water Affairs investigated several Dam sites from 1947 until 1965 (Mhlathuze Stakeholders Meeting, 1998), and concluded in 1965 that the Goedertrouw Dam site was the most suitable for the construction of a large storage dam. The farming community of the Heatonville region proposed to build a storage dam in the Mfuli River, with a system of irrigation canals to irrigate 5500 hectares in the Ntambanana Valley and along the northern bank of the Mhlathuze River. Further investigations showed that it would be more economical to build one big supply dam at the present site of the Goedertrouw Dam that can serve all the irrigation schemes.

The proposed construction of the Goedertrouw Dam (White Paper Q-73) was approved in parliament. It was estimated that the initial storage of 313 million cubic metres would be reduced by siltation to 288 million cubic metres after 20 years. The long term net reliable yield of the dam is 147 million cubic metres per annum. The White Paper (Q-73 and Q-79) indicated that the water resources of the system may have to be augmented by 1997. The technical detail of the constructed Goedertrouw Dam are indicated in Table 3.3.4.

Table 3.3.4: Technical detail of the Goedertrouw Dam:

Type of dam wall:	earth fill embankment
Height of dam wall:	*81 m*
Dam capacity:	320 x 10^6 m^3
Surface area:	12 km^2
Catchment size:	1279 km^2
Maximum capacity of sluices:	61 m^3/second
Flow gauges at the Goedertrouw Dam site:	
W1R001:	calculated inflow from a dam balance
W1H006:	flow measured in Mhlathuze River before dam construction.
W1H027:	measured irrigation abstraction (i) before Dam construction
W1H028:	measured outflow from Dam
W1H029:	measured irrigation abstraction (i) after Dam construction
W1H030:	measured irrigation abstraction (ii) after Dam construction

The Goedertrouw Dam was constructed by the Department of Water Affairs and completed in 1981. The abstractions of water from the Goedertrouw Dam are done for downstream water usage, which includes irrigation, domestic and industrial usage. These are described under "Water Users".

3.3.4 Lakes

The main lakes which contribute to the water resources of the Mhlathuze River system are the lakes of Nsezi, Mzingazi, Nhlabane, Chubu, Mangeza and Mpangeni. These lakes have been described extensively by (Kelbe, Germishuyse, Fourie and Snyman, 1998). Only a summary of the morphology of the bigger lakes and their contribution to the Mhlathuze water resources is provided here. Refer to Figure 1.1 for the positions of the lakes.

3.3.4.1 Lake Nsezi

The Nseleni River flows into Lake Nsezi. It is the primary reservoir for water abstraction by Mhlathuze Water (MW). There is a permanent augmentation scheme which pumps water from the Mhlathuze River to Lake Nsezi to supplement supplies and enhance the quality. The lake is maintained at a level of 6 metres above mean sea level, to sustain a reliable yield for MW at all times.

The lake is generally about 1 metre deep and is covered in large sections by reeds, making it difficult to identify its full extent from aerial or satellite photographs. The storage capacity of Lake Nsezi was estimated by the DWAF to be 834 000 m^3 for a lake level maintained at 6.2 metres above mean sea level.

3.3.4.2 Lake Mzingazi

Lake Mzingazi can be seperated into two compartments. The southern part is separated from the northern part by a very shallow and narrow section which is exposed during extremely dry conditions. The southern part is about 14 metres below mean sea level at the deepest point and therefore suspectable to salt water intrusion under adverse conditions. Based on a bathymetric survey, the capacity of the lake, when filled to the level of the spillway (3.03 metres above mean sea level), is estimated at approximately

55000 m^3 (Kelbe *et al*, 1998). However, the DWAF has estimated the storage capacity to be approximately 40 000 m^3. This is reduced to 21000 m^3 when the lake level drops to mean sea level.

Richards Bay Transitional Local Council abstracts water from the lake to supply water to the municipality of Richards Bay, which includes several large industries. Richards Bay Minerals (RBM) also has abstraction rights from the lake. Water is also used by the Richards Bay Country Club for the golf course.

3.3.4.3 Lake Nhlabane

Lake Nhlabane has two main compartments separated by a narrow river section. It drains into the Nhlabane Estuary over a weir which has been raised by 1 metre in October 1998. The volume of the lake has risen from 28 x 10^6 m^3 to nearly 40 x 10^6 m^3 with the raising of the new weir spillway. The lake levels have been monitored by RBM for several years, but the only information currently available is from July 1998 to the present. RBM abstracts water from the lake for dredge mining purposes at an average rate of about 3800 m^3/day (Kelbe *et al*, 1998).

3.3.4.4 Lake Chubu

Lake Chubu is situated to the south of Richards Bay Harbour and is assumed to have originally been part of the Mhlathuze Estuary. During flood events, the overflow of the lake is believed to flow through to the Mhlathuze Estuary via a small canal linked to a series of channels.

The estimated level of the present outlet is assumed to be approximately 3 mamsl which gives the lake a full capacity of roughly 10.5 x 10^6 m^3 and a storage capacity of 0.7 x 10^6 m^3 at mean sea level (Kelbe *et al*, 1998).

Lake levels have been recorded since 1995. The lake has remained fairly static over the period of observation. Water abstractions from the lake are done by Esikhawini Water Treatment Works. During the 1994/95 drought the abstractions remained consistently at above 12 x 10^3 m^3/day, which suggests that the lake had sufficient storage to sustain these levels of abstraction during severe dry periods.

The surfaces of these lakes are believed to be an extension of the local primary aquifers. It is sustained by direct recharge, stream flow and groundwater seepage (Kelbe and Germishuyse, 1998).

3.4 Water Users

Records of historical abstraction from the Mhlathuze river by water users are limited. Only the licensed water users are well documented (Hughes and Smakhtin, 1999).

Based on the 1997 actual usage, the annual water requirements for the Mhlathuze River catchment have been estimated by the DWAF (1997) and a summary of the water requirements are indicated in Table 3.4.1.

Table 3.4.1: Water usage from the Mhlathuze River Resources:

User sector	Water Requirements (million m^3/annum) *
Irrigation	153.4
Industrial	60.7
Domestic	26.4
Total:	**240.5**

* Source: DWAF (1998)

3.4.1 Irrigation Schemes

There are several irrigation schemes operating in the Mhlathuze River catchment. The locations of the different irrigation schemes are indicated in Figure 3.10. Table 3.4.2 lists the water demands of each irrigation scheme, as provided by the DWAF (1997). These figures (from Table 3.4.2) have been revised by the DWAF and thus the total irrigation demand listed in Table 3.4.2 differs from the required irrigation water listed in Table 3.4.1.

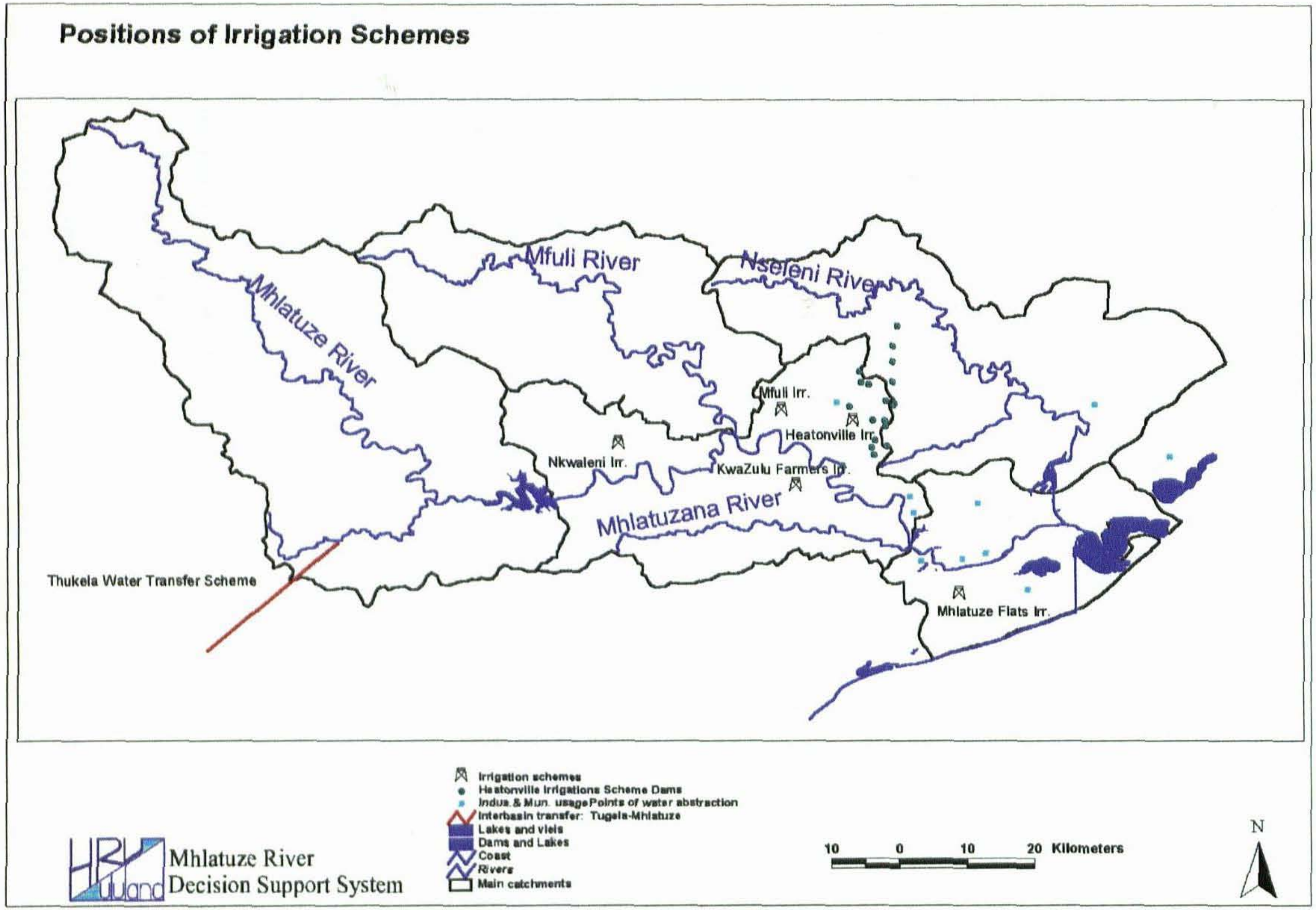

Figure 3.10: Positions of irrigation schemes and the balancing dams of the Heatonville Irrigation Scheme.

done on a weekly basis. The weekly order of water for the Heatonville Irrigation Scheme is computed by taking the difference between the amount of water on-hand in the balancing and storage dams, and the amount of water ordered. Rainfall and evaporation are taken into account when computing water orders for irrigation. A weather station in the Heatonville valley, measuring rainfall and evaporation, was established in 1996, and is still in operation. Some farmers have potentiometers installed, measuring the water moisture contents of the soil. Some soil types of the Heatonville area are such that, to prevent irrigation water run-off, overhead irrigation can be maintained for not more than six hours per day. This is the main reason for this scheme to operate only during the day.

It is estimated that the transit time for water running from the outlet of Goedertrouw Dam into the Mhlathuze River to Heatonville Irrigation Scheme pumps is approximately 60 hours (nearly three days).

The maximum capacity of the irrigation scheme is restricted by the maximum capability of the main canal, which is presently 3 m^3/s. Until July 1997 the maximum amount of water pumped was only about 1.5 m^3/s.

3.4.1.2 Nkwaleni Irrigation Scheme

This irrigation scheme consists of a network of soil lined canals, which are supplied with water from the Mhlathuze River itself. Two of these canals start just downstream from the Goedertrouw Dam. The amount of water released to these canals is controlled by the DWAF through weirs W1H029 (a small canal supplying water to the farm New Venture) and W1H030 (the main canal) where daily flow measurements are taken. These two gauges were opened after the completion of the Goedertrouw Dam construction. Before the construction of the Goedertrouw Dam, the DWAF weir W1H027 was measuring the amount of irrigation water pumped from the Mhlathuze River at the site of the present Goedertrouw Dam. This record only represents a small fraction of the total volume of irrigation water pumped from the Mhlathuze River under jurisdiction of the Nkwaleni Irrigation Board, as most of the irrigation water is pumped downstream from this weir directly from the Mhlathuze River.

Reliable records of the water abstracted for irrigation purposes from the river are only available since the calibration of these irrigation pumps. These records extend back to 1995, although the irrigation scheme started before 1926, when the Nkwaleni Irrigation Board was established. Records of abstractions are updated by measurements taken at the river pumps once a month.

The present irrigation scheme consists of just over 6300 hectares of irrigated land (DWAF, 1997). The main crops under irrigation include sugar cane, citrus, bananas and some vegetables (mainly tomatoes).

3.4.1.3 KwaZulu Farmers

This irrigation scheme has no farm dams or canals and only supplies irrigation water to riparian farms. Pumps along the Mhlathuze River extract water for about 900 hectares of sugar cane irrigation along the river banks (DWAF, 1997). Reliable records of the amount of water extracted only exist from January 1997 (Mhlathuze Water).

3.4.1.4 Mfuli irrigation scheme

The Mfuli Irrigation Board was established in 1935, and the irrigation scheme was completed in 1941. The original irrigation scheme consisted of 428 irrigated hectares on five farms, with an abstraction weir in the Mfuli River 10 km upstream from the confluence with the Mhlathuze River and 30 km of canals. This irrigation board was disbanded in 1962, and the administration was placed under the control of the Minister of Water Affairs. The present scheme consists of 773 hectares of irrigated land (DWAF, 1997).

3.4.1.5 Lower Mhlathuze Flats

The sugarcane fields on the Mhlathuze River flats, situated downstream from the DWAF weir W1H009 and upstream from the Mhlathuze Estuary, are situated in a high rainfall belt. Most of the year these fields do not need irrigation, but during the dry months of the year, some irrigation water is used from the Mhlathuze River, applying overhead irrigation methods. Because of the flat sugarcane fields, drainage canals are needed in the fields to drain excess water from the fields which gathers after bigger rainfall events.

3.4.2 Industrial water use

The main industrial development in the Mhlathuze catchment is situated in the Empangeni and Richards Bay area. Currently all industries are being supplied with water from either the Mhlathuze River, or the coastal lakes of Nsezi, Mzingazi and Nhlabane. The lakes therefore play a major role in the supplying of water to towns and industry.

Most industrial water use is under the control of Mhlathuze Water or the municipalities of the various towns where they are situated. However, Richards Bay Minerals and Mondi (Richards Bay) hold separate water permits (via an agreement with Mhlathuze Water) for usage from Lake Mzingazi. Mondi (Felixton) and Tongaat Hullett at Felixton holds free water allocation rights for water usage from the Mhlathuze River. The reader is referred to the DWAF (1997) for a detailed explanation of the water permits, water agreements, free water usage and actual water usage from the Mhlathuze Water Resources.

3.4.3 Domestic water use

The following towns presently depend on the Mhlathuze Water Resources for their water needs:

- Empangeni, from Lake Nsezi
- Esikhawini, from Lake Chubu
- Felixton, from the Mhlathuze River
- Kwa Dlangezwa, from Lake Mangeza
- Ngwelezana, from Lake Nsezi
- Nseleni, from Nseleni River
- Richards Bay, from Lake Mzingazi and Lake Nsezi
- Vulindlela, from Lake Mangeza

3.4.4 The Reserve

"The Reserve", as described in the National Water Act, is composed of the "Basic Human Needs Reserve", i.e. the amount of water required for basic human needs, and the "Ecological Reserve," which is the amount of water to be reserved to sustain the ecology of the water resources. The description of the Reserve includes both the quality and the quantity (and assurance) of the water resources. The White Paper on National Water Policy (1997) requires an amount of 25 litres of water per day per person, which is stated as a short term target to meet the basic needs of the individual water user.

According to the DWAF (1998) no specific provision is currently made for the water needs of the ecology of the different water resources in the Mhlathuze River basin. This document states further that "it is not easy to calculate the amount of water required to protect the ecology of water resources. Each of the plant and animal species that live in the water resources must be studied to determine how much water it requires to survive over time. Not only is the survival of species at stake, but also whether they flourish or not. In other words, if just enough water is released for the ecology, certain species will just survive. If more water is released, these species will flourish and increase. If less is released, some might cease to exist and become lost from the system, making the resources vulnerable for losing its function of providing water for human and economic use."

The Ecological Management Class of the water resources describes the level of health at which the ecology is to be protected. Three different scientific teams recently determined the amount of water required to protect the different plant and animal species at different levels of health for each of the water resources in the catchment. These reports are due to be released by the DWAF in the near future.

3.5 Land use

In terms of catchment management, land use information requirements are extensive and should cover features that impact both the water supply and water user sectors. This includes not only the present but also the natural conditions which are often used as a reference state. This is a very extensive information requirement, covering several scales of detail that can only be assembled with time. Consequently only the available data is presented here. All the land use information described in this section is available in digital map format and is directly accessible in the IB through the Arcview GIS.

3.5.1 Basic Infrastructure

The catchment consists of the eastern coastal zone and the western mountainous areas. A well-developed infrastructure exists along the flat coastal zone, particularly around the towns of Empangeni and Richards Bay. In this area most of the water schemes are also formally developed and well monitored. In the mountainous western section, where there are large areas with no articulated schemes, a network of tar roads along the catchment boundaries allow limited access to most of the area. Figure 3.11 indicates the positions of the development nodes and the associated roads, railways and powerlines in and around the Mhlathuze River catchment.

3.5.2 Land use

One available source of land use information for water resource management is the WR90 data set (Midgley *et al*, 1994). This includes spatial information on some of the various land use features in the catchment at a scale of 1:250 000. An example of the agricultural land use sectors is shown in Figure 3.12. In the mountainous areas, some parts are developed into formal farms, which produces sugarcane, timber, citrus and some vegetables. Several irrigation boards monitor the formal farms' water consumption and are described under "Water Users." Some of the land is used for informal living, with subsistence farming. Water for households and subsistence farming irrigation is drawn by direct extraction from rivers, springs and from groundwater. A very extensive program to supply water needs of the communities has been undertaken during the past few years by the Uthungulu Regional Council, Mhlathuze Water, provincial government and many other agencies. Very few (if any) water consumption measurements are done in these areas.

The land use from the WR90 data set (Midgley *et al*, 1994) was derived from data prior to 1990 at a scale of 1:250 000. In an attempt to evaluate this data set and to create a more recent estimate of the land use at a smaller resolution for numerical modelling, a 1996 satellite image was used to create various estimates of land use cover. Detail and development of the Land Use Model, derived from the satellite imagery, is described in Chapter 4.

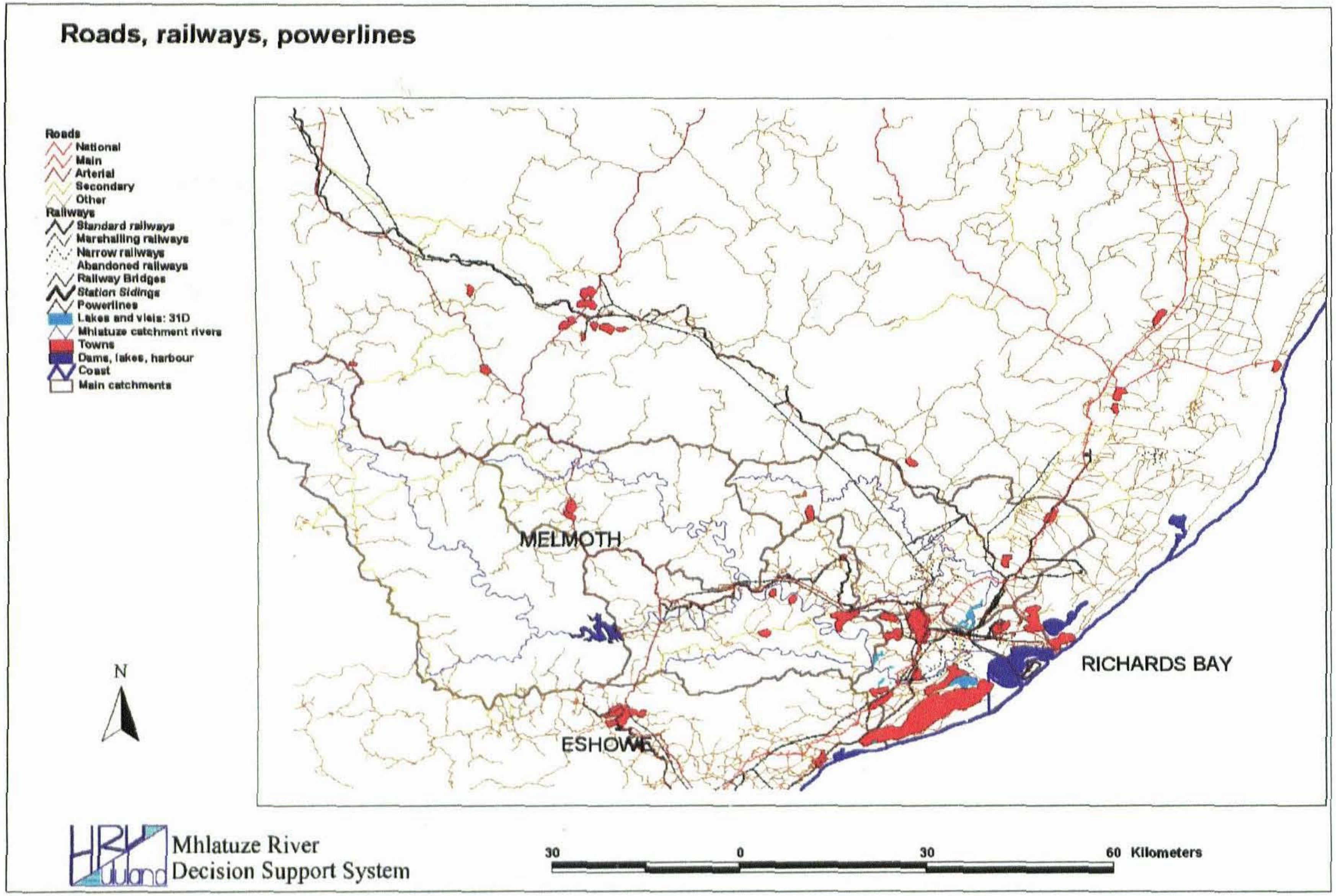

Figure 3.11: Infrastructure of the area in and around the Mhlathuze River catchment.

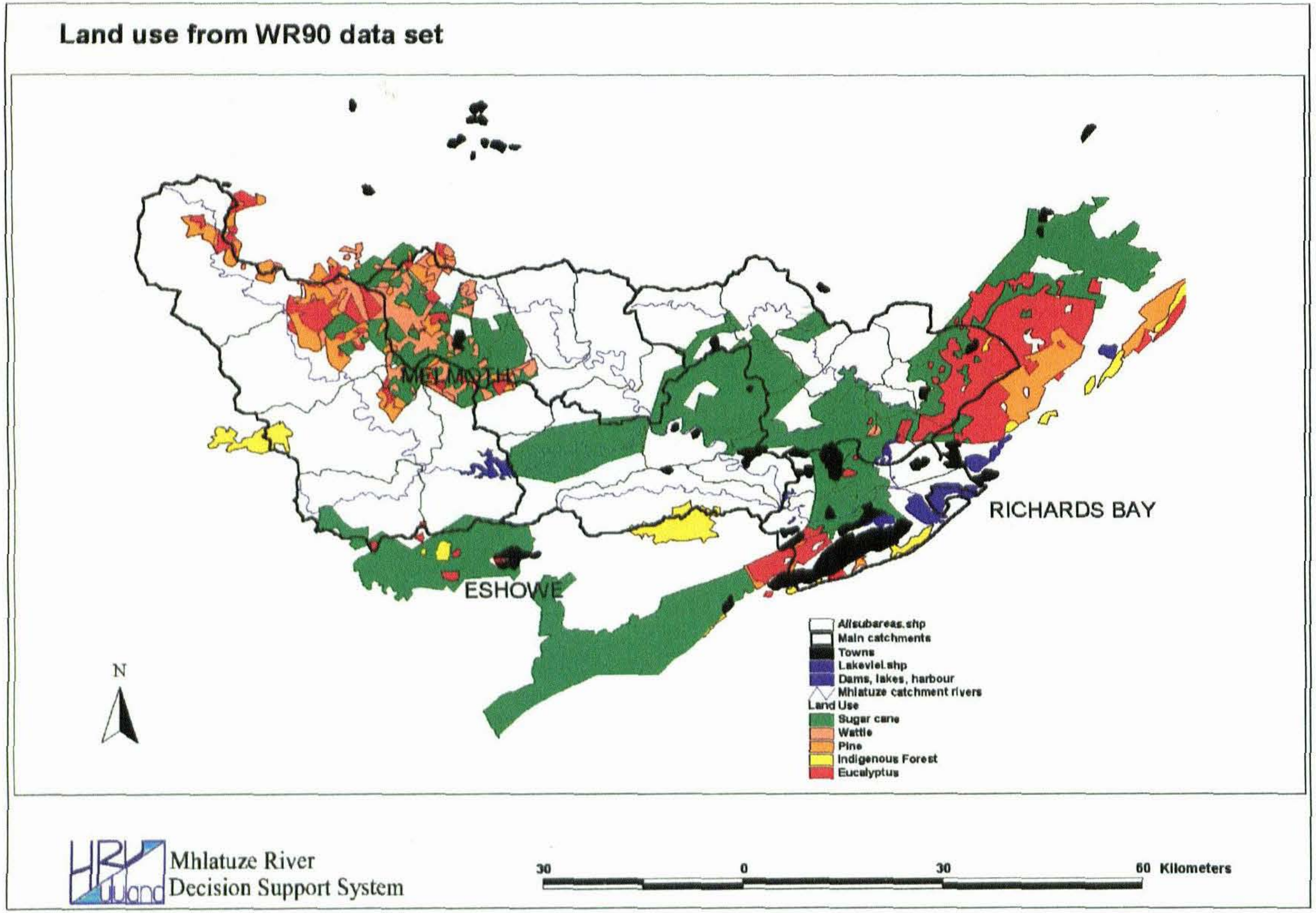

Figure 3.12: Land use from the WR90 data set: formal farms.

3.5.3 Industrial Development

A brief summary of the development of formal water supply in the Mhlathuze River basin , with reference to industrial development, is provided here. This was taken from a briefing document drawn up for a presentation at the Mhlathuze Stakeholders Committee Meeting held on 8 December 1998, at Richards Bay:

Between 1992 and 1994 several investigations were launched by the DWAF to identify the water shortages that were expected to occur in the Mhlathuze River System from 1997 onwards due to expected expansion of major industries in the Richards Bay/Empangeni region. The findings of these investigations were as follows:

- The yield of the Mhlathuze River System could not be sufficiently improved by the additional storage in the Mhlathuze system.
- The desalination of the sea water was too costly.
- Importation of water from the Mfolozi River, where numerous storage sites were investigated, was rejected largely on environmental grounds.
- Importation of water from the Thukela River remained the only feasible alternative.
- Two options for the ultimate transfer of 8.1 m^3/sec of water from the Thukela River were examined:
    - Pumping water from Mandini into a pipeline following the national road to the Mhlathuze System near Richards Bay
    - Pumping water from Middledrift into a pipeline and a tunnel discharging into the Mvuzane River, a tributary of the Mhlathuze River, upstream from the Goedertrouw Dam. (Figure 1.1)
- The Middledrift scheme was considered to be the most economical and therefore the preferred scheme.

In 1994 the proposed Tugela-Mhlathuze River Government Water Scheme (the Middledrift Scheme) was approved by parliament (DWAF, 1994). Details of the scheme are as follows:

- The proposed scheme would be developed in three phases to match future demands.
- Each phase would have a transfer capacity of 2.7 m^3/s.

- The estimated capital cost for the overall scheme was R395 million (March 1994 prices).
- The cost of the first phase was estimated at R258 million (at 1994 prices).
- Construction should commence during 1995.

Due to a lack of state funds, the proposed scheme was not built. The severe drought from 1993 until 1995 forced Mhlathuze Water and some of the major water users in the catchment to implement an emergency transfer scheme from Middledrift on the Thukela River. The transfer capacity of the emergency scheme is 1.2 m^3/s (37.8 million cubic metres per annum). The construction costs were about R100 million (1996 prices).

3.5.4 Agricultural Development

3.5.4.1 Sugar

Sugarcane irrigation is one of the major water usages from the Goedertrouw Dam. Irrigation methods used in the catchment are mostly overhead sprinklers, but underground drip irrigation is gaining popularity, especially since the installation of the Heatonville Irrigation Scheme, where some drip irrigation was implemented first. The optimisation of water usage by drip irrigation by far exceeds that of overhead irrigation (Mr Pat Brenchley, South Africa Sugar Experiment Station, personal communications).

The water consumption by the irrigation boards in the catchment is considered to be of the best monitored irrigation water consumption in the country (DWAF). Water is ordered, and records updated, on a weekly basis.

3.5.4.2 Forestry

Water used by forestry is not measured (no irrigation water is supplied to timber production lands), but the effects of timber production on stream run-off are the reason that afforestation in the catchment is controlled by permits. Tree plantations (eucalyptus, pine and wattle) contribute significantly to the land use in the upstream half of the Mfuli River, on the northern catchment slopes of the Mhlathuze River, upstream from the Goedertrouw Dam. The high rainfall coastal zones are also excellent areas for wood production. Plantations are significant in the catchment of Lake Nsezi (specifically the

Mposa River) and Lake Mzingazi. Figure 3.12 indicates the areas of formal timber and sugarcane production in the catchment.

3.5.4.3 Citrus

There are a growing number of Citrus orchards in the main river valley of the Mhlathuze River. Irrigation of orchards is done by under tree sprinklers, and (more often) by micro irrigation sprayers. Again the micro irrigation optimizes the water usage better than under tree sprinklers and is gaining popularity above the traditional under tree sprinklers. Methods which measure the water consumption of water by the trees are being implemented by more and more farmers, allowing the farmer to optimize the orchard's water supply (Etienne Boeke, Natal Irrigation Consultants, pers. comm.).

The main kinds of citrus produced are grapefruit, naartjies, lemons and oranges. Most of the citrus orchards are situated in the Nkwaleni valley, where irrigation water is taken from the Mhlathuze River, and is controlled by the Nkwaleni Irrigation Board.

3.6 Data Requirements of the IB

All of the above-mentioned information has been incorporated in the IB of the Mhlathuze DSS. While it is acknowledged that there are more data about the resources and their utilization for the Mhlathuze catchment than that which is presented above, it is difficult and costly to source and capture the data. In many cases, however, the data is missing and needs to be credibly estimated to provide the necessary information for catchment management. This section presents a preliminary effort to identify the additional functions that need to be created in the IB in order to provide the missing information. While it is often true that the availability of more information does not necessarily lead to better management decisions, it is also true that catchment managers need some information to make informed decisions.

The limited measured data needs to be integrated through numerical models, to provide additional information. In the Mhlathuze catchment, the observations of *quantity and quality of water run-*

off need to be both interpolated (to fill the frequently occurring gaps in existing records) and extrapolated (to provide some estimate of effects from different decision scenarios). This has traditionally been done by using calibrated run-off simulation software packages. The description of a numerical model (the HYMAS VTI model), which has been incorporated in the Mhlathuze IB, is presented in Chapter 4.

Simulation of the run-off in turn is dependant on the quality and quantity of the *rainfall and evaporation records*. The measured and patched records of both rainfall and evaporation were presented in section 3.1. Run-off is also dependant upon the *land use* and *geomorphology*. The next chapter contains the detail of the models created to describe these phenomena.

The *water demands* in the catchment can be estimated by studying the water permits granted to users in the catchment (DWAF, 1997). The actual water usage in the catchment is currently being measured at different places, but most of these records only extend back to the dry spell of 1995 when all consumers were forced to measure and report their water consumption.

Flow reduction activities need to be determined in accordance with the new water legislation for the management of water resources. The study of these activities is beyond the scope of this study. However, they are currently being determined by the Strategic Environmental Assessment (SEA) study undertaken by DWAF (Steyl, 1999, pers. comms.) and reports are planned to be released by April 2000. An initial estimation of the present land use activities in the catchment is being used to assist in these studies, and is presented in Chapter 4.

The *social and economic development* in the catchment of the Mhlathuze River must also be considered as an important component in the management of the system. The social importance of the Mhlathuze River was researched during the recent Mhlathuze Instream Flow Requirements workshops (1998 - 1999). Reports will be available from DWAF when the study is completed.

Both the *quantity and quantity of water* need to be estimated by law to manage the water resources. However, the quality of the Mhlathuze River resources was not considered to be a major problem in the Mhlathuze catchment during the recent Instream Flow Requirements workshops (DWAF, 1999). The quality of the water is being measured by Mhlathuze Water on a continued basis. The modelling of the water quality is one of the objectives of the greater Mhlathuze study undertaken by the HRU and is not reported in this thesis.

The data gathered and further enhanced by models can lead to such a wealth of information that even experienced managers can "drown" in the sea of facts that are available. Solving this problem means sifting the detail and presenting the core facts in a clearly and quickly-understandable fashion. Current application of this sifting process is implemented by lower level managers (or even researchers) who use computers to analyse and present the core facts with graphs and tables in reports to high level managers. The IB which is described in this thesis attempts to summarise the data from different sources and present the much needed core information in a more clearly understandable format.

4 Simulation modelling and Calibration

The last section of the previous chapter identified some of the information requirements that need to be determined in the IB. The principal one is the stream flow under previous and present catchment conditions to assist in water allocations. Since the run-off measurements are limited to certain reaches and are of short duration during periods of changing catchment conditions, alternate estimates are needed. These have traditionally been derived from calibrated simulation methods. Consequently, the IB has incorporated several numerical models which use the existing data to simulate stream flow records.

There are very limited measured records of the actual stream flow that are available, so the calibrations of stream flow models must rely heavily on measured rainfall records and well-estimated parameters. These parameters describe the catchment characteristics, at several scales, and are sensitive to the geomorphology and land use (amongst other characteristics). In an effort to refine the parameters of the stream flow models, a Land Use Model and a Digital Elevation Model (DEM) have been developed.

4.1 Land Use Model

4.1.1 Basic Information of the Satellite Imagery

A Landsat TM (Thematic Mapper) spectral image was bought from CSIR for the catchment of the Mhlathuze River with a spectral resolution of 25 by 25 metre pixels. This image was constructed from two different LANDSAT orbits. The image covering the upstream part of the catchment was taken on 22 April 1996, and the image covering the Richards Bay area was taken on 23 July 1997. The difference in the image from the two obits is clearly visible in Figure 4.1. This difference makes it difficult to apply a land use classification technique to the whole image.

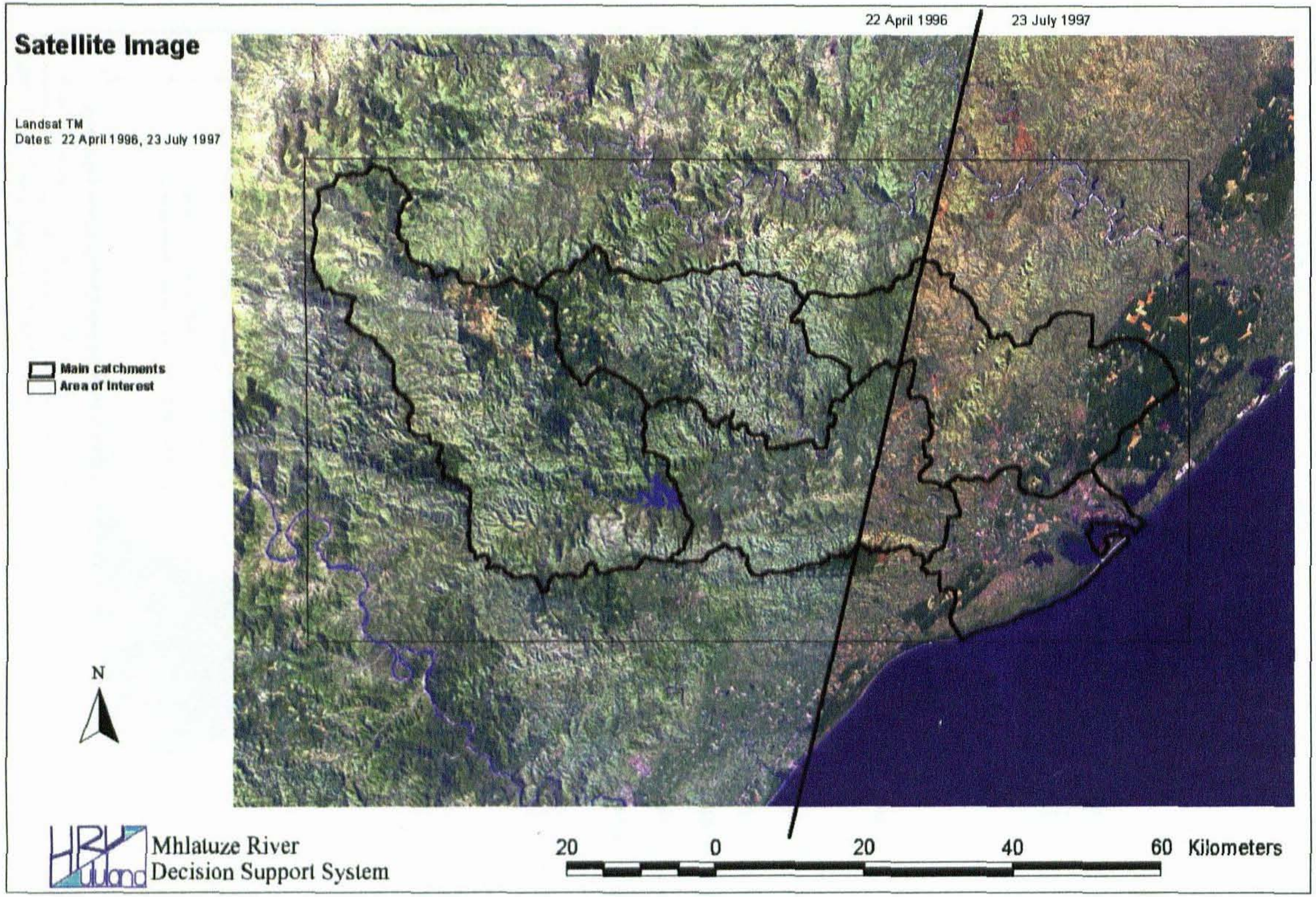

Figure 4.1: Landsat TM image of the Mhlathuze River catchment area.

Nevertheless, an attempt has been made to determine the spatial distribution of the main land use classes for the entire image.

4.1.2 Initial investigation of the catchment's vegetation

The Normalized Difference Vegetation Index (NDVI) is commonly used to describe the vegetation cover of an area under investigation. The NDVI image of the area of interest was constructed by taking the 3rd and 4th Landsat TM bands according to the following equation:

$$NDVI = (TM_4 - TM_3)/(TM_4 + TM_3)$$

where TM_3 = the spectral band in the *red* part of the colour spectrum

TM_4 = the spectral band in the *near infrared* part of the colour spectrum

The histogram of pixel values for the NDVI image of the catchment and surrounding areas shows a mean value of 0.35, which can be interpreted as vegetation with a reflectance of dense green leaf vegetation and medium green leaf vegetation (Meijerink, De Brouwer, Mannaerts and Valenzuela, 1994). The frequency distribution of the catchment is shown in Figure 4.2, and the image of the NDVI is displayed in Figure 4.3. Most of the values in the histogram lie between 0.1 and 0.8,

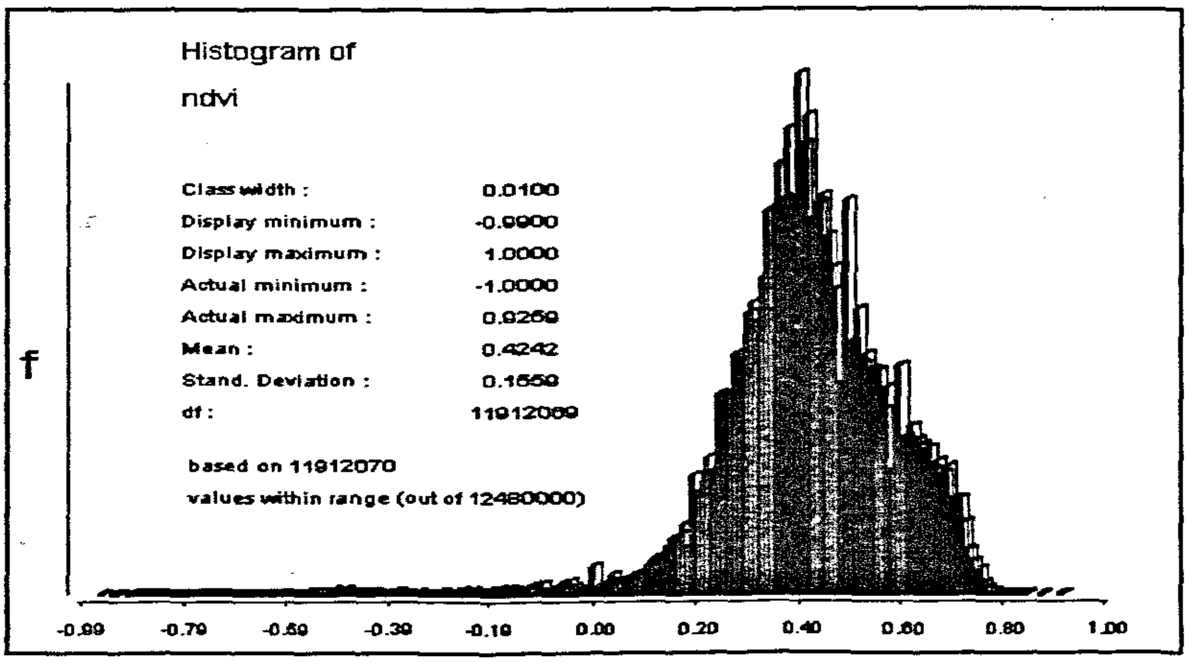

Figure 4.2: The frequency distribution of the NDVI for the Mhlathuze catchment.

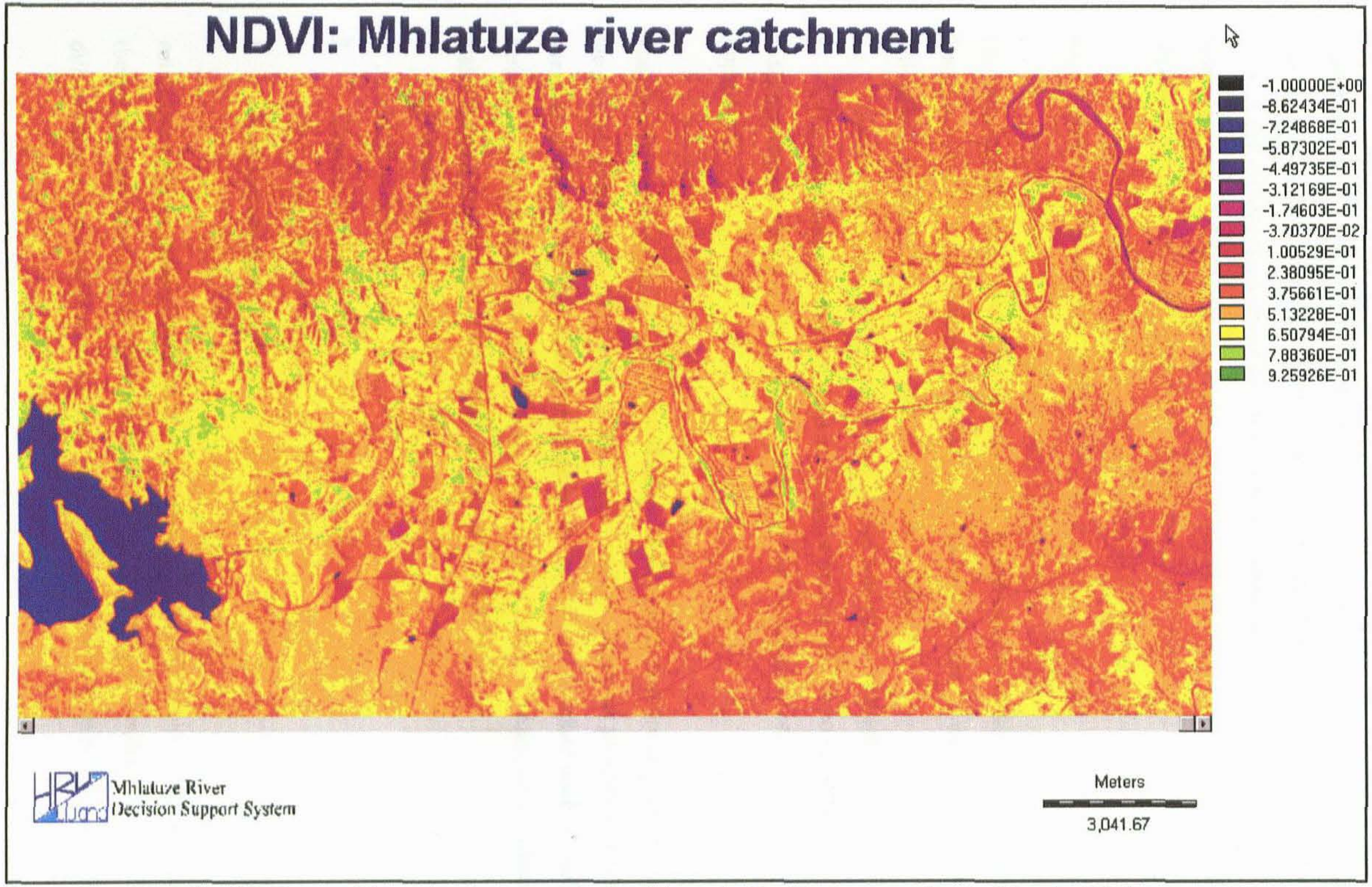

Figure 4.3: Normalized Difference Vegetation Indexes, calculated from the Satellite imagery, for the Nkwaleni Valley area of the Mhlathuze River catchment.

peaking on the mean and is distributed symmetrically around the mean. Leaving out the large number of negative values that indicate the water bodies (sea and lakes) in the image, gives a mean of 0.42, which coincide with the mode. This information indicates that these areas are generally densely vegetated in comparison to other catchments worldwide (Meijerink *et al*, 1994). Parameters in a hydrological model of the catchment which indicate a densely-vegetated catchment can therefor be accepted as a first estimate.

4.1.3 Land Use Classification Methods

The spectral reflectance of the different surfaces can be used to estimate the land use type (Eastman, 1997). Two methods of classifying the remotely sensed data have been proposed derived by Eastman (1997) and are used in this study. These are:

i. the unsupervised classification, using a cluster analysis method and

ii. the supervised classification method, using the maximum likelihood method.

A discussion on the theoretical background of each of the classification techniques is provided in Appendix 2.

The classification is dependant on the intended application of the land use data and the extent of the ground truth data. In this study the quantification of the land cover parameters was initially intended to support the derivation of parameters for modelling of surface water run-off. The derive parameters for hydrological modelling and to evaluate the classification methodologies, five major land cover classes were identified. These were classified as:

1. Dense trees
2. Bush or sparse trees
3. Dense crop or ground cover
4. Sparse crop or ground cover
5. Bare soil cover.

All main land cover classes identified by the analysis described below, were reclassed to one of these major land cover classes. This provided a way of comparing the results of the two distinctly different land cover classification methods and their use in hydrological modelling applications.

4.1.4 Ground truth data

Several field trips were undertaken within the catchment of the Mhlathuze River to collect ground truth data. During these field trips, photographs were taken of dominant land uses. Photographs of all possible land uses in the catchment were captured in digital and photographic images. Global Positioning System (GPS) readings were taken (and captured in the DSS) at each spot where photographs and images were taken. The digital images and written descriptions of the area have been incorporated in the DSS. The ground truth data are presented in Appendix 1 in the form of a table which lists the descriptions of photographs taken in the catchment. Appendix 2 gives more information on the background theory of the satellite imagery classification methods used in this study.

The initial ground truth data was used to determine the classifications. Subsequent ground truth data was first used to evaluate the classification methods and was then incorporated in the methods to refine the classifications.

4.1.5 Unsupervised classification

The following steps were applied to analyse the remotely sensed data using the unsupervised classification method with Cluster Analysis, using the IDRISI GIS program:

1. Identify the three most informative bands through Principle Component Analysis.
2. Create a composite image, making use of the three most informative bands.
3. Analyse the histogram of the composite image, and identify the "peaks" in the image.
4. Identify all possible clusters in the image.
5. Analyse the histogram of the pixel magnitude in the "clustered" image, to identify "peaks" in the frequency.
6. Repeat steps 4 and 5 until an optimal number of clusters are identified which depicts the major land cover classes on the image.
7. Display the resulting image and subjectively identify a land cover class for each cluster. Clusters can be classified together to make up one land cover class.

4.1.5.1 Principle Component Analysis.

Of the seven available bands, the three most informative bands were identified by means of Principal Component Analysis (PCA). Principle Component Analysis examines the statistical correlation structure between the seven bands. A statistical evaluation of the bands is given in terms of percentage variation of the information in the satellite image. A new set of orthogonal bands, i.e. the PCA components, are calculated. Each of these components is statistically different from the rest of the components (they are uncorrelated). All seven components contain different information of the satellite image. The first component accounts for the most variance, followed consecutively by the rest (Eastman, 1997).

The output from the Principle Component Analysis is listed in Table 4.1.1 for the first seven components. The three bands of the satellite image, which describes the most variation of the information on the satellite image, were chosen from this output.

Table 4.1.1: Output from the Principle Component Analysis

Component	Component 1	Component 2	Component 3	Component 4	Component 5	Component 6	Component 7
% variation	73.19	21.86	2.53	1.03	0.72	0.45	0.22
PCA Loading							
Band 1	0.49	-0.39	0.69	0.07	0.002	0.22	-0.20
Band 2	0.59	-0.25	0.67	0.009	0.008	0.21	0.31
Band 3	0.75	-0.46	0.32	-0.23	-0.15	-0.18	-0.004
Band 4	0.72	0.68	0.03	-0.006	0.009	-0.007	-0.002
Band 5	0.96	-0.24	-0.07	0.01	-0.03	0.02	0.0004
Band 6	0.54	-0.28	0.31	0.67	-0.006	-0.25	0.02
Band 7	0.86	-0.42	0.33	-0.05	0.25	-0.04	-0.002

The percentage variation explained by component one is 73%, that of component two is 22% and of component three is 3%. Together these components account for nearly 98% of all the variance. The PCA loading refers to the degree of correlation between the components and the different bands (Eastman, 1997). The satellite bands which are the most important in the first component, are the bands with the higher loading. These are band five (0.96), then band seven (0.86), followed by bands three (0.75) and four (0.72).

Band three (the red range of the spectral bands), band five and band seven (both in the mid infrared range) contain the most information of the satellite image while band four is linked to the second component where it has a loading of 0.68.

It is generally perceived that band four are useful to delineate water bodies (Lillesand and Kiefer, 1994). As there are large areas of the image covered by the sea and by water bodies (lakes, dams, etc), band four will naturally play a more important role in the composition of the first component. It also plays the most important role in the composition of the second component. Since the water bodies were found to be incorporated in the other bands, and band four is strongly associated with other orthogonal components, it has been excluded in this analysis. Bands six and two have a distinct spectral difference between the left and right-hand sides of the satellite image that are from separate orbits on different dates, and are not ideal for land cover analysis using this image. Band one's contribution is the least of all the bands, and was thus not used in the analysis. Consequently, the classification scheme was based on bands three, five and seven. Each of these satellite bands was converted to an IDRISI image.

4.1.5.2 Creation of a Composite image

Only one image of the remotely sensed image are analysed with unsupervised classification. The reason for using one image is that the mathematical methods, which are used to create one composite image from three images, are very much similar to the initial methodology applied to unsupervised classification. Making use of the composite image, calculated from the mentioned three images, saves on time and computer resources. From the Principle Component Analysis it is clear that the most information in the satellite image is contained in bands three, five and seven.

4.1.5.3 The histogram of the composite image

The histograms of the composite images (one for the left side and one for right side of the image) are shown in Figures 4.4 and 4.5. These histograms revealed several different distinct peaks, indicating the different land cover classes that can be identified with unsupervised classification.

4.1.5.3 The histogram of the composite image

The histograms of the composite images (one for the left side and one for right side of the image) are shown in Figures 4.4 and 4.5. These histograms revealed several different distinct peaks, indicating the different land cover classes that can be identified with unsupervised classification.

Cluster analysis was used to identify clusters of pixels which show similar spectral characteristics. The number of clusters was narrowed down to the number of major land cover classes, as indicated by the histogram of the composite image. The number of peaks on the histogram indicated the number of different land cover classes. Each of these classes was placed into one of the major land cover classes as defined for the hydrological simulations.

4.1.2.4 Presentation of Unsupervised Classification

The land cover classes that were revealed by the unsupervised classification method are listed in Table 4.1.2 and Table 4.1.3. All classes were assigned to one of five major land cover classes. Since the Landsat image was composed of two separate orbits one year apart, they were analysed separately. Figure 4.6 display the map of the land use createa via the Supervised classification method.

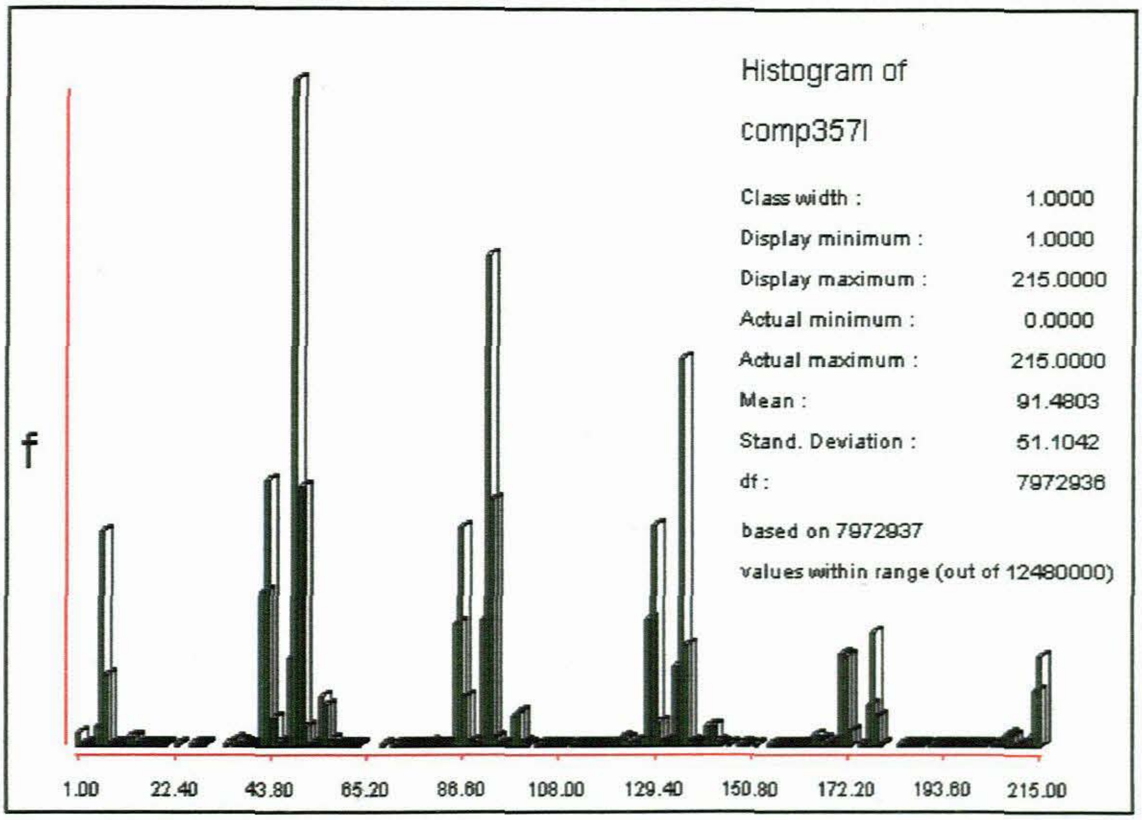

Figure 4.4: Histogram of composite image (left side of image).

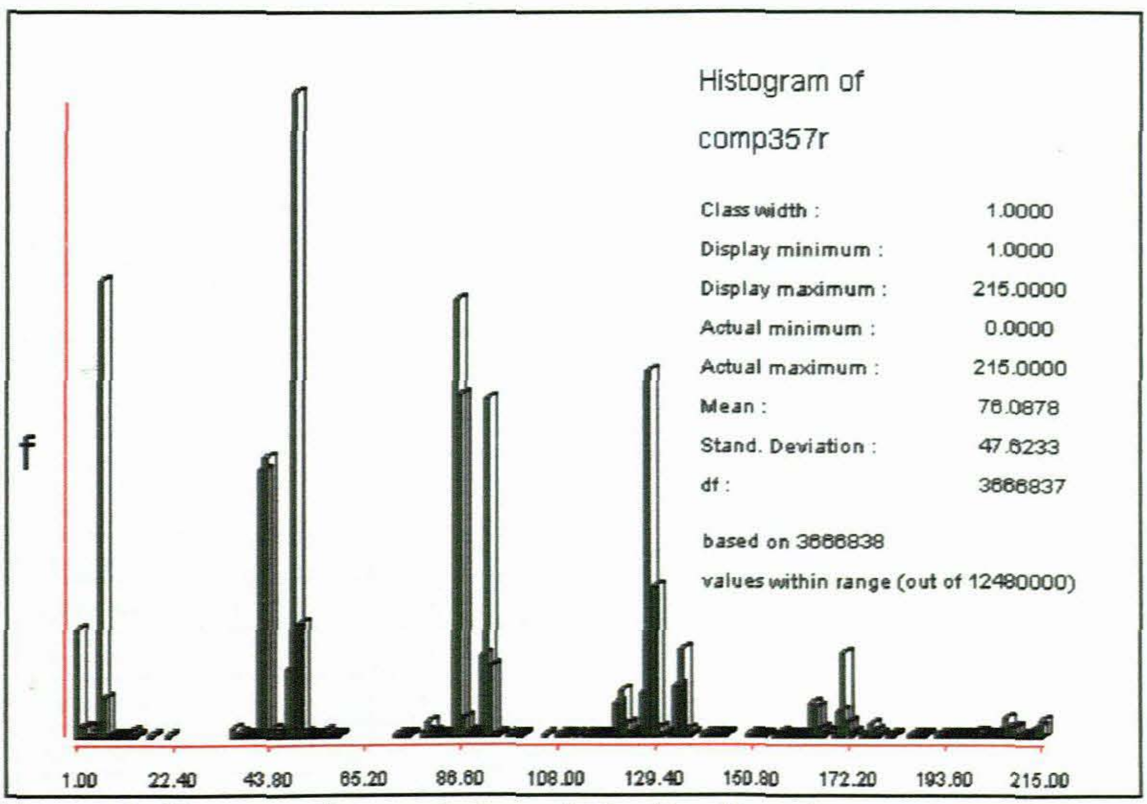

Figure 4.5: Histogram of composite image (right side of image).

*Table 4.1.2: Land cover classes as identified by unsupervised classification, with the associated major land cover classes for the **left** side of the image:*

LAND COVER CLASSES	AREA		ASSIGNED MAJOR LAND COVER CLASS
	km²	%	
plantations	963	20	dense trees
plantations/natural forest	456	9	
natural forests/mature sugarcane	147	3	
mature sugarcane	549	11	bush or sparse trees
natural forests/natural grass	306	6	
natural shrubs	672	13	
natural grass	496	10	sparse crop or ground cover
cut plantations/natural grass	200	4	
cut down plantations	181	3	
roads/natural grass/rivers	263	5	
roads/rivers	580	11	
roads	102	2.1	bare soil or ground cover
rivers	114	2.5	water
Deep water (Goedertrouw Dam)	20	0.4	
Unclassified pixels	13	0.0002	no class
Totals:	**5064**	**100**	

*Table 4.1.3: Land cover classes as identified by unsupervised classification, with the associated major land cover classes for the **right** side of the image:*

LAND COVER CLASSES	AREA		ASSIGNED MAJOR LAND COVER CLASS
	km²	%	
Plantations/Natural forest	374	13	Dense trees
Mature sugarcane	434	16	
Natural shrubs	156	6	Bush or sparse trees
Natural shrubs/Natural grass	389	14	
Natural grass	645	24	Dense crop or ground cover
Built-up areas/roads/sand	165	6	Bare soils or sparse ground cover
Deep water	447	16	Water
Shallow water	86	3.7	
Unclassified pixels	37	1.3	No class
Totals	**2735**	**100**	

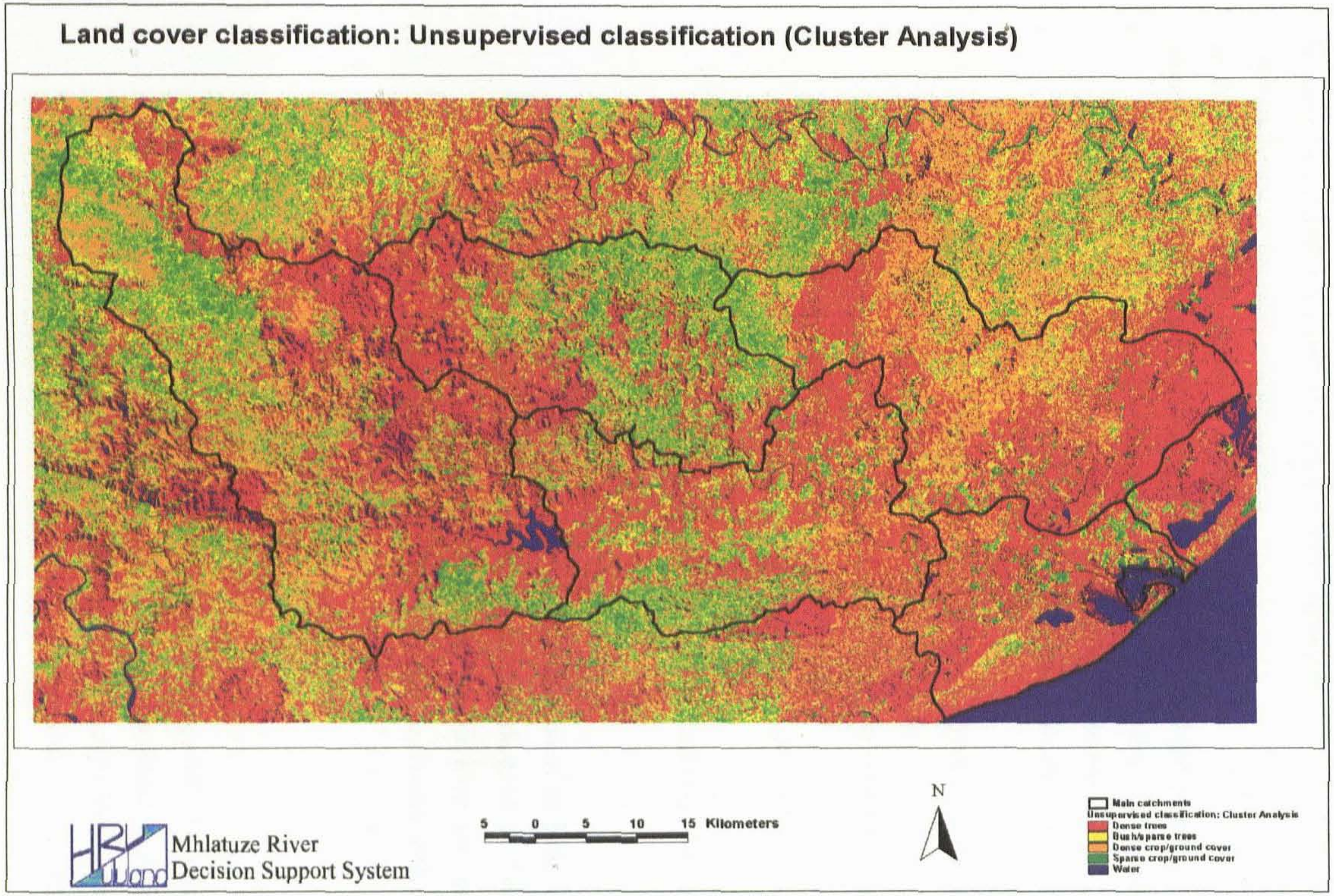

Figure 4.6: Land cover classification: Unsupervised classification (with Cluster analysis).

4.1.5 Supervised classification

The supervised classification method requires *a priori* knowledge of the land use and needs ground truth data for the major land use types.

The following steps were applied to analyse the remotely sensed data using supervised classification with the Maximum Likelihood method, using the IDRISI GIS program:

- The major land cover classes of the catchment were identified and listed by means of *a priori* knowledge of the catchment, using available ground truth data.
- Training sites with ground truth data were digitized on the screen with the remotely sensed image as a backdrop.
- These polygons were used to create spectral signatures of each land cover class, taking as input the seven spectral bands of the remotely sensed image.
- The spectral signatures were investigated and, if necessary, the training sites had to be redefined for improved representation of each land cover class.
- The maximum likelihood method was used to produce an image of the different land cover classes. This image was checked for erroneous classification.
- The whole process was repeated to refine each step until the final image was produced.

4.1.5.1 Identification of major land cover classes

Supervised classification was done after the initial investigation of the image using the unsupervised classification method. Although this eased the designation of land cover classes that are depicted by the sensors of the LANDSAT satellite, some new classes were added and some removed from the list during the supervised classification analysis. Table 4.1.4 lists the land cover classes identified with the Supervised Classification method, and the major land cover classes with which they were associated.

4.1.6.2 Training site identification

The "heart" of supervised classification is to digitize "training sites" (i.e. polygons) of areas where the land cover classes are known. The better the definition of the training sites, the better the classification of the land use. During the study of the Mhlathuze river, the identification of training sites was mostly done during field visits, taking GPS readings and photographs on several spots in the catchment. The remotely sensed image itself was also used to guide the process of defining training sites.

Table 4.1.4: Land cover classes identified with Supervised Classification, with the associated major land cover classes:

LAND COVER CLASS	CATEGORIES OF LAND COVER CLASSES	AREAS		MAJOR LAND COVER CLASS
		km²	%	
Tilled farm lands	-	2.6	0.03	Bare ground
Sugarcane	recently cut	0.3	0.003	Sparse crop or ground cover
	not canopied	12.5	0.16	Dense crop or ground cover
	well established/mature	229	3	Dense trees
Water	deep water (Goedertrouw Dam, big lakes, etc.)	331	4.2	Water
	shallow water (rivers, farm dams)	181	2.3	
	sand banks along rivers	16	0.2	Bare ground
	Goedertrouw Dam's wall	0	0	
Plantations	recently cut	960	12.3	Sparse crop or ground cover
	small trees	33	0.4	Dense crop or ground cover
	plantations on southern slopes	624	8.2	Dense trees
	big trees: two different kinds			
Roads	-	18	0.2	Dense crop or ground cover
Natural veld	natural forests	2351	30	Dense trees
	natural bush (bigger trees and shrubs)	1747	22	Bush or sparse trees
	Natural grass	1293	17	Dense crop or ground cover
Orchards	-	0	0	Not used
Built-up areas	-	0	0	
TOTALS		7800	100	

4.1.6.3 Creation of spectral signatures

The seven bands of the Landsat TM satellite image were analysed and the mean, maximum and minimum value of each of the bands were determined for each of the training sites. The histogram of the pixel values in each training site polygon were also determined.

4.1.6.4 Investigation of spectral signatures

The histogram of the remotely sensed data for each band of each training site was plotted and checked to see if it produced a normal distribution. In the cases of bimodal or skew histograms of spectral signatures, the training sites were redefined.

The maximum likelihood method was applied to classify the image, making use of the TM bands 1, 2, 3, 4, 5 and 7. The spectral signatures of most of the land cover types indicated that there is very little difference in band six for the training sites' spectral signatures, and consequently band six was ignored during the classification process.

During the initial classifications of the image into land cover types, it was noticed that the land cover types designated as "roads" and "shallow rivers" could be grouped together as their spectral signatures (Figure 4.7) were very similar. These land cover types occurred all over the image on places where no roads or rivers can be found, so it was assumed that these spectral signatures represent the bush and shrubs that generally occur next to the roads and near rivers and the features themselves. Some land cover classes

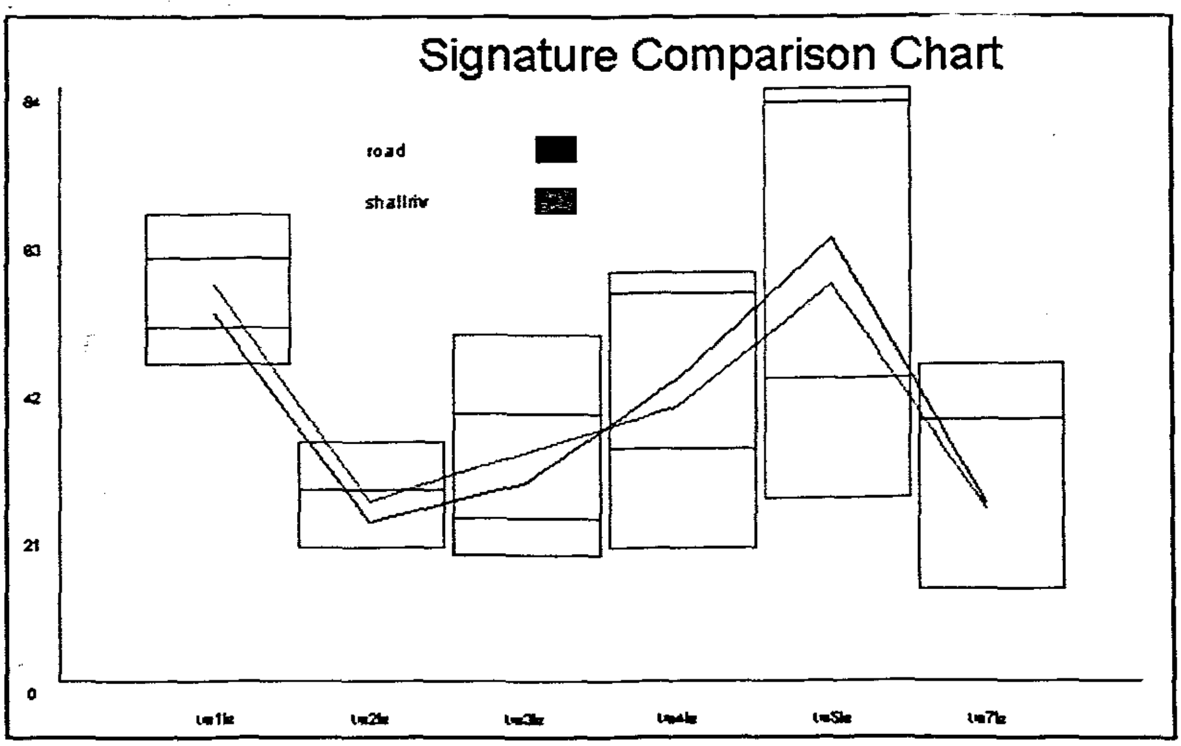

Figure 4.7: Spectral signatures of classes "roads" and "shallow rivers" on left side of image. The vertical axis represents the minimum, maximum and mean spectral reflectance, for each of the seven different bands, which are indicated on the horizontal axis.

were removed from the classification during the analysis because they did not have well-defined spectral signatures. In particular, the built-up areas and orchards were not classified separately, because the different pixels belonging to each of these land use classes are too complex in spectral reflectance characteristics to be represented by one spectral signature.

4.1.6.5 Maximum likelihood classification

The probabilities that each land cover type can occur on the image, were used in conjunction with the spectral signatures, for the final classification of the image. These probabilities originated from the outcome of initial classifications. It assisted in classifying the pixels into the best possible class. The values of probabilities for different land uses are indicated in Table 4.1.5.

After the final classification, the resulting land use image were filtered with a 3 x 3 mode filter. This filtering technique replaces the middle pixel of each 3 x 3 window with the mode of the surrounding pixels. This ensures that individual pixels are classified according to the surrounding land cover type. The final image of land uses depicted by supervised classification are displayed in Figure 4.8.

4.1.7 Comparison between the supervised and unsupervised classification methods

A comparison between the two classification schemes were conducted as a preliminary evacuation of the methods. The number and types of classes identified in each of the two methods, differs. To compare the two methods, it is necessary to reclassify them to a common set of land uses. Each land cover image was reclassified to one of the major land cover classes needed for flow simulations described in section 4.3. However, it is important to recognize the difference between the two techniques. The unsupervised classification method groups together all the pixels which have similar spectral qualities. This technique is useful for catchments where no ground truth data is available. The supervised classification creates the spectral signatures of known land use types which is used to group the pixels according to *a priori* knowledge of the catchment.

Table 4.1.5: The values of probabilities for different land uses identified with Supervised Classification

Left side of the image		**Right side of the image**	
Land use	**Probability to occur (%)**	**Land use**	**Probability to occur (%)**
Unclassified pixels and Right side of image	42.15	Unclassified pixels and Left side of image	75.88
		Hills: North facing	0.07
		Hills: South facing	0.13
Natural veld: southern slopes	0.45		
Natural forests	14	Natural forest	0.65
Natural bush	14	Natural bush	2.35
Natural grass	8.63	Natural veld	2.47
Plantations: newly cut	0.71	Plantations: newly cut	2.4
Plantations: small trees	5.48	Plantations: small trees	0.18
Plantations: dark colour	1.5	Plantations: dark colour	0.59
Plantations	1.6	Plantations	1.76
Plantations: southern slopes	0.77		
Rivers: shallow rivers	3.14	Rivers: shallow rivers	0.23
Rivers	0.02	Rivers	7.61
Sand banks	0.05	Sand banks	0.04
Roads	4.5		
Sugarcane: newly cut	0.08	Sugarcane: newly cut	0.13
Sugarcane: mature	2.6	Sugarcane: mature	1.62
		Water: Dark lakes	1.63
		Water: Sea	0.01
		Water: Sea (added later)	1.85
		Water: Light lakes	0.38
Water: Farm dams	0.03		
Water: Goedertrouw Dam	0.11		
Goedertrouw Dam wall	0.06		
Tilled farm ground	0.08		
Total probability (%):	99.96	Total probability (%):	99.98

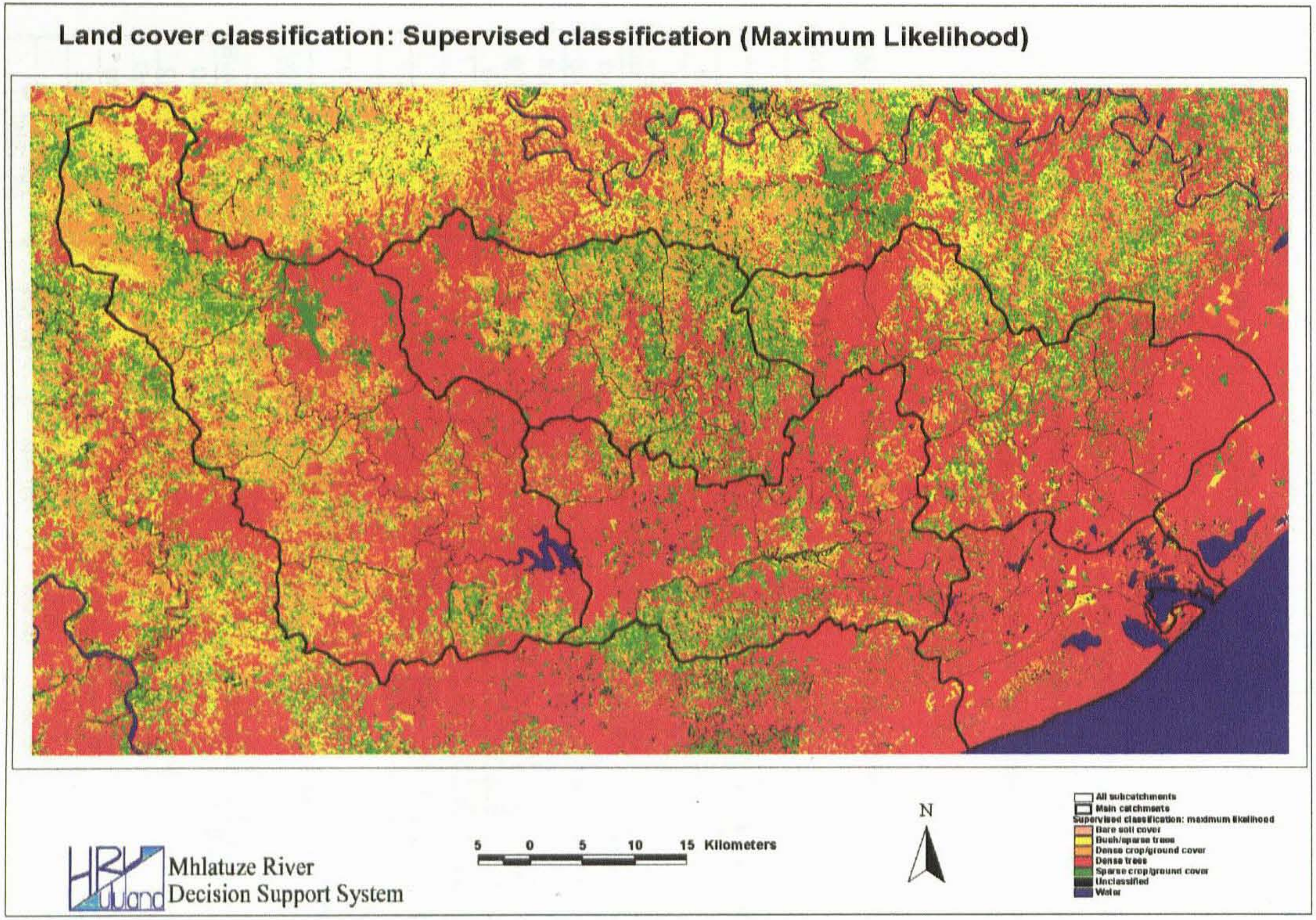

Figure 4.8: Land cover classification: Supervised classification (with Maximum Likelihood analysis).

4.1.7.1 Vegetation types in the major rivers' catchments

The percentages of major land cover classes as revealed by the image classification are listed in Table 4.1.6 for the five main subcatchments. This table suggests that the dense vegetated areas occur more frequently than the less dense vegetation types. The unsupervised classification method did not reveal any bare ground.

4.1.7.2 Cross tabulation comparison

A cross tabulation of the two images, where the individual pixels are compared to each other, was conducted on the whole image. Refer to Table 4.1.7. The unclassified pixels inside the catchment boundaries were grouped with the "background values," which are the pixels outside the catchment boundaries.

Table 4.1.6: Percentages of major land cover classes for the different main catchments as calculated by the two classification methods:

Supervised classification						
	Richards Bay	Goedertrouw	Lake Nsezi	Mfuli	Nkwaleni	Totals: (%)
Unclassified	0.00	0.00	0.01	0.00	0.03	0.01
Dense trees	71.82	37.76	57.90	40.30	57.87	49.61
Bush sparse trees	5.89	28.32	13.78	19.59	13.93	18.83
Dense crop or ground cover	8.56	19.89	14.69	18.29	11.39	15.79
Sparse crop or ground cover	3.84	11.39	12.54	18.11	13.31	12.39
Bare ground	0.51	0.42	0.07	0.74	0.79	0.48
Water	9.39	2.21	1.01	2.96	2.69	2.9
Totals: (%)	100.00	100.00	100.00	100.00	100.00	100.00
Unsupervised classification:						
Land cover class	Richards Bay	Goedertrouw	Lake Nsezi	Mfuli	Nkwaleni	Totals: (%)
Dense trees	43.54	31.39	39.50	31.14	37.17	35.35
Bush sparse trees	23.08	24.82	22.66	25.13	29.86	25.19
Dense crop or ground cover	16.08	21.77	27.12	17.28	16.33	20.53
Sparse crop or ground cover	7.06	14.28	6.83	20.59	13.03	12.84
Bare Ground	No "bare ground" revealed					
Water	10.24	7.7	3.89	5.87	3.62	6.09
Totals: (%)	100.00	100.00	100.00	100.00	100.00	100.00

The values indicated in bold (in Table 4.1.7) are the percentage of pixels that are classified as the same land use type. When comparing these values to those in the "Total" column and "Total" row, it reveals that, *in each land use category*, more than half of the pixels are classified to the same land use by both methods. Adding the bold values, indicates that 79% of *all the pixels* are classified in the same land use category. The totals of each land cover class also indicate that the distribution of pixels amongst the different land cover classes is the same within 4%, as shown in Table 4.1.8.

The land cover class Bare Ground (nr 5) is absent in the Unsupervised classification image. The high number of unclassified pixels in Unsupervised classification indicates that some of these pixels could have been classified as bare ground.

Table 4.1.7: Proportional Cross tabulation of Rows: Maximum Likelihood (supervised analysis) against Columns: Cluster analysis (unsupervised analysis):

	0	1	2	3	4	6	Total
0	**0.5297**	0.0000	0.0000	0.0000	0.0000	0.0000	0.5297
1	0.0138	**0.1341**	0.0388	0.0176	0.0024	0.0031	0.2097
2	0.0045	0.0259	**0.0532**	0.0160	0.0106	0.0003	0.1106
3	0.0006	0.0012	0.0104	**0.0467**	0.0176	0.0005	0.0769
4	0.0003	0.0020	0.0148	0.0153	**0.0272**	0.0000	0.0597
5	0.0000	0.0000	0.0001	0.0015	0.0007	0.0000	0.0022
6	0.0009	0.0004	0.0027	0.0011	0.0036	**0.0024**	0.0112
Total:	0.5498	0.1637	0.1200	0.0982	0.0620	0.0063	1.0000

0 = "background values" outside of catchment
1 = dense trees
2 = bush/sparse trees
3 = dense crop/ground cover
4 = sparse crop/ground cover
5 = bare soil
6 = water areas

Table 4.1.8: Comparison between the percentages of land use classes, as listed in Table 4.1.7, with the differences in these percentages:

Land Use Classes	Unsupervised Classification	Supervised Classification	Differences in percentages of classifications:
Dense trees:	20.97%	16.37%	4.6%
Bush/sparse trees:	11.06%	12.00%	0.94%
Dense crop/ground cover:	7.69%	9.82%	2.13%
Sparse crop/ground cover:	5.97%	6.20%	0.23%
Bare soil:	0.22%	no classification	0.22%
Water areas:	1.12%	0.63%	0.49%

The overall Kappa Index of Agreement (KIA) (Eastman, 1997) for this comparison, was 0.68. The KIA is a correlation coefficient that ranges from 0.0, indicating no correlation, to 1.0, indicating perfect correlation (Eastman, 1997).

The KIA was also calculated by comparing the two land cover classifications, taking the one image as the ground truth image, and the other as the classified image. The results are listed in Table 4.1.9. An overall KIA of 0.44 was calculated. This comparison technique is in essence the same as the cross tabulation comparison technique, but differs from the cross tabulation technique in that it ignores the vast number of "background" pixels which falls outside the catchment. (These background values overlap on the two images.) Thus, the smaller KIA of 0.44 is a better estimation of the overlap in the two classification techniques.

Table 4.1.9: The table of Error Measurements: Cluster analysis (unsupervised analysis) compared to Maximum Likelihood (supervised analysis):

Category	Dense trees	Bush / sparse trees	Dense crop / ground cover	Sparse crop / ground cover	Bare soil	Water
Error of Omission	0.21	0.53	0.52	0.57	0.0	0.18
Error of Commission	0.33	0.49	0.41	0.55	1	0.29

A second comparison was made between the image containing only the training sites of the different land classes, and the final classification done with the supervised Maximum Likelihood classification method, which uses the training sites to classify the image. The output of this comparison is listed in Table 4.1.10. The overall KIA for this comparison was 0.97.

Table 4.1.10: The Table of Error Measurements: Training sites compared to final classification via Maximum Likelihood (supervised analysis):

Category	**Error of Omission**	**Error of Commission**
1: Mature Sugarcane	0.06	0.00
4: Plantations	0.003	0.0009
5: Newly cut plantations	0.03	0.21
9: Natural forests	0.03	0.19
10: Natural scrubs	0.08	0.04
11: Natural veld	0.03	0.03
12: Deep water	0.0003	0.0002
15: Roads	0.76	0.14
17: River sand banks	0.005	0.005
19: Plantations of small trees	0.14	0.000
20: Shallow rivers	0.08	0.20
21: Tilled ground	0.02	0.01

The Table of Error Measurements (Table 4.1.10) indicates erratic classification of the land use classes for several of the classes:

- Newly cut plantations
- Plantations of small trees
- Natural Forests
- Roads
- Shallow rivers

These categories were not classified very well. Some of these pixels were classified into some other classes, which could have been due to the mode filter that changed pixels' land use to conform with surrounding pixels. The categories of Roads and Shallow Rivers represent areas which are fairly narrow or small and may not be suitable for classification using 25 metre by 25 metre imagery. The reason for bad classification of the Plantations (Small Trees and Newly Cut) and Natural Forest categories, could be due to the natural variability of pixels' spectral signatures within those categories.

4.1.7.3 Suggested improvements of the classification

The classification of the image was done, making use of two methods which differs distinctly in nature. Comparing the results from the two methods, shows clear similarities, but underlying problems occurred during the analysis of both methods:

Problem 1. Not all the land cover classes were revealed properly. The main agricultural crops (like the citrus orchards and different kinds of plantations) could not be classified successfully.

Problem 2. The effects of hill shading were problematic. Surface albedo varies with angle, and consequently the spectral signatures for southern facing slopes could be different to the northern facing slopes.

4.2 Digital Elevation Model

The geomorphology of a catchment is the result of weathering processes on geological formations that culminate in the resulting stream network. The geomorphology of the catchment can be analysed and characterized by an appropriate Digital Elevation Model (DEM).

The hydrological modelling of a catchment basin incorporates the estimation of parameters which describe the geomorphology of the catchment. These parameters usually include the catchment elevation, slopes, aspects, river lengths, and related parameters. First estimates of the catchment features are often done by investigating elevation contour maps of the catchment. However, the construction of a DEM can largely assist with quick and more accurate estimates of these parameters. Kelbe and Snyman (1993) have used a DEM to examine the hydrological processes in a research catchment near Empangeni.

4.2.1 Model Development

DEM models can be used to conduct analytical assessments of many geomorphological features, like the angle and direction of slopes and streams channels, as well as the catchment structure and erosion potential (Kelbe and Snyman, 1993). A DEM consists of a matrix of values specifying the average heights of the topography, represented by picture elements (pixels) at fixed horizontal intervals (resolution) above mean sea level.

4.2.1.1 Spatial resolution

The resolution of the DEM (which is the size of each pixel or spacing between pixel centres) must be chosen primarily according to the scale of hydrological analysis. The bigger the scale, the coarser the parameter estimates will be, no matter how well the DEM is constructed. However, other factors to consider in this decision are the size of the catchment, and the capability of the computer to generate and analyse the DEM. A bigger catchment needs a bigger matrix to cover the whole catchment area, and thus needs more computer resources during processing. Usually the process of DEM construction from a set of contours, involves a huge amount of computer time and resources. Other constraints of the DEM resolution include the availability of contour data in digital format (and the scale of these contours), as well as the general topology of the catchment.

4.2.1.2 Input to DEM construction

The Department of Land Affairs, Chief Directorate of Surveys and Land Information, have vectorized the 100-m contours from 1:250 000 maps, which were used to construct the DEM. They have also created coverages of the 20-m contours from the 1:50 000 topographical maps which were available for the coastal section of the catchment (Figure 4.9). The DEM was constructed using the IDRISI 2 for Windows GIS package. The position of the coast and some contours in the sea were added. The flat areas along the coastal zone were initially not well constructed due to the sparsely spread 100-m contours

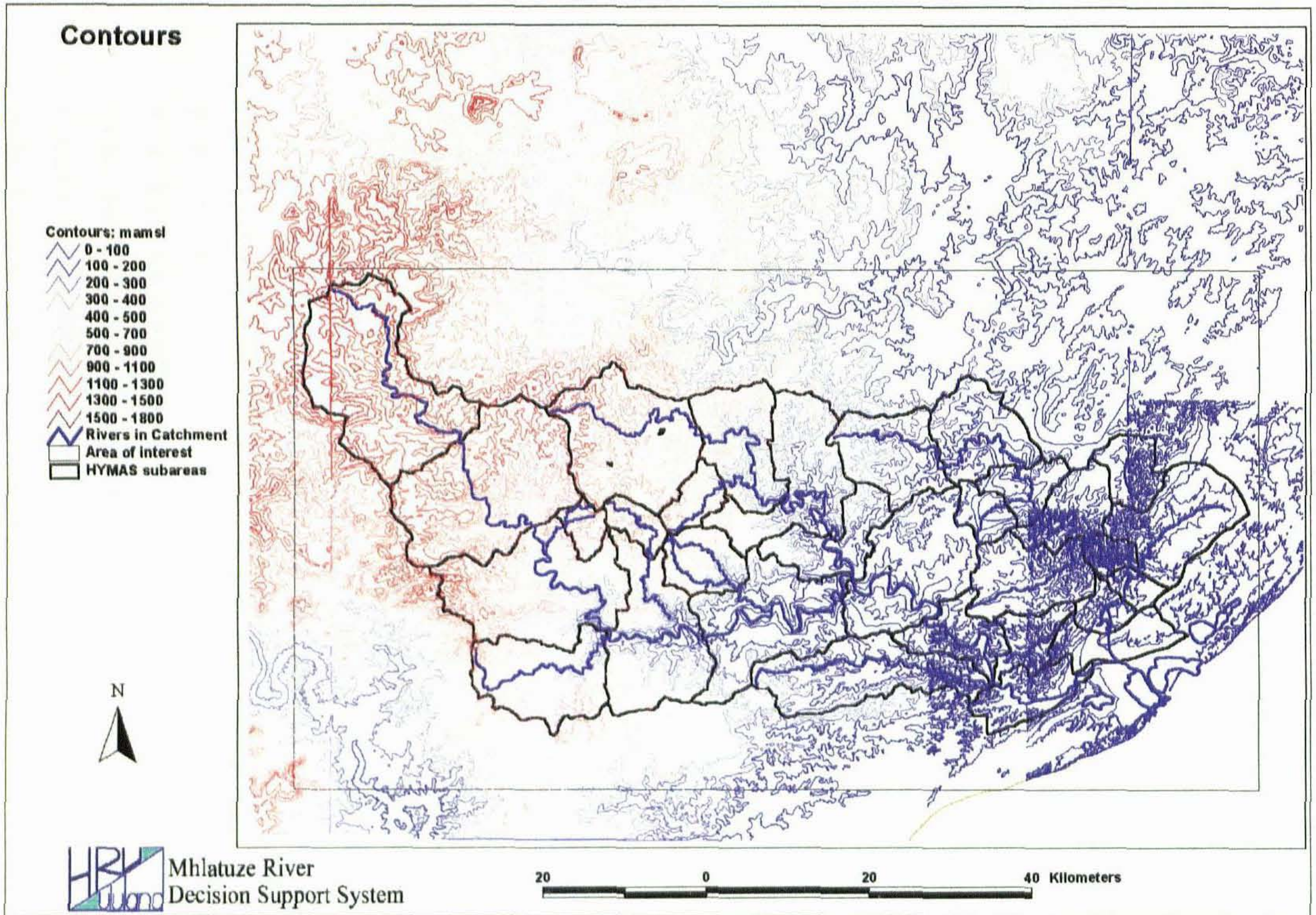

Figure 4.9: Contours used for construction of the Digital Elevation Model of the catchment.

in this area. Some of the 20-m contours from 1:50 000 maps had to be added along the flat coastal zone. Figure 4.9 shows the available contours which were used during the final construction of the DEM.

4.2.1.3 Method of DEM construction

The catchment stretches over an area of 65km by 120 km. Initially, a DEM of 2600 rows by 4800 columns (pixel size of 25m by 25m) was constructed. Calculating the slopes revealed flat areas (areas of zero slopes) and visual inspection of the constructed model revealed "stars and stripes" in some badly constructed areas of the DEM. These areas required the supplementation of some contours in those areas where the original set of contours were to far from each other, due to the flatness of the areas. The constructed DEM image was smoothed by a "mean filter," which replaces the middle cell of each 3 x 3 cell window with the mean of the 8 surrounding cells. After filtering, the image was contracted by pixel aggregation using a factor of 5 in both the x and y directions, to an image of 520 rows by 960 columns, with cell sizes 125m by 125m to match the source map resolution of the 100-m contours. See Figures 4.10 and 4.11 for the two and three-dimensional views of the constructed Digital Elevation Model. All considerations of the DEM are restricted to the areas inside the Mhlathuze River catchment.

4.2.2 Evaluation and Quality

There are several quick ways to test the quality of a constructed DEM:

- Calculate the slopes and aspects from the DEM and investigate the flat areas (of zero slope) in the DEM. Very large areas of zero slope can cause problems when creating the river network. Rivers usually meander through flat areas in a catchment, but are calculated as straight lines through an area of zero slope. Hydrological modelling parameters, relating to river lengths and catchment boundaries, are then calculated inaccurately. It is necessary to force the topography modelled in the DEM to conform to known features by adding appropriate contours.
- Calculate the river network from the DEM and compare them to the actual river network of the catchment.

- Calculate the catchment boundaries from the DEM and compare them with the catchment boundaries obtained from other sources.

4.2.3 Slopes and aspects

The slopes and aspects were calculated from the DEM to support further analysis of the catchment features. The spatial map of slopes is shown in Figure 4.12.

The slope grid indicated areas of zero slopes (indicates as black areas in Figure 4.12) along:

2. sections of the Mhlathuze River valley downstream from the Goedertrouw Dam,
3. sections of the Mhlathuze River valley between the Mfuli River confluence and weir W1H009,
4. along some catchment boundaries,
5. around Lake Mzingazi and Lake Nsezi,
6. in the vicinity of the Nseleni River and the Okhula River confluence,
7. in the vicinity of the Mhlatuzana River and the Mhlathuze River confluence.

The DEM (derived at a resolution of 125 x 125 metres) shows an escarpment (Figure 4.12) with steep slopes across the central part of the catchment upstream of the Goedertrouw Dam and upstream of the confluence of the Mfuli and Mhlathuze rivers.

4.2.4 Flow directions and sinks

Because of the poor resolution of the contours at the pixel resolution, the DEM created sinks or pits where flow terminates at a point. Flow directions (indicated in Figure 4.13) were used to calculate the positions of sinks which are indicated in Figure 4.14. Initially more than one thousand sinks were indicated but these were eliminated, because the catchment of the Mhlathuze does not have many natural sinks and sources at the scale of DEM. The software eliminates all sinks in the DEM, and the natural sinks will have to be manually added in again.

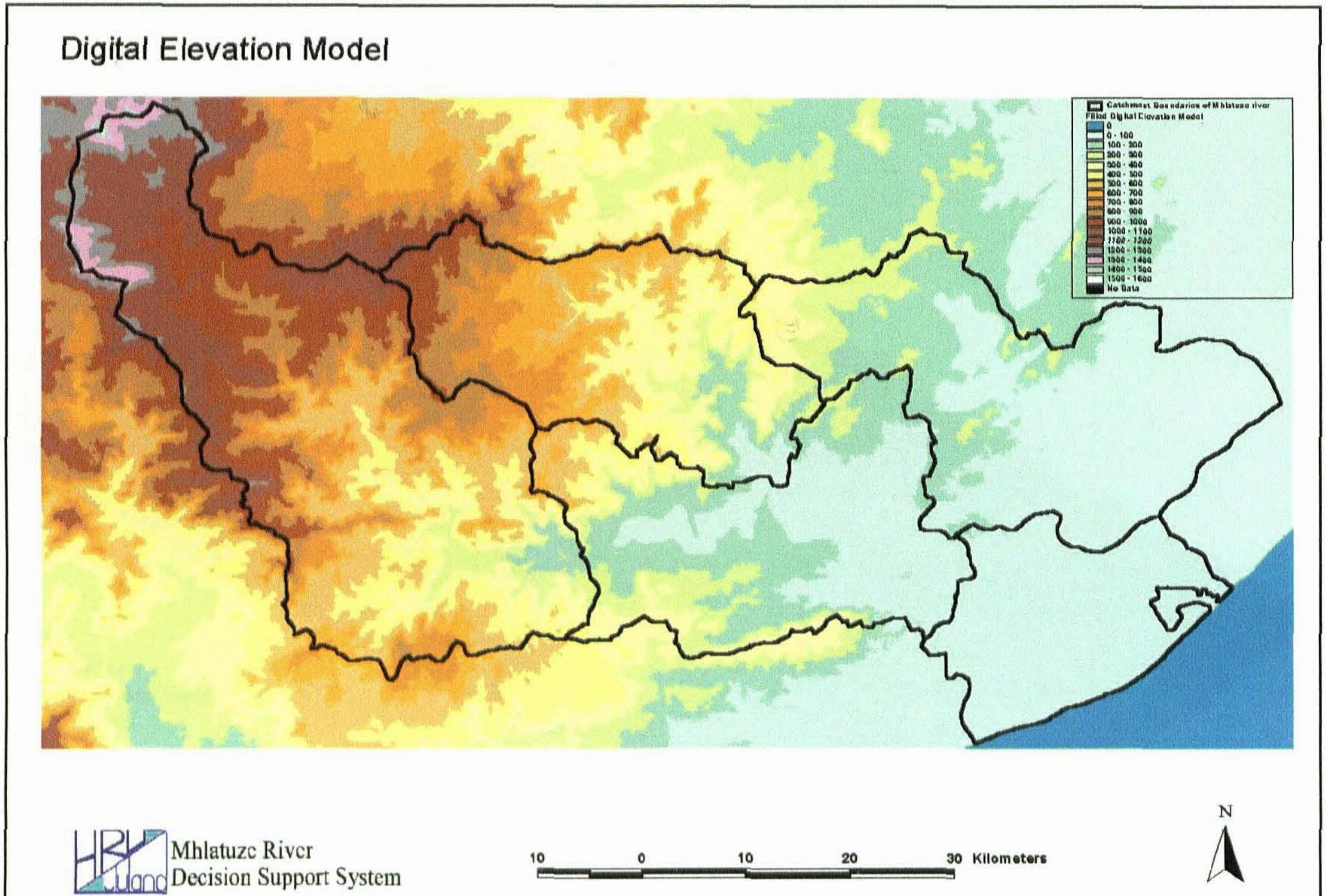

Figure 4.10: Digital elevation model of the Mhlathuze catchment.

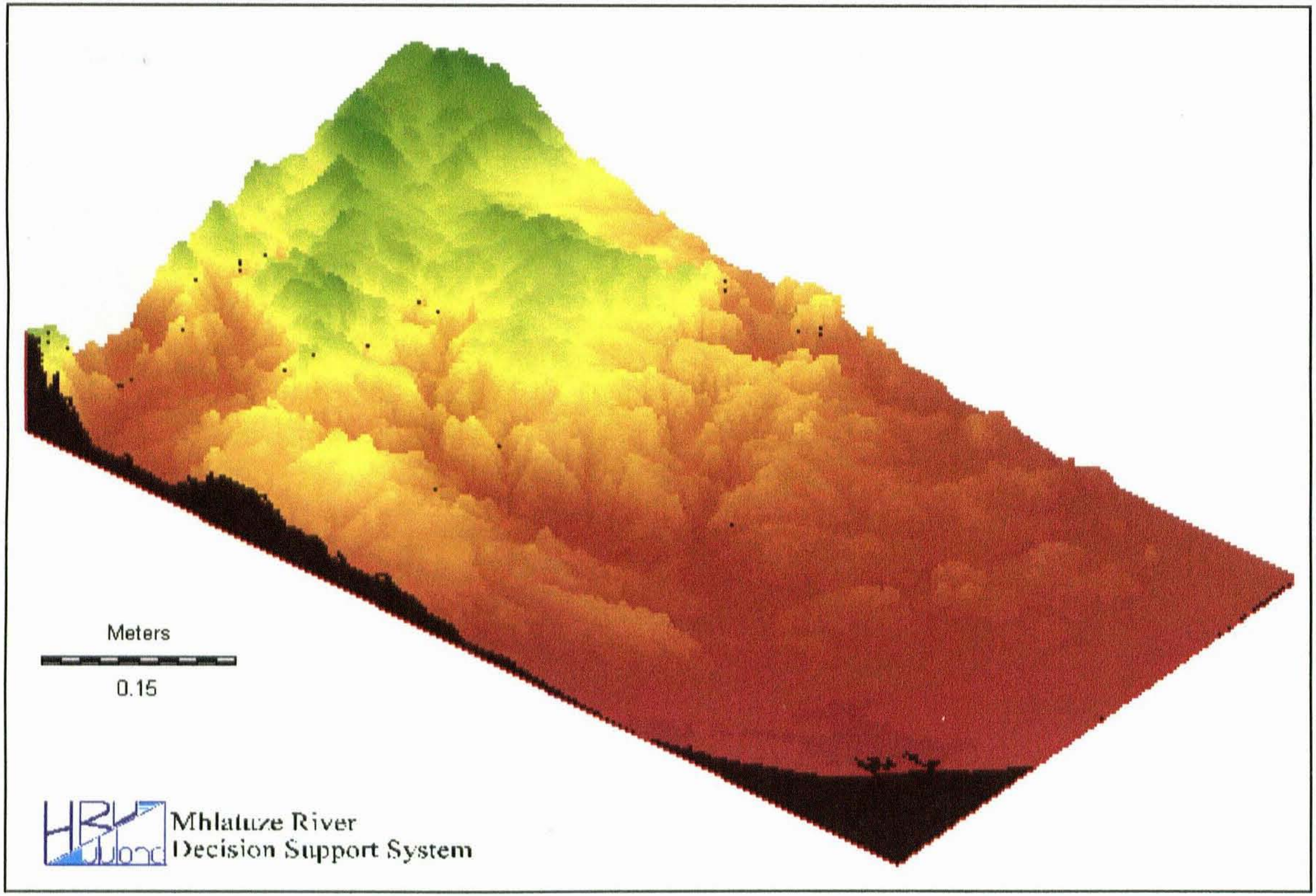

Figure 4.11: Digital elevation model of the catchment: a three dimensional view.

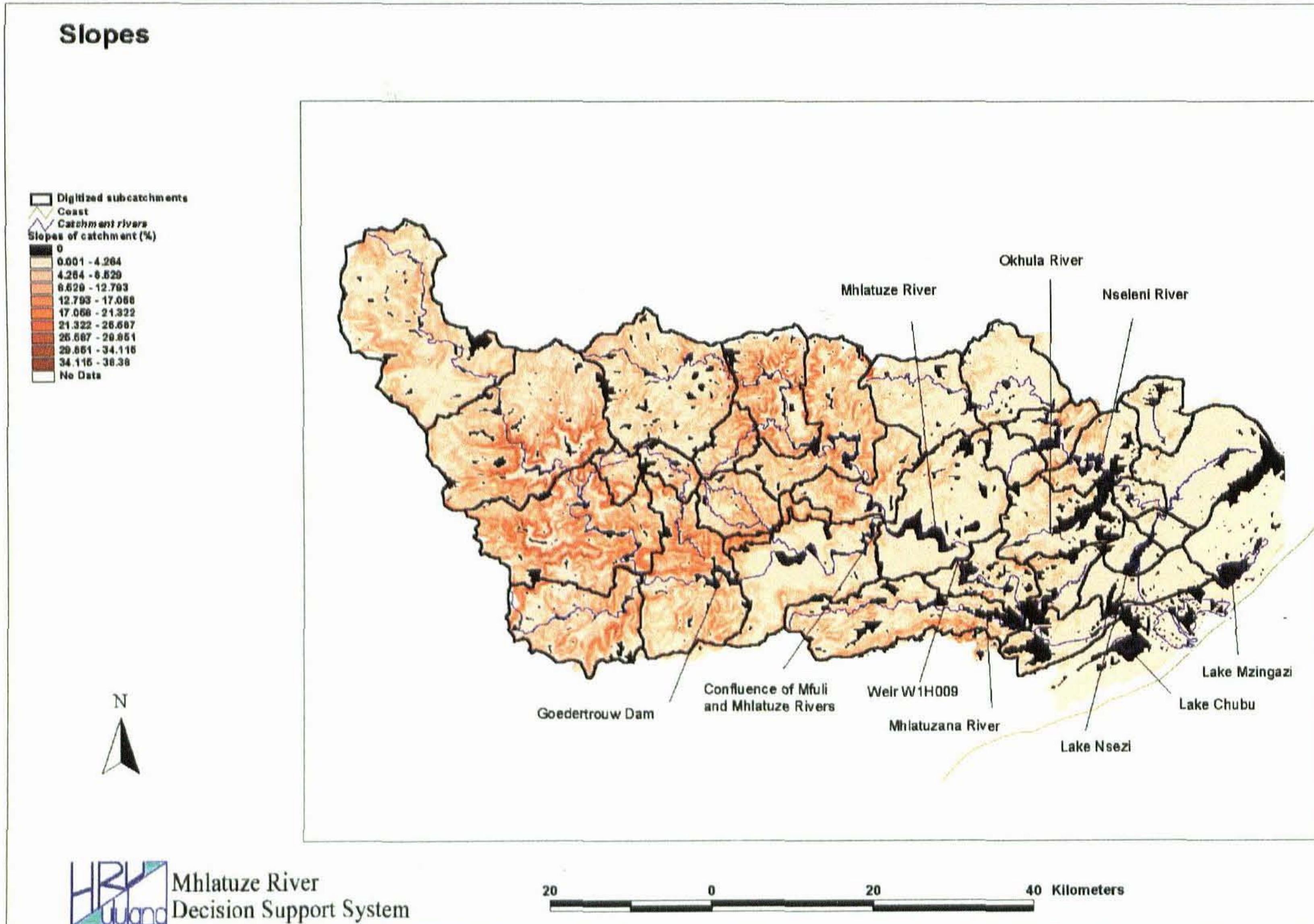

Figure 4.12: Percentage slopes of the catchment, with areas of zero slopes indicated in black.

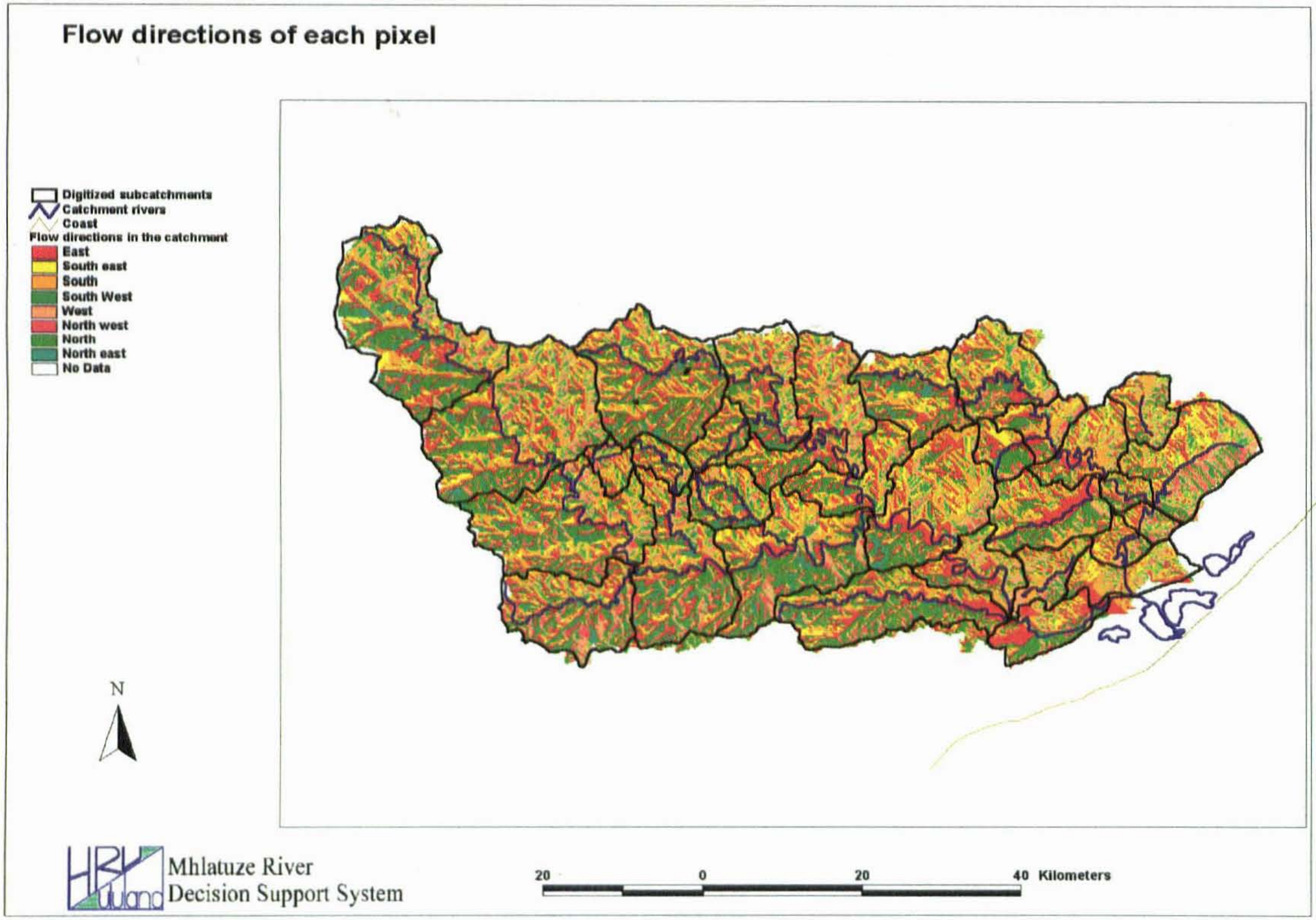

Figure 4.13: Flow directions of each pixel in the DEM.

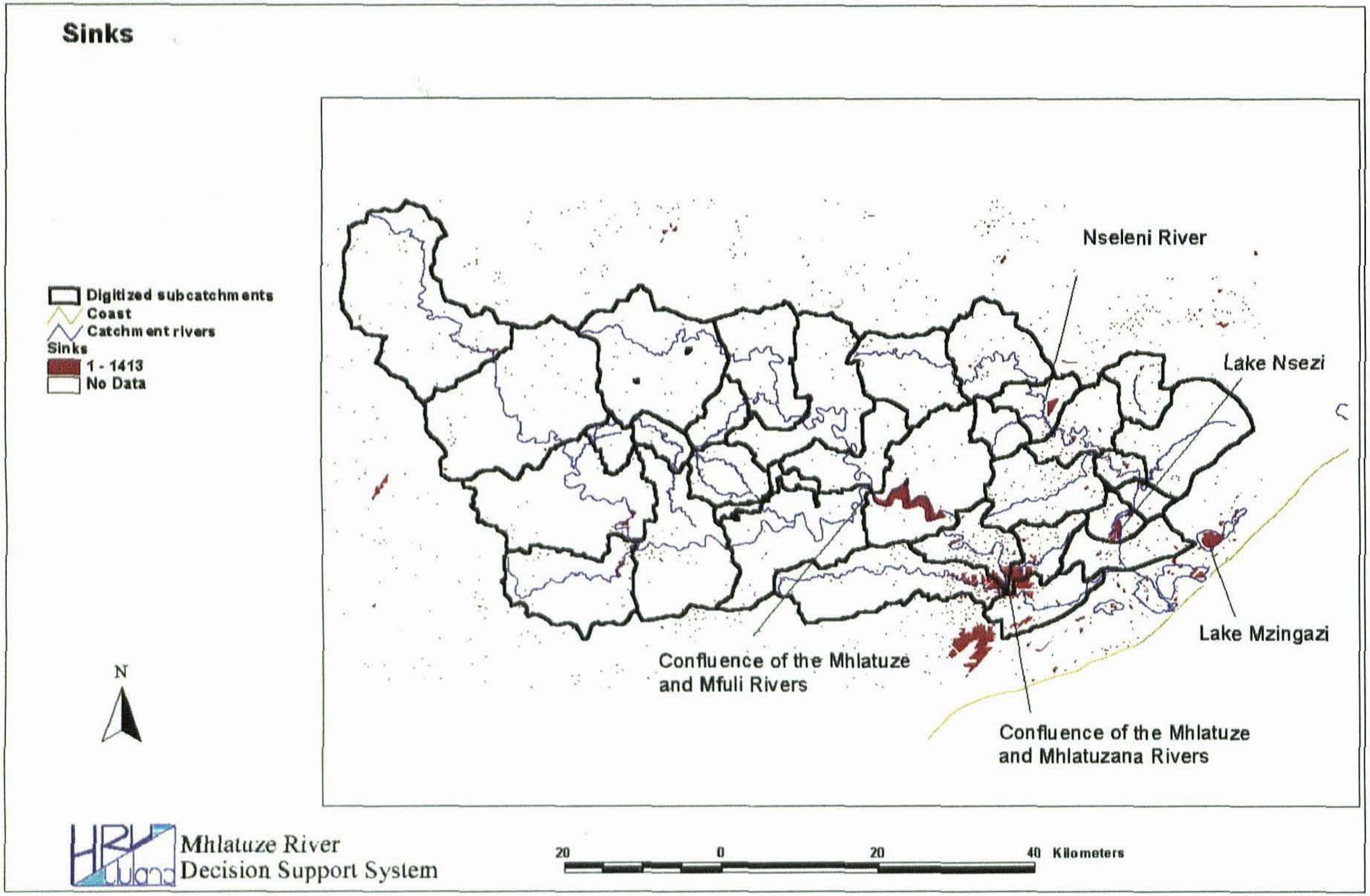

Figure 4.14: Positions of sinks which were filled.

Positions of the larger (calculated) sinks are located

1. along the Mhlathuze River valley downstream from Mfuli confluence with Mhlathuze, up to weir W1H009,
2. in the Nseleni River catchment,
3. inside Lakes Nsezi and Mzingazi (these two sinks are natural sinks observed in the catchment), and
4. at the confluence of the Mhlatuzana River and the Mhlathuze River (which acts as a natural sink in the catchment).

The course of the Mhlatuzana River ends in a marshy low-lying area with no definite flow into the Mhlathuze River, resulting in a natural wetland that acts as a natural sink. It is suspected that water moves through the ground and through marshes areas to the Mhlathuze River. This produces a flow direction problem and calculation of sinks in this area on the DEM. The positions of Lakes Nsezi and Mzingazi were identified as sinks, and although some of these identified sinks are actual natural sinks, all sinks in the DEM had to be filled for proper calculation of river courses, so these natural sinks were also filled during DEM construction.

4.2.5 Effects of the flat coastal plains on the DEM quality

Despite the inclusion of 20-m contours (from 1:50 000 maps) which were added in some areas, some catchment boundaries were calculated incorrectly on the flat coastal plains. The flat plains south west of Lake Nsezi are calculated to drain incorrectly towards the Mhlathuze river instead of towards Lake Nsezi.

4.2.6 River and catchment delineation

The positions of rivers and catchment boundaries were calculated from the flow direction grid and the flow accumulation grid. A visual comparison between the calculated and digitized river courses indicates a good overlap, except in some flat areas (Figure 4.15). This reveals that, in the flat coastal area, the calculated river course follows straight lines where the river should be meandering.

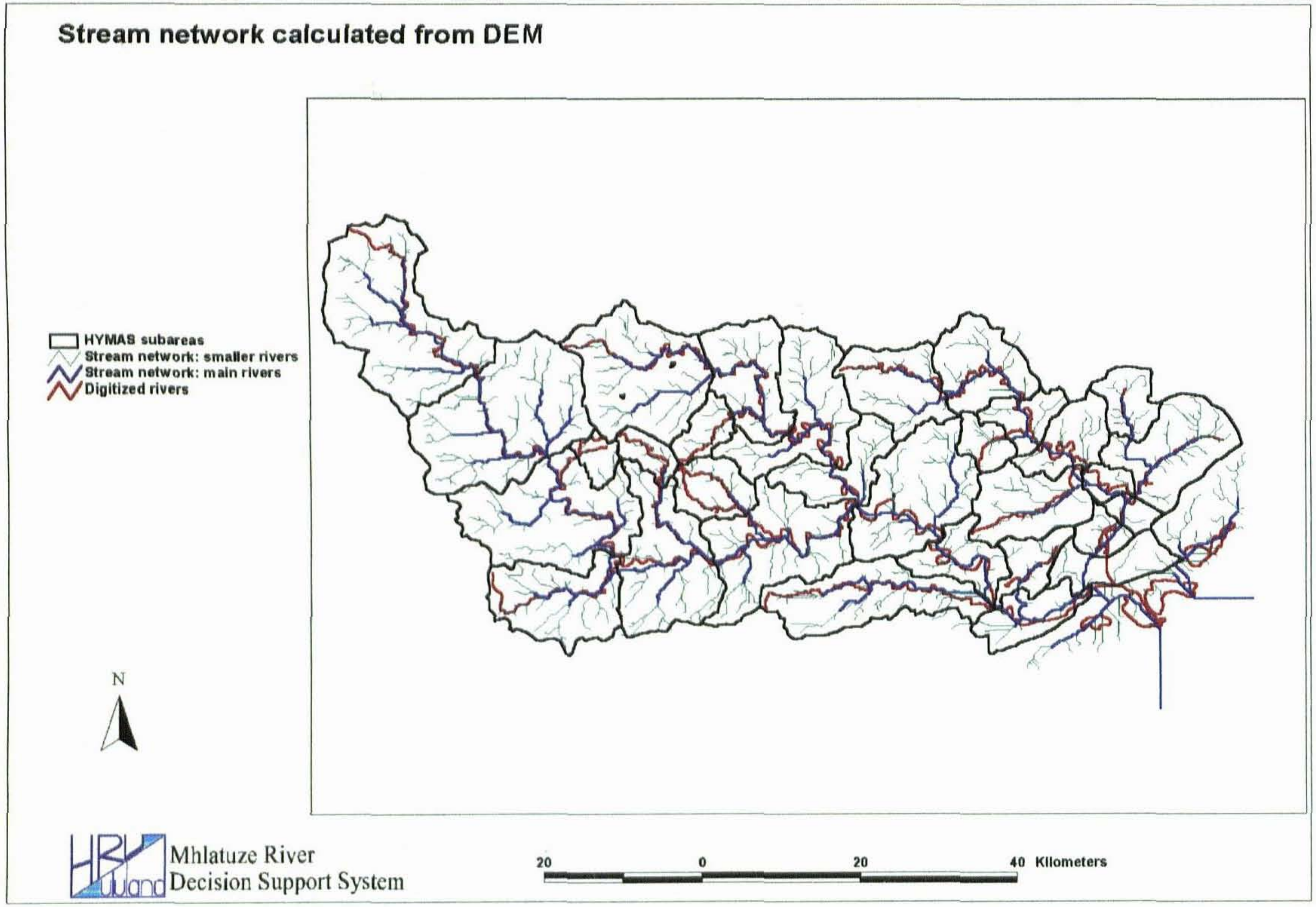

Figure 4.15: Calculated stream network and digitized river courses.

The catchment boundaries did not correspond exactly to the digitized boundaries which were digitized using the 20-metre contours as guidelines (Figure 4.16). The final DEM still needs improvements in some areas, particularly the flat coastal zone, where 20-m contours are presently not available. However, in general the quality of the constructed DEM is assessed as exceptable at the resolution of 125 by 125 metre pixels for the modelling support purposes.

4.3 Surface run-off model

The run-off observations of the Mhlathuze River are very limited and generally inadequate for management of the water resources. One pragmatic and efficient method to extend the observational records is through the application of a simulation model driven by the more extensive rainfall measurements in the catchment.

The hydrological modelling of a catchment engages three major phases of development:

i) The first step is the collection of all possible hydrological relevant data of the catchment. These have been described in Chapter 3 and in Appendix 1 (The database).

ii) The next step is to set up the hydrological model to simulate the different components of the water resources that are dominant in the particular catchment. The choice of the hydrological model requires knowledge of the forces at work which dominates the water cycle in the catchment.

iii) The final step is the calibration and analysis of the simulations, generation of different scenarios and comparisons of the different simulation output.

There are numerous hydrological models that have been developed and which could have been incorporated into the IB. These models range from simply empirical rainfall-runoff equators to complex three dimensional systems. For the development of this IB of the Mhlathuze DSS it was considered important to generate run-off in response to changing land use within the catchment. Several modelling systems were made available and it was decided to select the HYdrological Modelling And Simulation(HYMAS) software system (Hughes, 1994) because of local support and because it provided several models that operated at a range of temporal scales. This study

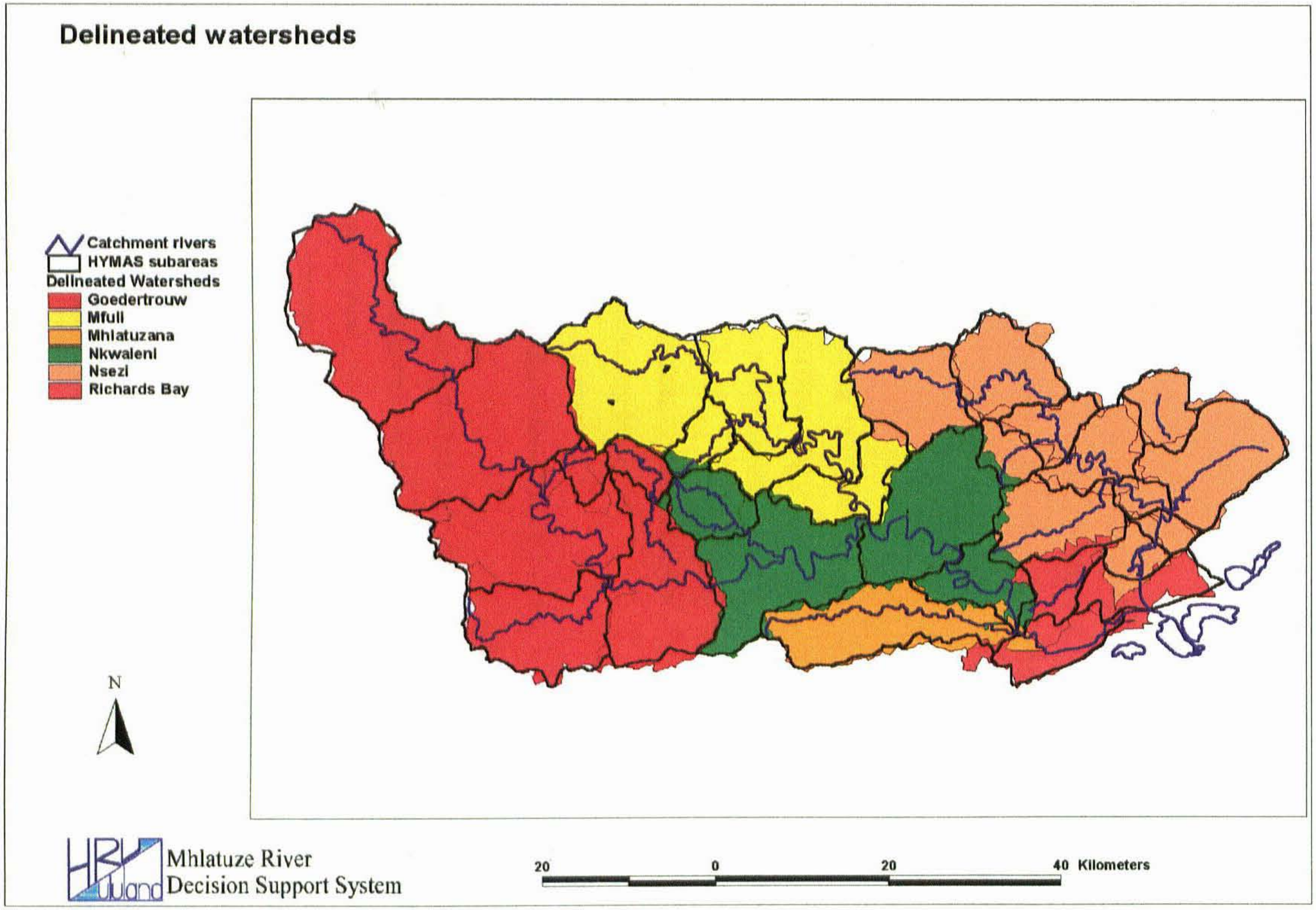

Figure 4.16: Catchments delineated from the DEM.

has selected one of these models for the initial development of the IB: the Variable Time Interval (VTI) model.

4.3.1 The HYMAS and VTI Model

4.3.1.1 Description of HYMAS

The HYMAS software is a suite of water resource simulation models (Hughes, 1994). The system is flexible regarding the incorporation of other water resource simulation models. This sets the scene for simulations with different models from the same operating environment, making use of a standardized data file format for the sequential data.

Certain operations, which are model independent, but are needed during most water resource simulation modelling, were identified:

- Utility operations (file management and DOS interaction),
- Establishing and editing projects (specifying the names of data files and model executables),
- Preparation and editing of parameter data,
- Compilation of time series data,
- Model runs,
- Display and analysis of model output results.

A standard approach has been developed to cater for all these operations in the form of a menu-driven operating environment. The suite of simulations models, as well as the operating environment, are written in "C" language, and users can customize the operating environment to add simulation models. One of the hydrological models in HYMAS, the Variable Time Interval (VTI) model, was applied to the Mhlathuze River catchment.

4.3.1.2 Description of the VTI model

The VTI model is a semi-distributed conceptual model that operates in a lumped mode at subcatchment scale. These subcatchments are linked through routing methods. At subcatchment scale it is necessary to have representative parameters that generally depict hydrologically homogenous conditions. VTI uses the hydrological time series incorporated in HYMAS and calculates the necessary information to do the run-off simulations. The VTI model also uses the physiographical variables specified in HYMAS to calculate its own specific set of model parameters. A full description of the HYMAS variables and VTI parameters, as well as their estimation methods, is provided in Appendix 3. Appendix 4 contains the lists of each subarea's derived parameter estimates.

The study area of the whole Mhlathuze River catchment was divided up into five main catchments which are defined in HYMAS as simulation *projects*. The five project areas were defined as:

- the catchment of the Mhlathuze River upstream of the **Goedertrouw Dam**,
- the catchment of the **Mfuli river**,
- the catchment of the **Nseleni river** upstream of Lake Nsezi,
- the **Nkwaleni** catchment of the Mhlathuze River (from Nkwaleni valley to the inflow of the Mhlatuzana tributary), and
- the **Richards Bay** catchment area of the Mhlathuze River (from downstream of the "Nkwaleni" catchment to the Mhlathuze Estuary at Richards Bay).

The catchments of each of the five *projects* were subdivided again into relative hydrological homogeneous subcatchments, referred to as *subareas*. Figure 4.17 indicates the positions of these main catchments, the subareas, the subarea numbers and the positions of flow gauging stations with suitable flow records that was available for the calibration of the surface run-off simulation model.

Subdivisions of the catchments were done with the following data in order to create relative homogenous subareas:

1. Surface Water Resources of South Africa 1990 GIS data set (Midgley, Pitman and Middleton, 1994), and
2. 1:50 000 topographical maps in digital format, as purchased from the Department of Land Affairs, Chief Directorate Surveys and Land Information.

4.3.2 Subarea identification

In the context of a DSS, some of the characteristics of these subareas will change to conform with the management options that will involve changes to land use over time. Consequently, the criteria for dividing the catchment into subareas were not based on existing land use practices, but rather on the identification of hydrological homogeneous subareas represented by the main physiographic characteristics in the model. However, in the case of commercial plantations, this land use practice was considered as a criteria for subdivision of very large catchments, because these tend to be long term land uses, and because they are believed to have a large impact on the catchment run-off. This does not restrict the run-off simulation model from simulating a different land use practice (from commercial plantations) in these subareas. The principal criteria used in catchment subdivision were soil types, slopes, riverbeds and geology. As a last criterion, commercial plantations were also used, with the other criteria having overriding preference.

Criteria taken into account from the WR90 data set in determining subareas with homogeneous hydrological response units, are:

1. Vegetation: Coastal tropical forest,
   False grass veld types,
   Karoo and Karoied types,
   Temperate and transitional forest,
   Tropical bush and savanna types.
2. Commercial Agriculture: Pine,
   Eucalyptus,
   Wattle,
   Sugar cane,
   Indigenous forests
3. Geology: Assemblage of tillite and shale,
   Assemblage of tillite, shale, sandstone,
   Basic/Mafic or ultramafic intrusive
   Basic/Mafic lavas
   Compact sedimentary strata
   Intercalated arenaceous and argillaceous strata
   Intercalated assemblage of compact sedimentary and intrusive rocks
   Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks
4. Positions of stream flow gauging stations
5. Positions of major water abstractions and interbasin water transfer.
6. The soils' maps from the WR90 data, which originated from 1:2 500 000 SIRI maps.

Table 4.3.1 provides a summary of the hydrological characteristics of each subarea in tabular format. Numbers in the "Soils" column refer to descriptions of soil types defined in Table 3.2.2 in Chapter 3.

Table 4.3.1: Hydrological characteristics of each subarea in the Mhlathuze river simulations

Where more than one characteristic are mentioned, the descriptions in **BOLD** are the dominant characteristics used to define the homogeneous nature of the subarea. Where no description are highlighted in bold, it indicates a 50-50 combination of the listed descriptions.

VTI PROJECT	SUBAREA NO	VEGETATION	SOILS	GEOLOGY	AFFORESTATION
Goedertrouw	1	Temperate and transitional forest and scrub types	20	Assemblage of tillage and shale	Plantations, **Natural veld**
	2	Coastal tropical Forrest types, in riverbed: Tropical bush and savanna types (Bushveld)	18	Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks, *Intercalated arenaceous and argillaceous strata*	Natural veld, **Plantations**, sugar cane
	3	Coastal tropical forest, in riverbed: Tropical bush and savanna types (Bushveld)	18	Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks	**Natural veld**, indigenous Forrest
	4	Coastal tropical forest	18	Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks	Sugarcane, plantations
	5	Coastal tropical forest	18	Intercalated assemblage of compact sedimentary and intrusive rocks	Sugarcane, plantations
	6	Coastal tropical forest, in riverbed: Tropical bush and savanna types (Bushveld)	18	Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks, Intercalated arenaceous and argillaceous strata	Natural veld, little sugar cane
	7	Coastal tropical forest, in riverbed: Tropical bush and savanna types (Bushveld)	18	Intercalated arenaceous and argillaceous strata	Natural veld
Mfuli	1	Coastal Tropical Forrest	18	Intercalated arenaceous and argillaceous strata	Plantations, sugar cane, natural veld, town (Melmoth)
	2	Coastal Tropical Forrest	18	Intercalated arenaceous and argillaceous strata	Plantations, **sugar cane**
	3	Coastal Tropical Forrest River: Tropical bush and savanna types	18	Intercalated arenaceous and argillaceous strata	Natural veld
	4	Coastal Tropical Forrest River: Tropical bush and savanna types	18,17	**Intercalated arenaceous and argillaceous strata**, Assemblage of tillage and shale	Natural veld

VTI PROJECT	SUBAREA NO	VEGETATION	SOILS	GEOLOGY	AFFORESTATION
	5	Tropical Bush and savanna types (Bushveld), Coastal tropical Forrest types	17	Intercalated arenaceous and argillaceous strata	Natural veld
Nkwaleni	1	Tropical Bush and savanna types (Bushveld)	17,18	*Intercalated arenaceous and argillaceous strata*	**Sugar cane, orchards**, natural veld
	2	Coastal tropical Forrest types	18	Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks	**Natural veld**, little sugar cane, plantations
	3	Coastal tropical Forrest types, Tropical Bush and savanna types (Bushveld)	17	Intercalated arenaceous and argillaceous strata	*Sugar cane*
	4	**Coastal Tropical Forrest Types**, Tropical Bush and savanna types (Bushveld)	**18**, little 17, 15	**Intercalated arenaceous and argillaceous strata**, *Undifferentiated assemblage of compact sedimentary extrusive and* intrusive rocks	**Natural veld**, little tropical forest, sugar cane
	5	Tropical Bush and savanna types (Bushveld)	17	Intercalated arenaceous and argillaceous strata	Sugar cane
Richards Bay	1	Coastal Tropical Forest Types	17, **15**	Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks, Basic/mafic lava	Natural veld, *sugar cane, towns* (Empangeni, Kwadlangezwa, Matshana)
	2	Coastal Tropical Forest Types, Tropical Bush and savanna types (Bushveld)	15	***Compact sedimentary strata***, Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks	**Sugar cane**, plantations, natural veld, lakes, town (Kwadlangezwa, Felixton)
	3	Coastal Tropical Forest Types	15	*Compact sedimentary strata*	**Sugar cane**, natural veld, town (Mondi, Alton)
Nsezi	1	Coastal Tropical Forest Types	17	Assemblage of tillite and shale	Natural veld, little sugar cane, town (Ntambanana)
	2	Coastal Tropical Forest Types	17	**Intercalated arenaceous and argillaceous strata**, Assemblage of tillite and shale	Natural veld, little sugar cane
	3	Coastal Tropical Forest Types	**17**, 15	***Intercalated arenaceous and argillaceous strata***, Basic/Mafic lavas	sugar cane
	4	Coastal Tropical Forest Types	**17**, 15	Intercalated arenaceous and argillaceous strata, **Basic/Mafic lavas**	Natural veld, little sugar cane

VTI PROJECT	SUBAREA NO	VEGETATION	SOILS	GEOLOGY	AFFORESTATION
	5	Coastal Tropical Forest Types	17, 15	Basic/Mafic lavas	**Natural veld**, sugar cane
	6	Coastal Tropical Forest Types	17, 15	**Basic/Mafic lavas**, Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks	Natural veld, sugar cane
	7	Coastal Tropical Forest Types	15	**Basic/Mafic lavas**, Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks	Natural veld, sugar cane
	8	Coastal Tropical Forest Types	17, 15	Basic/Mafic lavas	Natural veld
	9	Coastal Tropical Forest Types	15	**Compact sedimentary strata**, Basic/Mafic lavas	Sugar cane, natural veld, **plantations**, towns (Nseleni, Kwambonambi)
	10	Coastal Tropical Forest Types	15	**Compact sedimentary strata**, Undifferentiated assemblage of compact sedimentary extrusive and intrusive rocks	**Sugar cane**, plantations, Natural veld, lake Nsezi, Town (Aquadene-RBay)

4.3.2.1 Goedertrouw Dam catchment

Subarea 4 and 5 of project "Goedertrouw" represents the different soil types and slopes from the rest of subarea 3. Subarea 6 represent the inflow of the Mvusana River, which receives the input of water from the Thukela Water Transfer Scheme.

4.3.2.2 Mfuli River catchment

The formal farming area around the town of Melmoth was separated from the informal subsistence farming which occurs nearer to the catchment outlet. A major tributary near the Mfuli outlet was separated on the basis of a different soil type and geology in its catchment.

4.3.2.3 Nkwaleni catchment of the Mhlathuze River

The Nkwaleni area, where formal irrigation farming takes place, was separated from the informal settlements area, with greater slopes in subarea 2. The Mhlathuze River catchment downstream from the Mfuli inflow, and upstream of the stream flow weir W1H009 is distinctly different on the two sides of the river. Irrigated sugarcane occurs on the northern banks, with mainly subsistence farming and informal settlements occurring on the southern banks. The inflow of the Mhlatuzana River is simulated as a separate subarea, as well as the area from the weir W1H009 to the inflow of the Mhlatuzana River.

4.3.2.4 Richards Bay catchment of the Mhlathuze River

The catchment of Lake Mpangeni and the Empangeni town area are simulated as a separate subarea. The Richards Bay Flats were simulated on its own (taking into consideration only those parts of the Mhlathuze Flats which actually contribute to the Mhlathuze River system), up to the pump station where Mhlathuze Water Board abstracts water for Lake Nsezi, at weir W1H032. The abstractions is monitored by and available from the DWAF, Durban. The catchment of the Nseleni River, downstream of Lake Nsezi, are included in this catchment, as a part of the Mhlathuze River catchment which contributes to the river flow into the Mhlathuze Estuary.

4.3.2.5 Catchment of Lake Nsezi

The division of the Nsezi Project's catchment were mainly based on differences in geology, as the data base indicated a uniform soil type and vegetation throughout the region. Subarea 3 were included to account for the differences between the hydrological response of sugar cane farming and that of subsistence farming and natural veld.

4.3.3 Catchment rainfall and evaporation in HYMAS

Catchment rainfall is calculated within HYMAS for each of the subareas from the available (unpatched) rainfall stations. The positions of the rainfall stations and the extend of each subarea are specified in a grid of one minute by one minute block cells. The user specifies the number of rainfall stations that must be averaged to generate the catchment rainfall for all subareas. It is recommended (Dr. Vladimir Smakhtin, 1997, pers. comm.) that the user specify that at least *two* stations are used. The positions of the rainfall stations used in the VTI simulations are indicated in Figure 3.1, in Chapter 3.

HYMAS calculates the subarea rainfall value for each of the time intervals in the simulation as follows:

1. HYMAS investigates the rainfall records of the (say) two stations closest to the centre of the subarea.
2. If no rainfall is measured at these rainfall stations for the time interval, HYMAS will search for the next closest rainfall station and check for available rainfall measurement for that time interval.
3. If a rainfall measurement is available, it will be used for catchment rainfall calculation.
4. HYMAS will continue the search for the next closest rainfall station, until the required number of stations were found with rainfall measurements for the selected time interval.
5. If no stations with rainfall measurements are found within a user-specified distance from the subarea centre, a rainfall value is calculated from the median rainfall grid (Dent *et al*, 1989) (Figure 3.3). This grid specifies twelve median monthly rainfall estimations for each minute by minute grid in South Africa.

This procedure is repeated for each subarea, for each time interval of the simulation. It is up to the discretion of the user to verify the generation of the catchment rainfall.

Evaporation in the catchment is specified as mean monthly values, estimated from observed Simons pan evaporation measurements in the Mhlathuze catchment (Table 4.3.2).

Table 4.3.2: Evaporation estimations for water resource simulations in HYMAS (VTI):

HYMAS Project	Estimated Potential Mean Annual Evaporation	Evaporation stations used to calculate mean monthly values:
Goedertrouw	1700 mm	W1E011
Mfuli	1300 mm	W1E012
Nkwaleni	1600 mm	W1E003 and W1E011
Richards Bay	1500 mm	W1E003 and W1E005
Nsezi	1500 mm	W1E003

4.3.4 Model calibration

Generally, there is a lack of adequate physiographic (especially soils and aquifer properties) information for the catchment and doubts have been expressed about the reliability of the observed stream flow records (DWAF). Additional information that can be used during calibrations, is the WR90 monthly time step simulation results, although these have been based on the same basic information and therefor are subject to the same errors. The best that can be expected is that the simulations are broadly representative of the flow conditions in the river (Hughes and Smakhtin, 1999).

Because of the unknown effects of upstream abstractions, it is extremely difficult to base the calibration on present or historical conditions. Therefor, the main calibration of the model for natural conditions was based upon two comparisons:

1) the simulated mean annual volumes and monthly distributions which were compared to those given in the WR90 data set and
2) a comparison of simulated daily flow hydrographs in subarea 3 of the Nkwaleni Project, to measured flows at weir W1H009 (Figure 4.17).

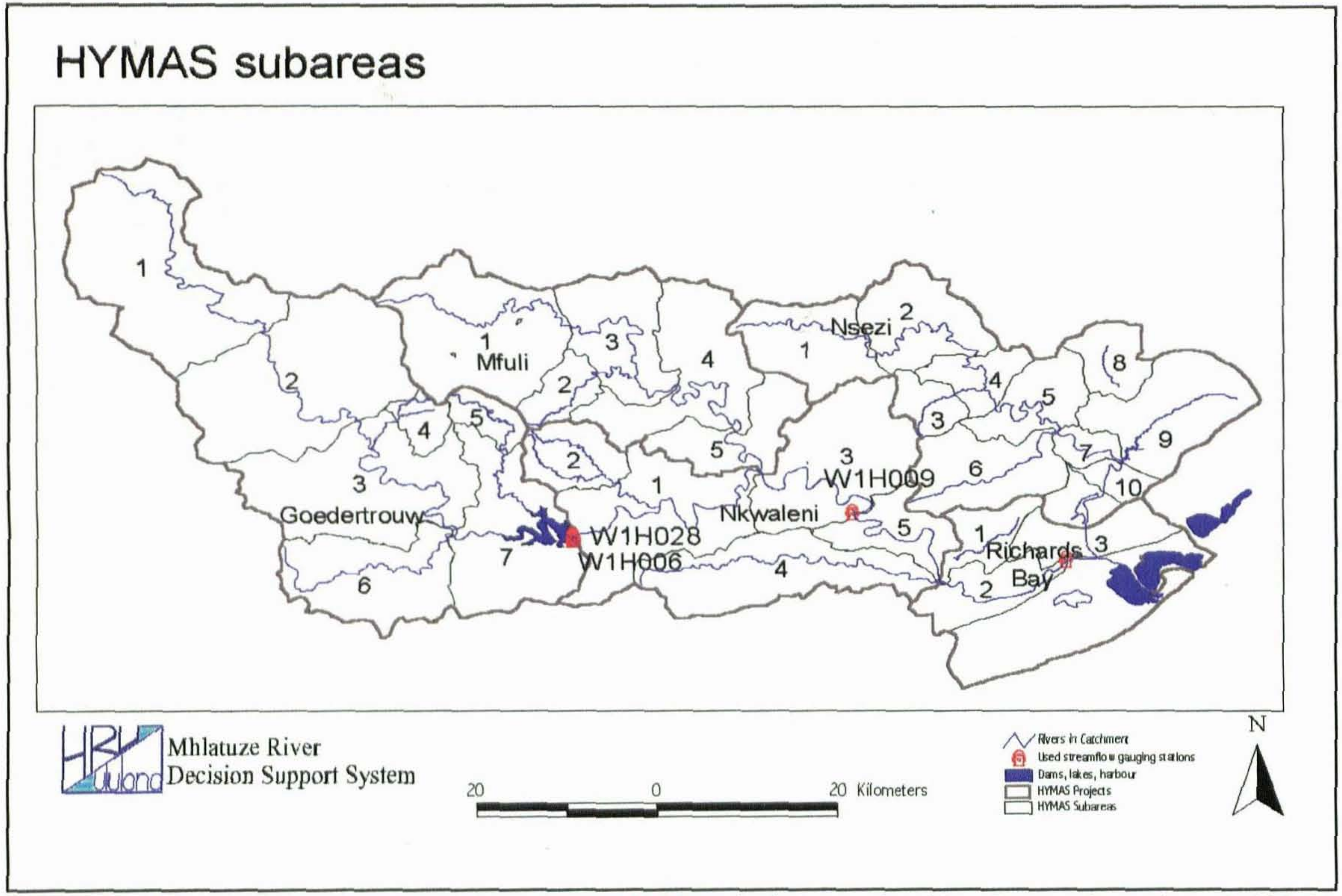

Figure 4.17: Subareas of the main catchments as used in HYMAS VTI simulations, and positions flow gauging stations of which the records were used during calibrations of flow simulations. The names of the different HYMAS projects are indicated on the map.

The first comparison is based on other simulations which may also be erroneous, while the second comparison is for a short period that may not be fully representative. Observed daily records measured at W1H006 for the period of 1964 to 1973 were also available, but contains long periods of missing data. Calibrations of the simulation for the Goedertrouw Dam catchment were based on this period. *Because of the unknown abstractions, the model is expected to* overestimate the historical low flow values in most years (Figure 4.18).

Calibrated parameters for the Mhlathuze River upstream from the Mhlathuze Estuary (excluding the catchment of the Nseleni project) were first obtained. These values were used to estimate the parameters of the Nseleni River catchment upstream of Lake Nsezi. As there are no measured flow records available to test the simulation results, these simulated records for the catchment of Lake Nsezi are given a very low rate of reliability.

4.3.4.1 Comparison between simulated and observed flows

Daily flow records at W1H009 were compared to simulated values. A section of the comparison period is shown in Figure 4.18. In general, the model identifies the peak flows but is inconsistent in simulating the recession rates. For several rainfall events, the simulated recession closely resembles the observed (see Days 0 to 60, and around Day 400). However, the comparison is particularly poor around Day 70 to 200.

The inconsistency in the comparison may be due to poor parameter selection and unrepresentative rainfall estimates. The model needs further refinement before it can be used with confidence in the IB.

4.3.4.2 Comparison between the VTI and WR90 run-off estimation

Simulations of the VTI daily model over a ten-year period from 1982 to 1992, using the preliminary calibration estimates, generate up to 2.5 times more mean annual run-off than simulated by WR90 data set (Midgley *et al*, 1994) over a 70 year period, from 1920 to 1990. A closer investigation reveals that two major floods (1984 and 1987 floods) occurred during the ten-year simulation period used in the VTI model. The WR90 data set (Midgley *et al*, 1994) estimates the monthly rainfall for the different sections of the

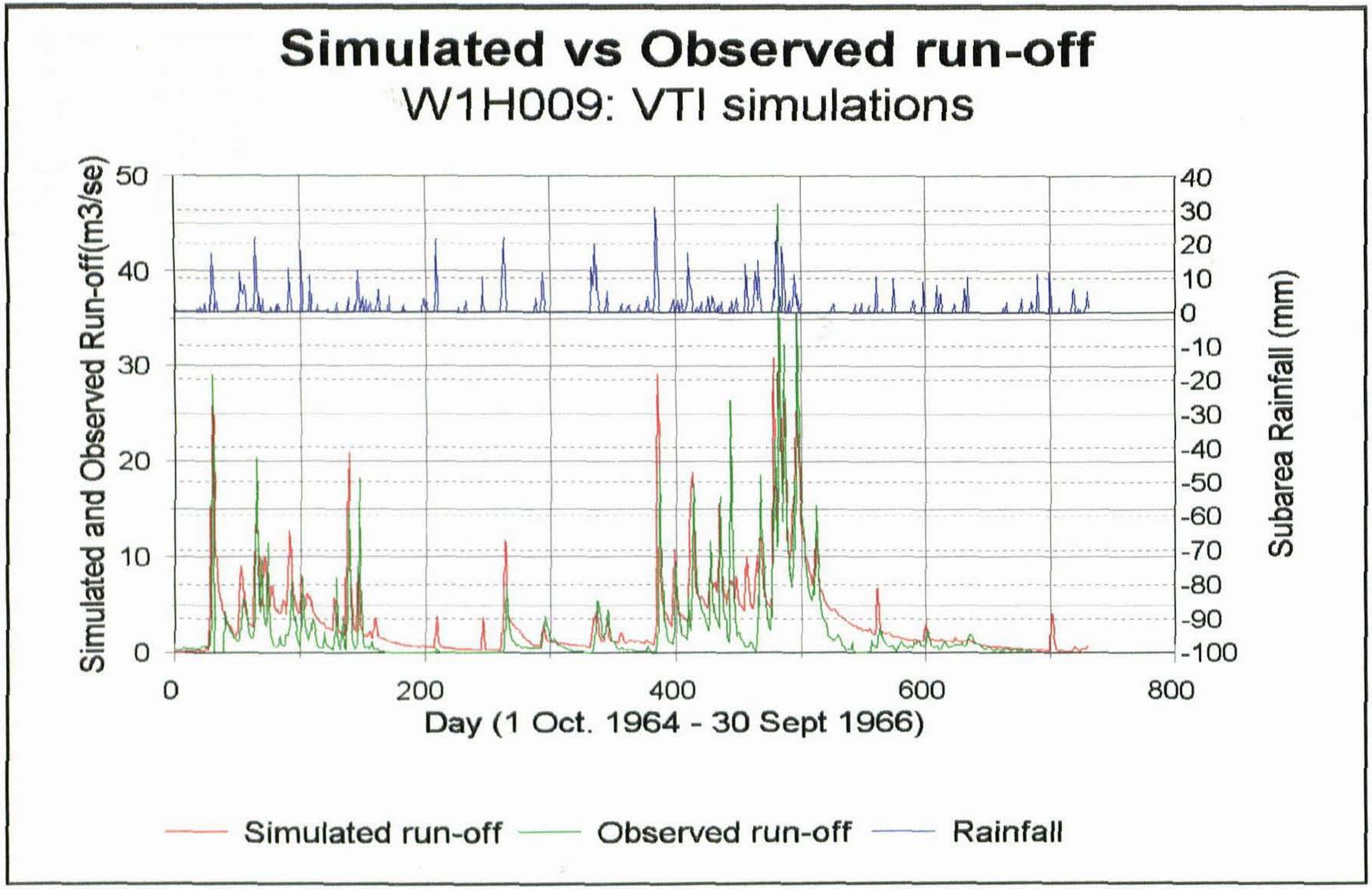

Figure 4.18: Graph of the daily simulated and observed runoff measured at weir W1H009, before the Goedertrouw Dam construction, over the period of 1 October 1964 to 30 September 1967. The catchment rainfall of subarea 3 (Nkwaleni project) of the same period is indicated on the left y axis.

Mhlathuze River catchment. Because these floods were estimated to be between 40% and 55% of the 70-year MAP, they would not be the cause of the large difference. The MAP estimated by Midgley *et al* (1994) for the period from October 1982 to September 1990 is between 103% and 108% of the 70-year MAP for the area of the Mhlathuze River catchment. It can therefor be concluded that the reason for the higher value of the VTI model's simulated MAR (over the period 1982 to 1992) cannot only be attributed to the two flood events of February 1984 and September 1987.

Selected sites were chosen for direct comparison between the simulated flow data from the VTI model and the WR90 simulation results (Midgley *et al,* 1994). Output from the VTI model are mean annual estimates for the simulation period from 1962 to 1992 (30 years), while the estimations from the WR90 data set originates from a 28 year simulation period from 1962 to 1990. Note that although the Goedertrouw Dam construction was completed in 1981, both the VTI and WR90 models simulate the river's *natural conditions*, which excludes the effect of the dam and other abstractions. Tables 4.3.3 gives a comparison between the models using *preliminary calibration parameters*. In this case, the VTI model simulated considerably different amounts of run-off in some catchments than the results presented in the WR90 data set.

Table 4.3.3: HYMAS VTI, using preliminary calibration parameters (Run-off from a catchment incorporates upstream run-off):

HYMAS project	VTI (1962-1992)		Catchment number	WR90 (1962-1990)		Difference (VTI - WR90)		
	MAP	MAR		MAP	MAR			
	mm	MCM*		mm	MCM*	MAP (mm)	MAR (MCM*)	MAR (mm)
Goedertrouw Dam (subarea 2)	886	53	W12A	893	55	-7	-2	-35
Goedertrouw Dam (subarea 7)	1070	186	W12B**	951	131	119	55	43
Mfuli (subarea 4)	760	105	W12C	916	53	-156	52	91
Nkwaleni (subarea 3)	852	383	W12D**	916	247	-91	136	56
Nkwaleni (subarea 4+5)	805	54	W12E	1124	45	-319	9	36
Richards Bay (subarea 2)	1346	469	W12F**	1388	349 (area weighted)	-42	120	42
Nsezi (subarea 4)	1040	73	W12G	902	31	138	42	129

*MCM: Million cubic metres.

**Flow from all upstream catchments included.

Independent calibrations were performed by the developers of the HYMAS VTI model (Hughes and Smakhtin, 1999) for all subareas, except for the Nseleni River catchment. Parameters were calibrated for both the present day conditions and virgin conditions as part of an Instream Flow Requirements study for the Mhlathuze River. Simulation results, after inserting these parameters, produces simulated mean annual run-off totals which are closer to the WR90 simulation results in most cases (see Table 4.3.4). However, there were still some fairly large differences in some catchments. The difference need to be explained and resolved to the satisfaction of all stakeholders in the social process of allocation before trust and credibility could be attached to any of the model results.

Table 4.3.4: HYMAS VTI simulation results, using calibrated parameters from the developers of HYMAS VTI (Run-off from a catchment incorporates upstream run-off):

HYMAS project	VTI (1962-1992)		Catchment number	WR90 (1962-1990)		Difference (VTI - WR90)		
	MAP	MAR		MAP	MAR			
	mm	MCM*		mm	MCM*	MAP (mm)	MAR (MCM*)	MAR (mm)
Goedertrouw Dam (subarea 2)	886	53	W12A	893	55	-7	-2	-8
Goedertrouw Dam (subarea 7)	1070	159	W12B**	951	131	119	28	22
Mfuli (subarea 4)	760	83	W12C	916	53	-156	30	52
Nkwaleni (subarea 3)	852	296	W12D**	916	247	-91	49	20
Nkwaleni (subarea 4+5)	805	34	W12E	1124	45	-319	-11	44
Richards Bay (subareas 1,2, and 3)	1346	346	W12F**	1388	349 (area weighted)	-42	-3	1

* MCM: Million Cubic Metres

**Flow from all upstream catchments included.

The simulation period from 1 October 1963 to 30 September 1989 (25 years) was chosen for further comparison between the two different simulation models' output and the observed data. The first year of the simulated flows (October 1962 to September 1963) were discarded, as the model takes some time to stabilise from the effects of the initial conditions. The sites chosen for the comparison were restricted to the weirs where observed data are available: W1H006 (at the present Goedertrouw Dam site) and W1H009 (in the middle of the Mhlathuze catchment). Figure 4.17 indicates the positions of these flow measuring gauges.

Comparisons between the simulation results from the VTI and WR90 models were restricted to simulated annual and monthly totals, because the VTI model simulates on a daily basis, while the WR90 model's results are based on a monthly time step.

The results of the estimated annual rainfall, as calculated for the catchments just upstream from weirs W1H006 and W1H009, are plotted in Figures 4.19 and 4.20 in a scatter plot. Although both models used the same available rainfall data from measurements in the catchment, the methods applied to patch these rainfall records and to calculate the catchment rainfall estimations, differ between the two models. The MAP are estimated higher by the HYMAS model than the WR90 model for the catchment of the Goedertrouw Dam (Figure 4.19). There are no rainfall measurements inside the catchment, and estimations are calculated from rainfall stations situated at the Goedertrouw Dam and along the mountainous catchment boundaries. The two simulation models estimate very similar annual rainfall for the catchment just upstream of the weir W1H009, where more measured rainfall records are available (Figure 4.20).

A similar comparison was made for the simulated run-off by the two models. The run-off estimated from the two models for the catchment upstream from the Goedertrouw Dam is compared in Figure 4.21. The VTI model simulates considerably more run-off than indicated in the WR90 data set. Note: The observed flow records contain too many gaps to present a meaningful comparison on an annual basis. The scatter plot of the monthly simulated and observed data (Figure 4.22) shows that the VTI model slightly undersimulates the run-off of the Goedertrouw Dam catchment.

The run-off estimated for the catchment monitored by weir W1H009 for the two models are indicated by the scatter plot of the two simulation models' results for annual values (Figure 4.23).
According to Hughes (1999), the Mhlathuze River's flows have a quite variable regime with frequent years in which the seasonal distribution of stream flow is not as clear as in other summer rainfall regions. There is a great deal of variation in flows during specific calendar months, even when grouping the typical wet, dry and intermediate years. The annual total flow can be very dependent upon the influence of events occurring within a

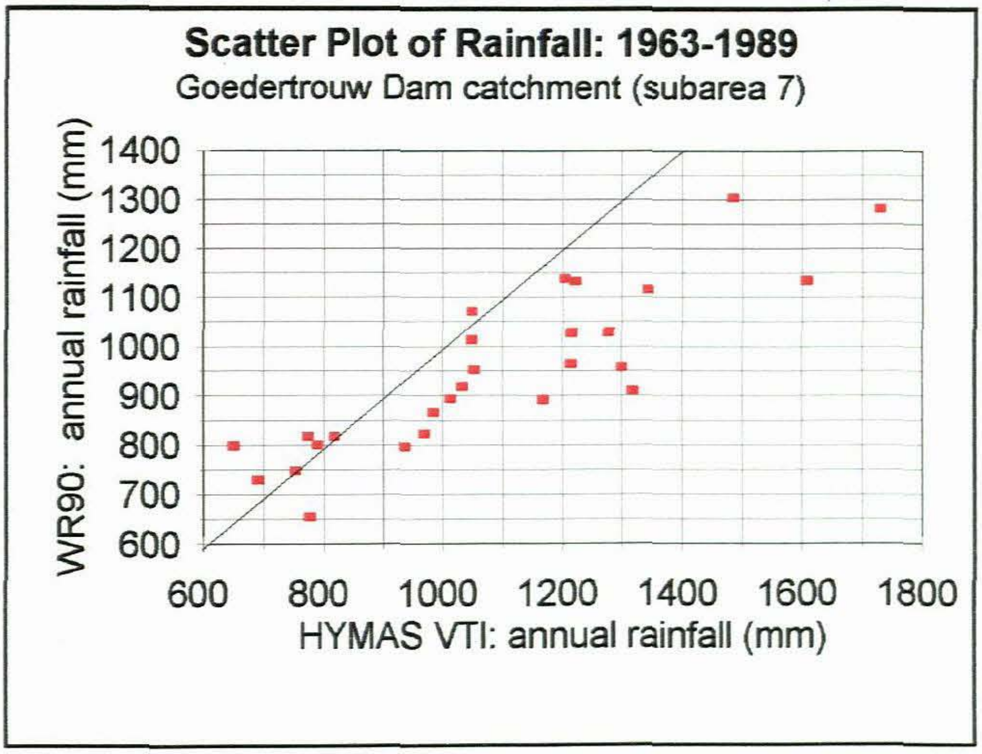

Figure 4.19: Scatter plot of the annual rainfall estimated by the VTI model and the WR90 model, for the simulation period of 1 October 1963 to 30 September 1989, for the catchment upstream from the Goedertrouw Dam (subarea 7 of the Goedertrouw Dam project).

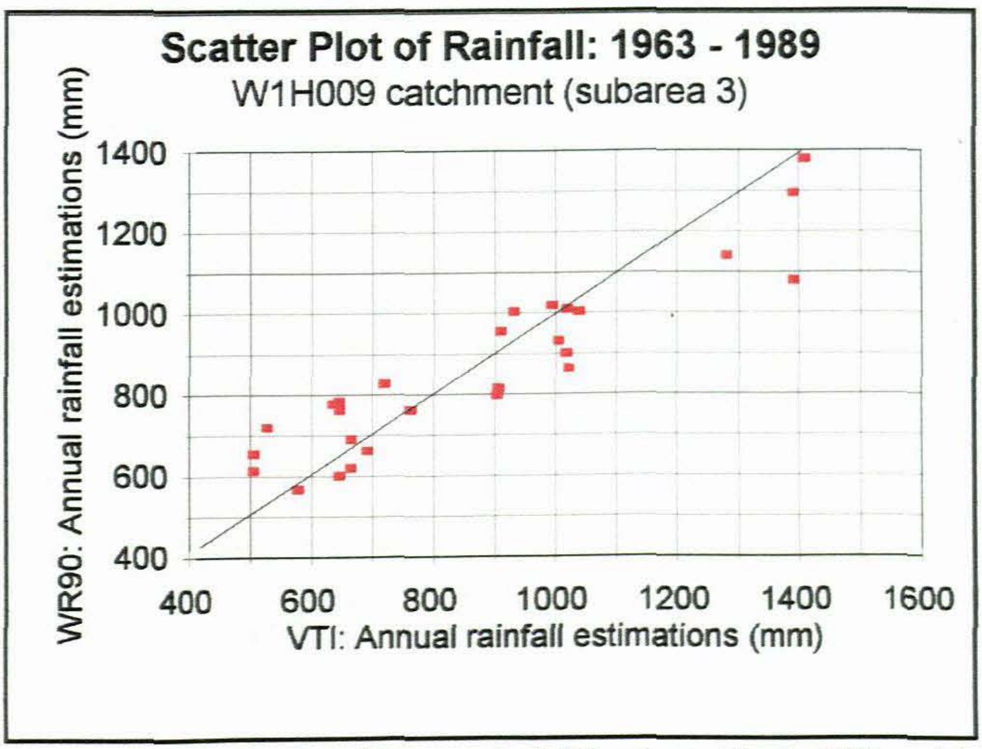

Figure 4.20: Scatter plot of the annual rainfall estimated by the VTI model and the WR90 model, for the simulation period of 1 October 1963 to 30 September 1989, for the catchment upstream from the DWAF weir W1H009 (subarea 3 of the Nkwaleni project).

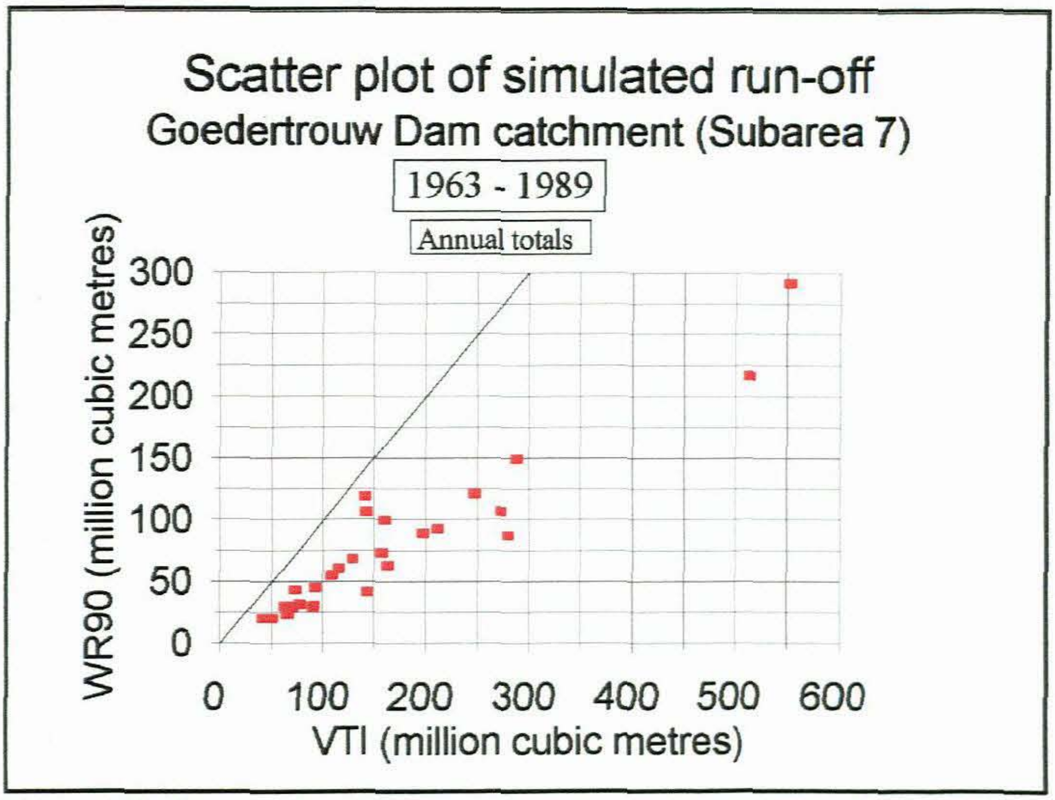

Figure 4.21: Scatter plot of the annual runoff as estimated by the VTI model and the WR90 model, for the simulation period of 1 October 1963 to 30 September 1989, for the catchment upstream from the Goedertrouw Dam (subarea 7 of the Goedertrouw project).

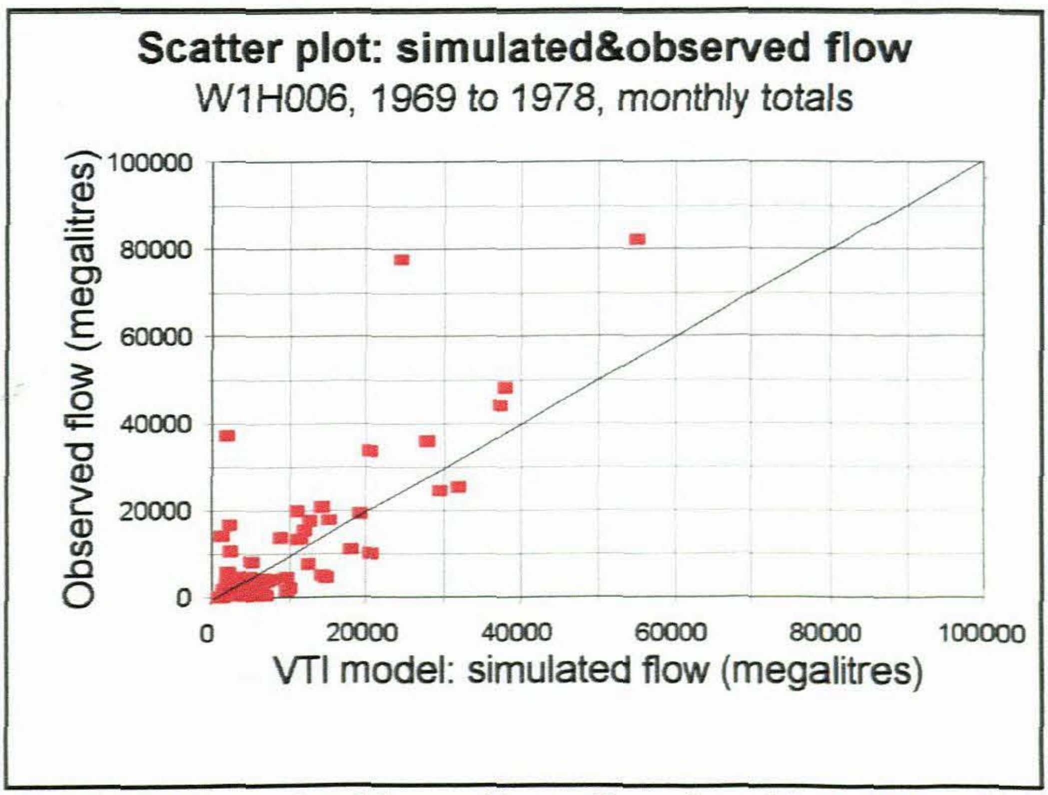

Figure 4.22: Scatter plot of the monthly runoff as estimated by the VTI model and the observed runoff, for the simulation period of January 1969 to December 1978, for the catchment upstream from the Goedertrouw Dam (W1H006).

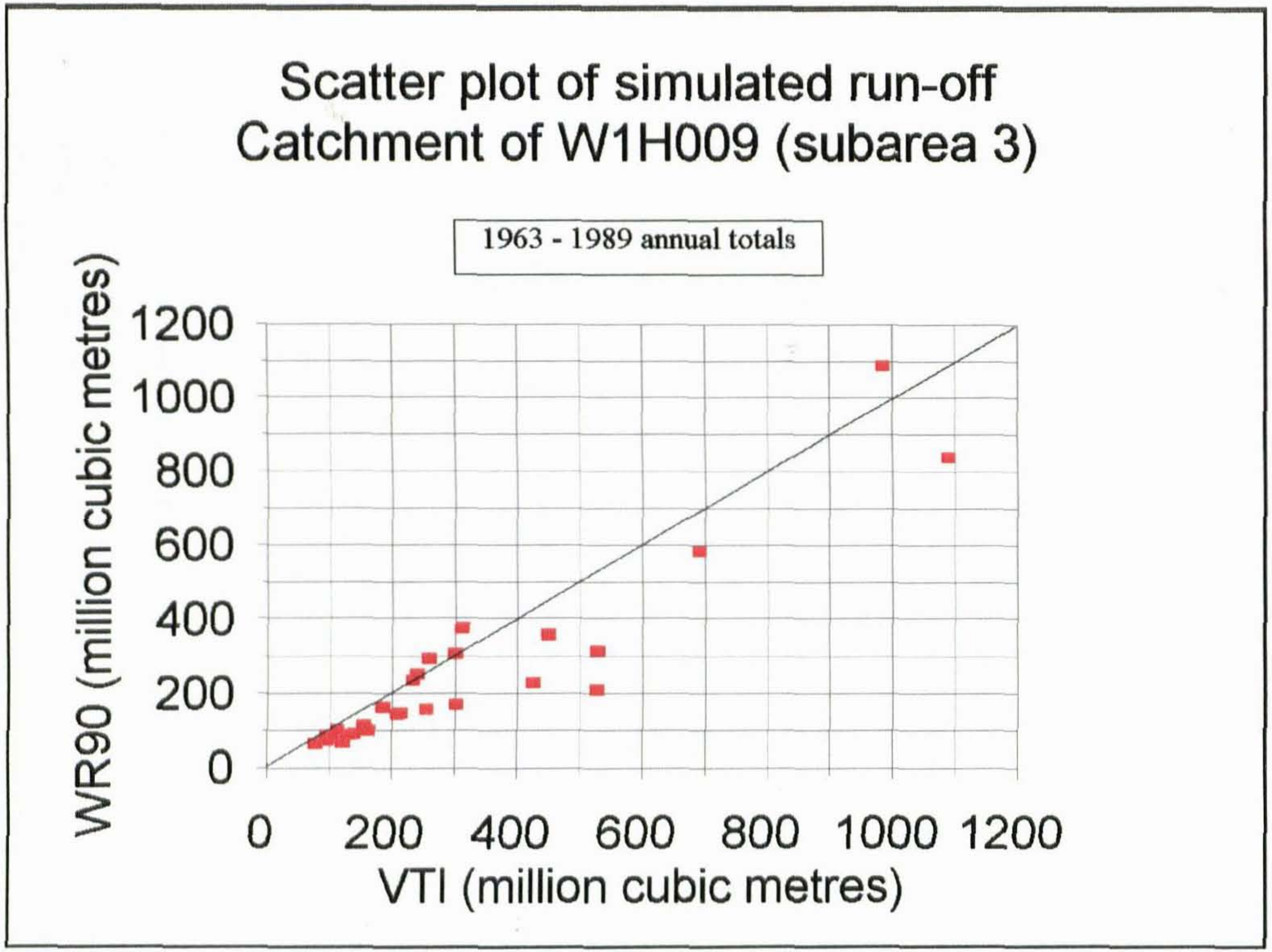

Figure 4.23: Scatter plot of the annual runoff as estimated by the VTI model and the WR90 model, for the simulation period of 1 October 1963 to 30 September 1989, for the catchment upstream from the DWAF weir W1H009 (subarea 3 of the Nkwaleni project).

wider range of months than typical summer rainfall regions of South Africa. It is therefor very difficult to select 'typical' years and all months have relatively high coefficients of variation of total flow, with September having the highest (greater than 3.0).

4.3.5 Application of the model in the IB

The VTI model was incorporated in the IB as a tool to assist IEM. It has been used in several studies since its inclusion in the IB.

4.3.5.1 Applications of the simulated catchment run-off

The calibrated VTI model was used during the Mhlathuze IFR workshop (1998-99) to estimate the amount of run-off at four different sites along the Mhlathuze river. These sites were selected by the participants of the Mhlathuze Instream Flow Requirements (IFR) workshop to meet the requirements of the IFR study.

The parameters of the VTI model for the Mhlathuze River catchment were used as guidelines to estimate parameters of the VTI model for the Nseleni River catchment as part of the Lake Water Requirements (LWR) study (Kelbe, Germishuyse, Fourie and Snyman, 1998). As mentioned in the previous section, the simulations of the Nseleni River catchment are not reliable, because there are no flow measurements available for calibration. However, the primary function of simulation models is to provide credible, trusted, plausible, accceptable information where there is no measured observations available. The simulated stream flow of the Nseleni River catchment from the IB was used during the Mhlathuze Lake Water Requirements (LWR) study to derive a water balance for Lake Nsezi.

4.3.5.2 Water balances for the main catchments of the Mhlathuze River

A preliminary water balance for each of the main catchments was calculated from the model simulations for the natural conditions, and is indicated in Table 4.3.5. Estimations of the MAP and MAR were taken from the VTI model for the time period from 1 October 1963 to 30 September 1978 (15 years). The long term "normal" climate can be assumed by using mean annual values in the water balance, for a 15 years simulation period. The long term storage should be negligible (zero) for a 15 year simulation period so that the difference in the water balance reflects an estimate of the long term error.

Groundwater seepage, as an output of water from the catchments, is ignored. It is assumed that water which flows into the groundwater, ultimately discharges from the catchment (through the river as base flow).

Catchment rainfall records are calculated in HYMAS, from unpatched rainfall records, for the different subareas. These values were used to calculate area-weighted means of the subareas in each catchment.

Evaporation from the catchments includes the soil and canopy evaporation, as well as evaporation from large natural water bodies that were simulated in the VTI model. The evaporation from Lake Nsezi is included, as this lake is a natural feature of the catchment.

*Table 4.3.5: Simulated water budgets for each main subcatchment of the Mhlathuze River basin, **for natural conditions:***

Main catchment	Area of the catchment (km^2)	Mean Annual Run-off (mm)	Mean Annual Precipitation (mm)	Mean Annual Evaporation (mm)	Storage** (mm)	Storage (%MAP)
Goedertrouw Dam	1281	83	874	744	47	5%
Mfuli River	660	151	815	659	5	1%
Nkwaleni	725	111	782	668	3	0%
Richards Bay	194	249	1198	931	18	2%
Whole Mhlathuze catchment, excluding Nsezi catchment *	**2860**	**117**	**859**	**721**	**21**	**3%**
Nsezi	780	192	882	779	3	0%

* The values in the table for the whole catchment (excluding the catchment of Lake Nsezi), are calculated on an **area-weighted** basis.

** Storage = Rainfall - Run-off - Evaporation

The last column in Table 4.3.5 gives an indication that the amount of water unaccounted for by the run-of and evaporation losses. For the Goedertrouw Dam catchment, the storage (unaccounted loss) is approximately half the simulated run-off. Consequently, any errors in the estimated rainfall and evaporation could have a big impact on the simulated run-off for the catchment. For the other catchments, the storage is only a small fraction of the run-off.

4.3.5.3 Making the results available from the GIS platform

The simulation results presented in this chapter are prone to many errors and uncertainties as a result of assumptions made during the application of the numerical models. The greatest difficulty is to inform management of the information, together with these uncertainties, in a suitable and appropriate manner. The IB is being developed to assist in the dissemination of the information created by the numerical models.

Comparing results from two semi-distributed models, like the VTI and the WR90 models, are traditionally done in the form of tables, charts and graphs, accompanied by written descriptions. This method is used in this report. In the context of the Mhlathuze IB and DSS, the results of rainfall estimations and flow simulations should be available from the GIS platform in the form of colour maps and diagrams, which gives an indication of the different MAP's and MAR's as estimated for each subarea, by the different models. These descriptive maps and diagrams should then be accompanied by graphs describing statistical analysis on the data. However, data file format standards differ between GIS packages and most hydrological simulation packages. This results in data restructuring which are executed (mostly manually) after the simulations are completed, to make the information (the output from the simulations) available from a IB GUI platform. This process was done for the calibrated simulation results of the natural Mhlathuze River simulation scenario.

The reason for incorporating a model in the DSS, is to simulate different scenarios and make the results available in a graphical way which summarises the effects of the change. Implementing a manual and error-prone method for writing simulation results to the IB GUI, degrades the effectiveness of the whole IB.

Very recently, software was released by the United States Geological Survey (USGS) which provides a solution to this problem. A single data file format is used to read the hydrological information during the hydrological simulation process, as well as during the summarising process. An additional program also extracts the information and makes it available for visual display from a GIS platform using the same file format. The Hydrological Simulation Software: Fortran (HSPF) developed by Johanson, Bicknell, Kittle and Donigian (1996) is a hydrological simulation software package which uses the Watershed Database Management (WDM) file structure for its hydrological time series input and output. The USGS has now released a software package called GenScn (Kittle, Lumb, Hummel, Duda and Gray, 1998) which reads the same WDM file structure (amongst other file structures) to display and analyse the simulations' input and output time series information from a GIS GUI platform. From GenScn's GUI platform, the model simulations can be initiated for different hydrological scenarios. Output from the different scenarios can be compared in the GIS to visually examine the effects of change in the catchment on the surface water run-off (Kittle *et al*, 1998). These programs are being incorporated in the IB for future applications but are to recent to include in this thesis.

Implementing the idea of one data file format for surface run-off simulation and post-processing of the simulation, into the Mhlathuze IB, means the incorporation of both a new simulation package and a GIS platform. The Mhlathuze IB is designed to incorporate new models, whether it is a hydrological simulation package or any other model which estimates water-related information. The existing GIS platform of the IB can be changed to incorporate another surface run-off package, as well as the platform from where the post processed information of the simulations can be viewed, interpreted and reported about.

The next chapter gives an overview of the GIS platform of the IB. The GIS GUI presents the database, together with most of the model outputs described in this chapter.

5 The Information Base framework

The concept of a DSS has been described in an earlier section. In this chapter, the basic components that give the intended user the access to the Information Base (IB) of the DSS will be described. The IB has been created on the Windows concept where icons replace lines of text to provide easy access without the need to memorize computer commands. A well-known GIS, Arcview, has been chosen for the interface between user and information.

5.1 Arcview Framework

The effective management of the water resources of a catchment relies heavily on the availability of water-related information derived from relevant data. The Arcview GIS platform is a front-end user interface to access the database containing all the hydrological-related data of the Mhlathuze River System. The data was (and continues to be) gathered for the ultimate development of a Decision Support System of the Mhlathuze River system. Both spatial and temporal data, contained in the database, will be made available to all stakeholders involved with the integrated catchment management of the Mhlathuze River resources.

5.1.1 An Overview of the DSS

The IB has been developed using Arcview 3.0 for Window 95, making extensive use of the Arcview programming language Avenue. Since the start of the project, the software has been upgraded to Windows 98 and Arcview 3.1, and also includes Spatial Analyst 1.1. Customized buttons have been inserted at strategic places to facilitate more user friendly access. When clicking on the buttons, Avenue scripts are executed which displays the data in the database in an informational format, giving the novice Arcview user easy access to the information on the database. Arcview is windows-based, with drop-down menus for retrieval, display and analysis of the data.

When entering the front page of the database, a *base map* of the region is presented, displaying the basic features of the catchment which include the main river channels, the coastal lakes, the main catchment boundaries for each HYMAS VTI project area and the larger towns of the area. Also available for display on the front page is the theme of the minute by minute grid of the altitudes of the catchment (Dent *et al*, 1989), which gives an indication of the catchment morphology. A theme is also presented which is linked to digital images originating from a video that was flown on the 10th March 1998 along the main channel of the Mhlathuze River course from the Thukela augmentation scheme to the estuary, as well as some of the coastal lakes. Figure 1.1 shows a display captured from this page of the DSS.

From the front page, a tool bar gives access to increasing levels of information in the form of detailed maps, which can be accessed by clicking on the appropriate button, described below. The maps include the optional display features, together with the basic features in the front page (main river channels, catchment boundaries, positions of major towns) for orientation purposes. The different features from the different maps can be overlayed on each other for comparisons, making use of simple GIS "copy-and-paste". Figure 5.1 indicates a few of the many possible combination of maps that can be created and displayed in the Arcview platform of the DSS. Figure 5.1 presents an example of the display with various "views" open as separate windows. The display capabilities are managed through the "menu bar" on the top of the page, with the display of the buttons available for the view on the "button bar" shown in the top row of icons. The second row of icons represent additional standard functions (or tools) in Arcview.

5.1.2 Descriptions of the views

 Infrastructure (roads, railways and powerlines)

This page provides a general view of the main infra structural features of the region. Digital data

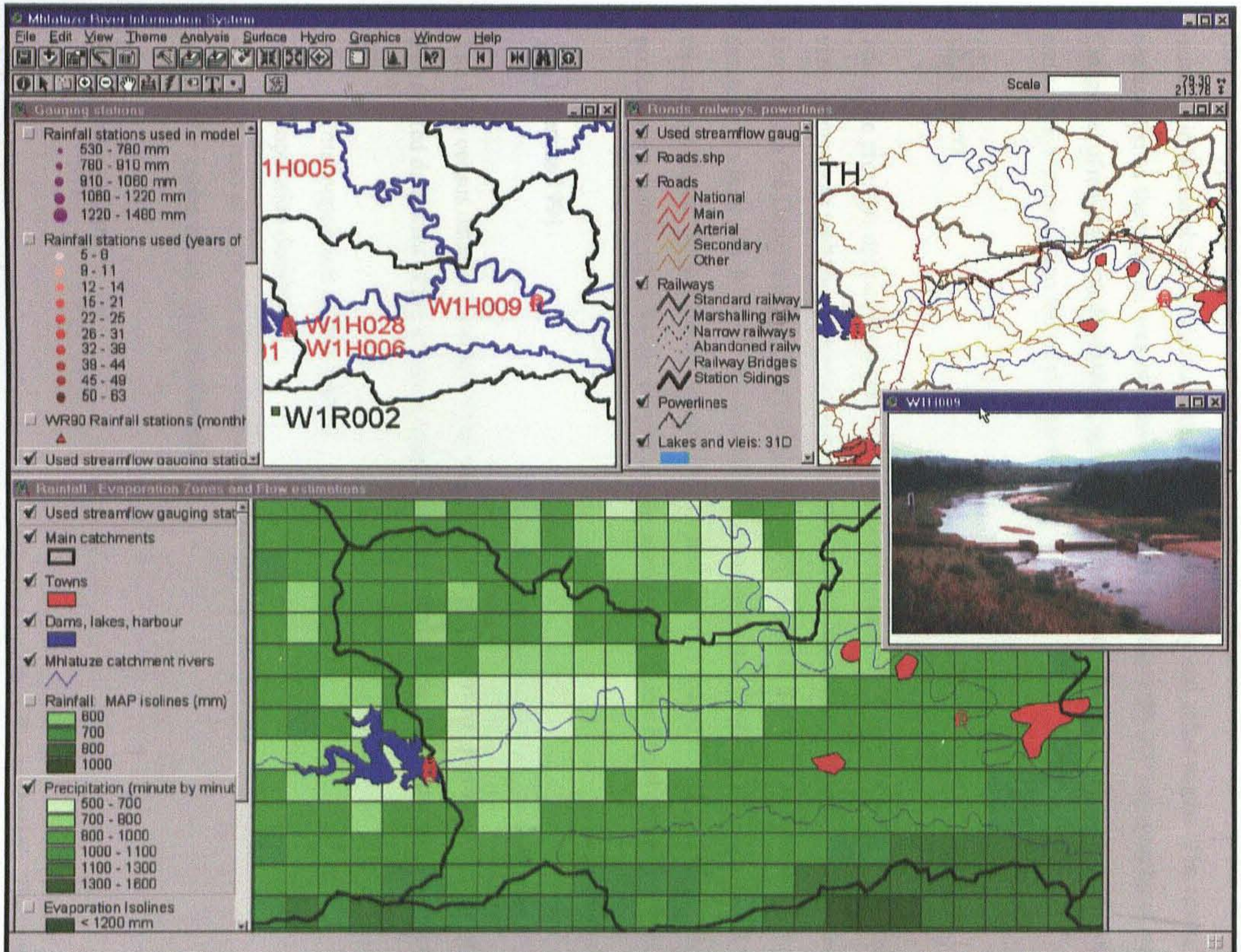

Figure 5.1: One of the many possible combinations of map displays in the Arcview platform of the IB.

bought from the Department of Land Affairs, Chief Directorate of Surveys and Land Information at a scale of 1:50 000 forms the basis of the view. The principle categories of roads and railways are displayed together with the base map themes. Cadastral data for Richards Bay can be added (the data supplied by the Richards Bay Transitional Local Council). Subdivisions of roads included in the database is national, main, arterial, secondary and other roads. The towns are represented as the built up area of a town, as indicated on the 1:50 000 topographical maps. Categories of railways include standard, narrow, marshalling and abandoned railways, with sidings and railways stations also indicated separately.

Rivers

This page provides options for displaying various categories of the water resources. The river view commences with the same base map information, but has information on various classes of rivers (from the Department of Land Affairs, Chief Directorate of Surveys and Land Information database at a scale of 1:50 000). The perennial and non-perennial rivers are presented by varying thickness of lines. Rivers can be viewed (and copied to other maps) for each of the HYMAS project areas developed in the IB, as well as the catchment of Lakes Mzingazi and Nhlabane.

Census 1991

The 1991 census data for KwaZulu Natal was provided by the DWAF, Durban Regional Office. The related databases of the different census districts are available. Maps prepared for viewing are:

- Total population of each district
- Population density
- A ratio of economically active to economically inactive people
- Per capita income (Rands/annum)

Hydro stations

This map presents the positions of most of the monitoring points in the catchment. The location of measurement stations containing hydrological sequential data included for rainfall (SA Sugar Association, Department of Agriculture, SA Weather Bureau, and Midgley *et al*, 1994), evaporation (DWAF), stream flow and reservoir gauging stations (DWAF), as well as many of the boreholes. The positions of the rainfall station sections and the numbers (DWAF) can also be viewed. A link is created to the theme indicating the stream flow gauging stations, which can be accessed by clicking on the "Hot Link" tool and then clicking on the gauging station symbol on the map. This will bring up a photograph of the gauging station. The photographs can be enlarged (and reduced) by making use of the standard windows resize buttons on the top right-hand corner of the photograph's windows. By using the Information Tool the general information related to each station can be displayed.

Hydrological data estimations

In the WR90 data publication (Midgley *et al*, 1994) several sets of hydrological data estimations were published. These studies were done on a broad scale, ranging between 1:250 000 and 1:1000 000. Data sets which can be viewed in this page, are mean annual precipitation isolines, mean annual evaporation isolines, mean annual run-off estimations for the quaternary catchments, as well as the minute by minute grid of rainfall estimations as extracted from the CCWR database.

General spatial information (WR90)

This information, imported from the WR90 data set, is also displayed as layers of spatial data that include the vegetation types, agricultural land uses, soil types and the geology. This information was originally used to establish the subarea boundaries of the surface water simulations in the VTI HYMAS project.

Groundwater and Lithology

The data for these views were taken from Martinelli (1994) and were provided by the DWAF. This view gives the user awareness of the expected yields from boreholes drilled in the region. It also covers maps of the Lithology, lineaments, faults, dykes and unit boundaries of the area.

The full descriptions of the features on these maps are found in the accompanying notes (Martinelli, 1994) and on the printouts of the maps.

Water resources, Usage

The points of water extractions, locations of water resources and the interbasin transfer scheme from the Tugela River to the Mhlathuze River are indicated on this page. Future development of this page will include irrigation board boundaries (the dams from Heatonville Irrigation Scheme dams are already included). The amount of water potentially used or supplied will then be viewed by clicking on the features. It will thus be possible to draw up a schematic presentation of the potential water supply and usage in the catchment.

Reports

This button opens the available official reports generated by the HRU from studies on the area, as well as detailed reports containing technical detail of the methods used in studies on the whole project. Legal documents can be viewed from a Word Perfect hyper linked file.

Theme Data Source button

This button provides information of the highlighted theme on any view, with reference to the data source, the scale of the data source maps, and any other important piece of information regarding the different themes.

5.2 Spatial Analysis

The previous section has outlined the acquired data and information that have been chosen for presentation as initial support for integrated catchment management. In addition to this, some data has been acquired and transformed into more appropriate information which is also presented in the IB as separate projects. These are:

1. Water Resources Modelling project
2. Satellite Imagery project
3. Digital Elevation Model project

5.2.1 Water Resources Modelling project

This project has several pages, covering maps which display different themes. These have been designed to be of assistance in Hydrological studies and parameter estimations in the VTI model. The project presents:

- The front page of the Water Resources Modelling project
- Hydrological gauging data
- Boreholes map
- Characteristics of subcatchments
- A map of Lake Nhlabane area

5.2.1.1 The front page

This page displays the HYMAS projects, the subareas of each project and the location of photographs and images taken in the catchment. Selected photographs can be displayed when the "Hot Link" tool is activated and the location symbol on the page is selected. Images captured in the field with a digital camera and a GPS can be accessed from this page. Notes of each photograph are included in Appendix 1 (see Field Trips), and can be called up from this view (using the "Hot Link" tool).

5.2.1.2 Hydrological gauging data

The Hydrological gauging map is a repetition of the "Hydro Stations" view in the Mhlathuze River Main Project. This duplication is due to the necessity to access hydrological data and monitor the positions of stations during parameter estimation in HYMAS. Positions of soil profiles from the Land Type map for Richards Bay (2830) which were used in the soil parameter estimations are also indicated. The information in the map's memoir on each soil profile can be viewed by clicking on the Profiles theme, then on the "Info" tool , and then on the location of any soil profile on the page.

The related table of the "Profiles" theme contains the records of each soil profile, as described in Chapter 3, Section 3.2.3. The "Query Builder" button  provides searches on soil types on the catchment, making use of this related table. The different fields of the table are listed, as well as the available values for each field. Easy "select and search" navigation in the "Query Builder" window provides searches for selected characteristics in all the soil profiles. The outcome of each search (be it a new set of profiles, or a set which is added to an existing set of profiles) appear as highlighted profiles on the page.

5.2.1.3 Boreholes view

This view shows the positions of boreholes, arranged in themes by the different data sources. These include the National Groundwater Database, two sets of borehole data provided by Richards Bay Minerals (around Lake Nhlabane), and data from the Uthungulu Regional Council. The borehole data are available in HYDROCOM format. HYDROCOM is the national standard for groundwater data format, and can do the necessary searches for groundwater data.

Two buttons were included to do searches on the borehole database for information on the water level, and the geological information of each borehole. On activating the first button, it searches a specific borehole theme for boreholes where either *water level information* or *geological information* is available, and highlights these boreholes. A legend appears at the bottom indicating the search result. With this button the user can get a quick assessment of the availability of data in the catchment, although no indication of data quality is attached to this facility.

Once a set of boreholes, which indicate available geological data, is selected, the second button can be used to search for the occurrence of a certain geological feature. A list of geological features, which occur in the set of selected boreholes, will be produced for the user to choose from. The resulting selected boreholes contain the specified geological feature, and a table is opened up which provides more detail of the geological feature of each borehole (e.g. the top and bottom depth of the chosen geological feature for each borehole). The legend at the bottom of the map is updated again to indicate the search result. This button can provide an overall look at information on a specific geological feature, but again no detail of data accuracy or quality are included.

5.2.1.4 Characteristics of subcatchments

Most of the themes in this view were used for estimating the hydrological parameters in the HYdrological Modelling Application System (HYMAS) program. This page provides locations where soil profiles were dug, positions of subarea centres, the positions of small farm dams, with catchments, positions of irrigation scheme dams, as well as the positions of the different topographical maps covering the catchment. Attached to each theme is a table containing data relating to features displayed on the map. This data gives an overview of the hydrological characteristics of the area. The theme containing the small farm dams presents the capacity, dam wall height, etc. that are listed in a related table. Clicking on a farm dam (while making use of the "Information Tool") makes the information applicable to that dam visible in a table.

In this view the "trace route" tool has been adopted from Kruger National Parks Rivers Research Program Integrated Catchment Information System (ICIS, 1999). This feature highlights all the subcatchments which are upstream (or downstream) from the subcatchment clicked on. In this way the movement of water through subcatchments in the whole catchment can be viewed spatially.

Two buttons are included on this page with which prepared flow data can be viewed. Data from the VTI HYMAS surface water run-off simulation output can be imported into the format that this software can read for graphical analysis and display with the first button . Duration curves can be plotted with the second button. This buttons makes use of software developed and described by Hughes (2000).

5.2.2 Satellite Imagery Project

The satellite imagery of the catchment has been purchased from the CSIR, Satellite Application Centre. The image is a Landsat TM image, with 25 m by 25 m pixel resolution and 7 bands of data. Any of the available vector data in the rest of the DSS (roads, rivers, towns, ground truth points, etc.) can be overlayed on the satellite image. IDRISI 2 for Windows was used for analysis of the land use classification, described in Chapter 4. Images produced from these analysis can be viewed as backdrops in Arcview for overlaying the different vector features available in the IB.

The different images available for viewing, are:

- The raw Satellite Landsat TM image consisting of the seven bands
- Land Use Classification with Supervised classification method (Maximum Likelihood)
- Land Use Classification with Unsupervised classification method (Cluster analysis)
- A black-and-white image of the Normalized Difference Vegetation Index (NDVI).

The development of the land use classification images and the NDVI image are described in the first section of Chapter 4.

5.2.3 Digital Elevation Model

The DEM was constructed to provide the necessary geomorphological information of the catchment in order to simulate the quantity (and eventually the quality) of water run-off from the catchment. Although the DEM was constructed using the IDRISI 2 for Windows software (refer to the second section of Chapter 4), all information used to create the DEM are presented here. Analysis of the DEM was accomplished by using the Spatial Analyst 1.1 in Arcview 3.1.
Views available in this project are

- Contours,
- Digital Elevation Model,
- DEM Analysis, and
- Watershed Analysis.

5.2.3.1 Contours

This theme shows all possible contours used during the creation of the DEM. The 100 metre contours from the 1:500 000 maps were originally used to create the DEM, supplemented by some 20-metre contours from the 1:50 000 maps along the coastal zone. After the initial construction of the DEM, more 20-metre contours were digitized and added, as well as the line and point information of the coastal lakes' bathymetries (Kelbe *et al*, 1998).

5.2.3.2 Digital Elevation Model

This view simply gives the DEM in two dimensional format (Figure 4.10). More software needs to be acquired to view the DEM in three dimensions from the Arcview platform. A three-dimensional view is available from the IDRISI 2 for Windows software (Figure 4.11). It is stressed again that the DEM was constructed to be used only inside the catchment of the Mhlathuze River resources, which includes (in this case of the constructed DEM) the catchment of the Mhlathuze River and the Nseleni river. Areas outside of these catchments were not tested and may contain elevation errors.

5.2.3.3 DEM Analysis

Derived information from the DEM, which are presented in this view, are the percentage slopes, the aspects and the hill shading. Hill shading was calculated by specifying both the azimuth and sun elevation as 35 degrees. This takes into account the position of the sun during the capturing of the satellite imagery at seven o'clock in the morning. The hill shading can be recalculated easily with different values for the azimuth and sun elevation.

5.2.3.4 Watershed Analysis

The watershed analysis entails the calculation of the flow direction grid (which presents the direction of water flow in each cell of the DEM). Some of the pixels have zero flow directions, or form closed loops of water flow which stems from sinks in the DEM. These sinks (the lower areas with no point of water outflow) are calculated from the flow direction grid and are presented in this view. The sinks were eliminated from the DEM before further analysis of the DEM was undertaken. From the corrected DEM (which contains no sinks) another (corrected) flow direction grid was calculated, which is presented here. This corrected DEM is regarded the final product of the DEM construction, and is used as such throughout the IB.

The flow accumulation grid presents the number of up-slope cells for each cell, based on the flow direction grid. From the flow accumulation and flow direction grids, the positions of river courses are calculated. Both the calculated river courses and digitized rivers are presented here. Subcatchment delineation can be done on different scales by delineating more (or fewer) subcatchments as the need arises. Some of the calculated subcatchments were combined, where necessary, to correspond with the catchment subdivision done for the surface water run-off simulations. Both sets of catchment boundaries are presented here.

5.3 The IB on the web

The information described in this chapter (and more) is presented on a web page (*http://water.hruzulu.ac.za/*) managed by the Hydrological Research Unit (HRU, University of Zululand), as part of the greater study on the Mhlathuze River sponsored by the Water Research Commission. Details of development of this web page is beyond the scope of this study. Only a brief summary on the potential of Internet access and the effect of this on the IB described in this chapter, is provided here.

The development of the IB was done using Arcview, which is part of a suite of GIS software package that has been developed by the Environmental Scientific Research Institute (ESRI). Some of these are compatible with web-based software which can display and manipulate GIS information. ESRI has developed a software package called Internet Map Server (IMS), with which the GIS data of the IB can be made available to web users, who can access the GIS data making use of their web browsers. Currently research is being done to evaluate the approach and to investigate the use of cheaper software with which the IB can be presented on the web. The current web site of the DSS only contains images of the different maps contained in the IB, with no zooming or search facilities. One of the maps (all maps printed in this dissertation are available from the web site as images) are indicated in Figure 5.2. The image resolution has been reduced intentionally to accommodate the present bandwidth for accessing the Internet using dial-up modems.

The main advantage of a web site is the easy and "free" access to update facilities that it provides to all users. A report such as this one becomes out-of-date within a few months, as new developments are made in the IB. A web site is not restricted to time-consuming printing and dissemination of data and information in a report format. However, it is restricted in the type and format of the copy-rights of data, which cannot be released without authorization.

5.4 Future Developments

As more data become available, it can be included in the IB and made visible through the GIS platform and on the web. As more models are developed within the IB, the outputs of their simulations (which extends the available data and information) can be included in the IB and published on the web. Better information extraction and displaying capabilities (which are currently being developed in other parts of the world) can be included as they become available in the so-called freeware software realm.

The current version of the IB does not include a quick link between the simulation model outputs and the GUI platform of the GIS, in the sense that the simulation model output is independently processed before the summarised results can be displayed graphically from the IB's spatial GUI platform. The IB is in need of a higher level of interaction between simulation model outputs and the GUI platform. A bridge needs to be developed which can close the gap between the time series output from the simulation models and a spatial map which can, for example, display the output values of the simulated variable for the different subcatchments, accompanied by graphs which describes the statistical analysis of the scenario. ICIS (1999), GenScn (Kittle *et al*, 1998), BASINS (Lahlou, Shoemaker, Choudhury, Elmer, Manguerra and Parker, 1998) and many other models are all being developed to establish this interactive linkage. This link will be implementedin the Mhlathuze IB when the HSPF (Johanson *et al*, 1996) and GenScn software packages have been incorporated in the IB, as mentioned in the last section of Chapter 4. This will be the next step towards the ultimate goal of an interaction system between user and computer which provides information when a certain issue is addressed. It is a daunting task to list all possible problems which can be foreseen in integrated catchment management, simply

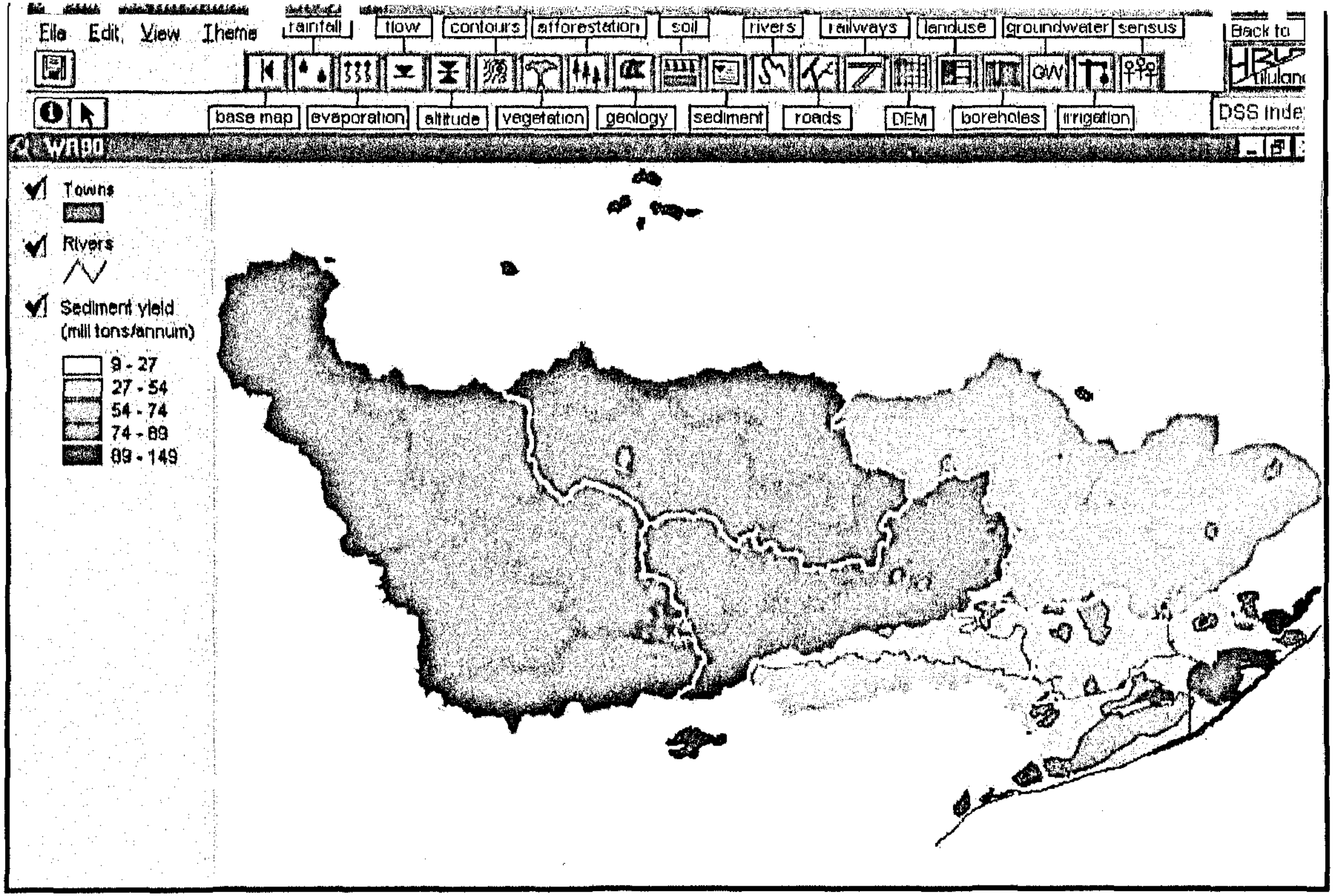

Figure 5.2: One of the pages in the web site where the IB can be accessed: *http://water.hru.uzulu.ac.za.* The maps indicated at the top are available from the web site as images.

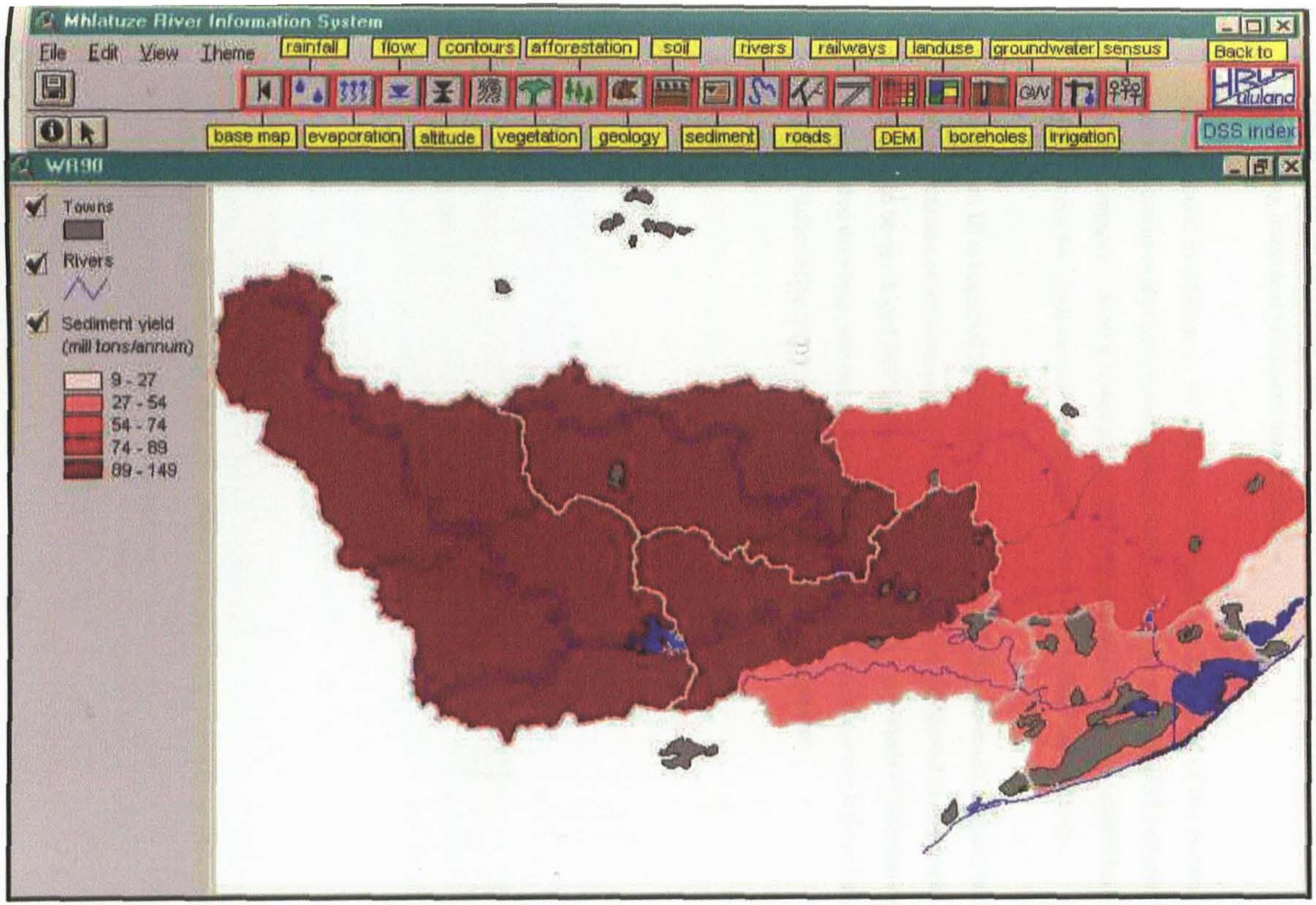

Figure 5.2: One of the pages in the web site where the IB can be accessed: *http://water.hru.uzulu.ac.za.* The maps indicated at the top are available from the web site as images.

because of the wide concept included in the term *integrated catchment management*. Thus the DSS needs to be developed with the flexible capability to incorporate all of the issues that can arise during integrated catchment management.

As mentioned in Chapter 2, the Dialogue Designer (an extension of the current version of Arcview) can be exploited to develop such an interaction system in the DSS between the IB user and the computer. Such a development of the IB should enhance the capabilities of the IB to make it a tool for quick analysis and interpretation of many different scenarios.

The current IB is regarded by the author as a preliminary effort to combine data for the creation and presentation of information needs to support integrated catchment management. It has the potential to be developed into a platform from where many more kinds of information needed in water related decisions, can be extracted and from where many more models can be accessed to create the information relating to integrated catchment management.

6 Summary and conclusions

Effective management of a catchment is dependant on a sound knowledge of the condition and processes controlling the resources in the catchment. The resources are many and varied and the controlling processes cover a huge range of spatial and temporal scales. To enhance the knowledge and support understanding of the condition and processes, there is a need for relevant information. This information generally originates from monitoring programs that have very specific purposes and consequently they seldom support the scale of interaction appropriate for integrated catchment management. Consequently, the information needs cannot be met by the present level of monitoring but require additional transformation and integration of the data. The information needs arrises from emerging issues that constantly change. This study has focussed on the water resources of the Mhlathuze catchment. It has concentrated on the data collection, together with information generation and dissemination using appropriate technology.

6.1 Database

The available data for the region is extensive and varied (Allcock, 1999), but seldom in a suitable format for easy and quick access. Consequently, the creation of a specific database is difficult and time consuming and often involves extensive negotiations with the data providers. As a result, the IB in the DSS reflects a portion of what could be required. However, it does represent that data which has been considered as a requirement for the continued development of the DSS. It has been obtained in various formats from many organizations, including government bodies, non governmental organizations, universities, transitional local councils and many private organizations. It is important to realise that the development of the IB in the DSS is critically dependant on the support of these organizations.

6.2 Information Requirements

The information summarised in the IB of the Decision Support System for the Mhlathuze Water Resources are restricted to the application of water management. Information is created from the data, making use of conceptual models. This report describes three models that have been incorporated in the IB. The Land Use model was created from data which originated from satellite imagery. The Digital Elevation Model was created from the digital contours of the region. These two models in turn provided information to simulate the quantity of water run-off from the catchment. These simulations extend the measured flow records of water quantity in the catchment.

The current IB describes the current situation of the water resources of the Mhlathuze catchment. It can also provide analysis and descriptions of effects from some different management scenarios to meet some requirements of integrated catchment management. However, more development of the simulation models included in the IB is necessary to widen the nature of the management scenarios which can be analysed in the current IB.

6.3 Model Needs

The Information Base has been designed to address other catchment information needs. It can be expanded into a system which incorporates many other different models, all related in different ways to the water resources of the catchment. Water quality models, forestry models, crop growth models, socioeconomic models and irrigation models are all possible models which can be incorporated in the system. All these components can operate individually as different components in one system. If the different models or components are operated from the same background information in a single operating environment, it will provide support for catchment management.

Cooperation with other organizations to use the Information Base in developing management options, is in progress. A Strategic Environmental Assessment (SEA) of tools for defining stream flow reduction activities (SRA) by the DWAF (Steyl and Versfeld, 1999) is another cooperative project. The impact of riparian vegetation, studied by the Institute for Natural Resources (Quinn, 1999), is another project in process.

6.4 Transferability of the IB

The basis of this system was adopted from the Integrated Catchment Information System (ICIS, 1999) developed for the Kruger National Park Rivers Research Program (KNPRRP) by the CCWR. The Mhlathuze IB has adapted many of the features from the Integrated Catchment Management System that was developed for the KNPRRP. The changes, which need to be made to the existing system to implement it in another catchment, can, in essence, be summarized as follows:

- The development of the database for the catchment
- Assessment of existing and developing Decision Support Systems worldwide
- The setup of a hydrological simulation system for the water resources in the catchment
- The setup of specialist models for simulations of the important issues in the catchment, which can address the important water relating issues raised in the catchment and supplement the information provided by the hydrological model of the catchment.

Most of the Mhlathuze catchment DSS components can be adapted for the catchment of interest. Restrictions to be considered when transferring the system to another catchment, are

- the availability of data for the catchment,
- the availability of capacity to develop the new system to its required potential, and
- the availability of funds to meet the needs which arise as the system develops and the purchase of copyrighted material and programs.

The capacity and funds requirements both depend heavily on the size of the catchment, as well as the kinds and of issues raised in the catchment.

6.5 Conclusions

Many challenges have been put to water resource managers by the new South African Water Act, with the adoption of Integrated Catchment Management which must be implemented by a Catchment Management Agency. Other demands are being put on the water resources of the Mhlathuze River system, as towns and industries expand in the catchment.

Greater computer resources (both hardware and software resources) are becoming available and affordable. This brings more computing power to the desktops of both the managers of water resources and the developers of tools that support these decision processes. Consequently, the development of management support tools, which provide such facilities, should not be restricted, but must recognize increasing capacity of information technology in data warehouses and communications.

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APPENDIX 1

DATABASE

The IB within the DSS has been created to provide a convenient means of making available information easily accessible by interested and affected parties. This report has described the means of making data and a brief summary of the information available. It has not given a full coverage of available data. This appendix is a more detailed summary of the data. It is presented in a series of tables in three sections:

- SEQUENTIAL DATA
- SPATIAL DATA
- DATA GATHERED FROM FIELD TRIPS

SEQUENTIAL DATA

This section provides a tabular summary of the sequential data that has been gathered for the purpose of the study. This database will grow as more information is sourced and captured.

Kind of data	**Source of data**	**Time step of records**	**Contact***
Rainfall	CCWR	Daily	CCWR, University of Natal, Pietermaritzburg
Evaporation	DWAF	Monthly	DWAF, Durban Regional Office
Flow measurements	DWAF	Daily, Monthly	DWAF, Durban Regional Office
Ground water	National Groundwater Database, DWAF	N/A	DWAF, Head Office, Pretoria

* The contact listed are the organization from where the original (and updated) records can be ordered.

SPATIAL DATA

Source of digital data	**Scale of maps**	**Features on maps**
Department of Land Affairs, Chief Directorate Surveys and Land Information.	1:50 000	Roads Railways and powerlines Built-up areas Rivers Water features Dams and dam walls 20 metres contours
Department of Land Affairs, Chief Directorate Surveys and Land Information.	1:500 000	International boundaries, magisterial districts, federal provinces Roads Railways Powerlines and telecommunication towers Built-up areas and small centres Rivers Pans, marshes, lakes and vleis Dams and dam walls Nature reserves Assorted feature Wooded areas Contours: 100 metres
DWAF, Durban Regional Office	1:1000 000	Magisterial districts Pollution and water quality monitoring points, with dam safety data 1991 Census (with related database) Water quality data (Range of Electrical Conductivity) Settlements in former KwaZulu Occurrence of groundwater Lithology
WR90 data set	Different scales	See Reference: Water Resources (1990)
CSIR, Satellite Application Centre	25 m by 25 pixels	Landsat TM Satellite Imagery
Soil, Climate and Water Institute	1:250 000	Soil Type map Richards Bay, with accompanying memoir

Data for Mhlathuze river catchment area

Digital maps for the Mhlathuze river catchment has been developed from the available spatial data and are available from the HRU Internet Web site. These include the:-

- Main catchment boundaries, towns, rivers and lakes
- Rivers

- Roads, railways, powerlines
- Water usage
- Rainfall distribution from CCWR database
- Gauging stations: rainfall and evaporation stations
- Gauging stations: flow and reservoir gauging stations
- Boreholes
- Occurrence of groundwater (in Zululand)
- Lithology (of Zululand)
- Data from Mhlathuze Water Amanzi shapefiles: forested areas, pumps, pipelines, irrigation, dams, canals, properties
- Census data from 1991
- Contours used for construction of Digital Elevation Model
- Digital Elevation Model
- DEM analysis: delineated watersheds and rivers
- DEM analysis: Slopes
- DEM analysis: Flow directions of each pixel
- Satellite image: Landsat TM (22 April 1996, 23 July 1997)
- Satellite image analysis: Land cover classifications

DATA GATHERED THROUGH FIELD VISITS

Field trip to catchment of Goedertrouw Dam

Staff on field trip: Talita Germishuyse, Nina Snyman

Date: 14 July 1999

GPS Reading		Amount of satellites[1]	ID[2]	Talita[3]	Name of file with photo	Time	Direction into which photo was taken	Description
Long	Lat							
31 ° 29·07	28°46 ·49	6	1		Mvc-774f.jpg	9:00	East	Thorn tree bush veld
31°28 ·42	28°46 ·41	5	2	14	775_776.jpg	9:10	West	Goedertrouw Dam and catchment
31°19 ·43	28°51 ·09	4	3	13	Mvc-778.jpg	9:50	North	Subsistence farming: sugarcane, wattle
31°17 ·32	28°51 ·26	4	4		Mvc-779.jpg	10:10	South west	Gumtrees all around us
31°17 ·32	28°51 ·26		5		Mvc-780.jpg	10:10	North	Communication tower in gumtrees
31°16 ·54	28°52 ·30		6	12, 11	Mvc-782.jpg	10:30	North West	Subsistence farming
31°16 ·54	28°52 ·30		7	10 (NW)	Mvc-783.jpg	10:30	North West	Sugarcane in foreground, grassland in background

[1] Amount of satellites used by the Global Positioning System (GPS) to calculate the latitude and longitude of the position.

[2] The identity number of the photograph on the digital camera.

[3] The identity number of the photograph on Talita Germishuyse's camera.

31°16 '54	28°52 '30		8	9 (N)	Mvc-784.jpg	10:30	North West	Sugarcane in foreground, grassland in background
31°16 '54	28°52 '30		9		Mvc-785.jpg	10:30	North West	Sugarcane in foreground, grassland in background
31°16 '54	28°52 '30		10		Mvc-786.jpg	10:30	North West	Sugarcane in foreground, grassland in background
31°16 '54	28°52 '30		11		Mvc-787.jpg	10:30	North West	Sugarcane in foreground, grassland in background
31°16 '54	28°52 '30		12		Mvc788-.jpg	10:30	North West	Sugarcane in foreground, grassland in background
31°16 '09	28°53 '		13		Mvc-789.jpg	10:45	North	Catchment of Goedertrouw Dam, gumtrees, at turn-off to Entumeni
31°14 '08	28°52 '00		14	7	Mvc-790.jpg	11:00	South west	Subsistence farming
31°11 '05	28°50 '42		15		Mvc-791.jpg	11:10	North	Erosion, grassland, slopes
31°11 '05	28°50 '42	5	16	6,5,4, 3	Mvc-792.jpg	11:10	North west	Subsistence farming
31°11 '20	28°50 '15		17					Where Tugela water goes over catchment boundary, where three roads meet.
31°11 '51	28°48 '58		18	2	Mvc-793.jpg		Upstream	Stream (Mvusana river

31°11 '51	28°48 '58		19		Mvc-794.jpg		Upstream	Stream (Mvusana river
31°11 '51	28°48 '58		20		Mvc-795.jpg		Downstream	Stream (Mvusana river
31°10 '59	28°48 '05		21	1	Mvc-796.jpg		East	Grassland, little bit of trees
31°10 '59	28°48 '05		22		Mvc-797.jpg		North East	Grassland, little bit of trees
31°10 '59	28°48 '05		23		Mvc-798.jpg		North East	Grassland, little bit of trees
31°10 '59	28°48 '05		24		Mvc-799.jpg		North	Soil profile
31°08 '24	28°44 '39		25		Mvc-800.jpg			Start of natural forest along the road, travelling northern direction
31°07 '44	28°44 '44		26	23,21	Mvc-801.jpg		North East	Catchment: natural forest and grass
31°07 '44	28°44 '44		27	22	Mvc-802.jpg		West	Natural forest, grass
31°08 '07	28°42 '56		28					End of natural forest along road, travelling northern direction
31°09 '56	28°42 '35	3	29		Mvc-803.jpg		South east	Border of Nkandla forest
31°09 '56	28°42 '35	3	30		Mvc-804.jpg		South east	Border of Nkandla forest
31°05 '27	28°39 '31		31		Mvc-805.jpg			Catchment: subsistence farming
31°09 '34	28°31 '12	5	32	20,19				

31°13 '30	28°31 '37		33		Mvc-806.jpg	2:10	North	Gumtrees: different colours for same kind of tree
31°15 '11	28°31 '26		34		Mvc-807.jpg	2:15	South East	Edge of Pine plantation
31°14 '02	28°31 '38		35		Mvc-808.jpg	2:19	North east	Edge of Pine plantation
31°17 '33	28°28 '13		36		Mvc-809.jpg	2:30	East (North of road)	Wattle plantation
31°17 '33	28°28 '13		37		Mvc-810.jpg	2:30	West (north of road)	Pine plantation
31°17 '33	28°28 '13		38		Mvc-811.jpg	2:30	South of road	Gum plantation
31°19 '27	28°37 '02		39		Mvc-813.jpg		North west	End of Pine plantation north of road
31°25 '16	28°39 '23	4	40		Mvc-814.jpg	3:10	North	At road, combination of Pine plantation and sugarcane. Farm: Percival

Field trip to catchment of Mhlatuzana river

Staff in field trip: Talita Germishuyse, Nina Snyman

Date: 19 July 1999

GPS Reading Long	Lat	Amount of satellites	Photo ID	Talita's camera	Filename	Direction	Description
31 50 19	28 51 04	4	16	16		North	Lake Mangeza
31 50 19	28 51 4	4	17	15	Mvc-017f.jpg	East	Catchment of Lake Mangeza
31 48 29	28 51 44	5	18	0	Mvc-018f.jpg	North-northeast	*Sugarcane farming in catchment*
31 48 2	28 50 38	5	19	4,13,12	M v c - 0192021f.jpg	North-north east	Univ of Zululand
31 48 11	28 49 54	5	22	11	Mvc-022f.jpg	North west	Water from rocks
31 48 11	28 49 54	5	23	0	Mvc-023f.jpg	Down stream	River course, pipe that goes underneath road
31 48 11	28 49 54	5	24	0	Mvc-024f.jpg	North east	Road where pipe goes underneath road
31 48 11	28 49 54	5	25	10	Mvc-025f.jpg	North	River Course

31 48 20	28 49 36	5	26	9	Mvc-0262728f.jpg	West	Catchment of Mhlatuzana, marshes
31 48 33	28 49 31	6	29	0	Mvc-029f.jpg	North	Lake Mpangeni, "confluence" of Mhlatuzana and Mhlathuze rivers
31 48 15	28 49 21	6	30	8	Mvc-030f.jpg	north west	Papyrus and marshes of Mhlatuzana river
31 48 4	28 49 17	7	31	7	Mvc-031f.jpg	South	Catchment, rocks, burnt veld, grassland
31 48 4	28 49 17	7	32	6	Mvc-032f.jpg	North	River (marshes), southern direction with Talita's camera
31 48 4	28 49 17	7	33	5	Mvc-033f.jpg	North	road and river
31 48 4	28 49 17	7	34	4	Mvc-034f.jpg		Flower in river
31 46 35	28 48 10		35	0	Mvc-035f.jpg	down stream	river crosses road (no river visible)
31 45 03	28 46 26	5	36	2	Mvc-036f.jpg	North west	Vegetables grown next to river
31 45 03	28 46 26	5	37	0	Mvc-037f.jpg	west	Natural bushes, less grassland, sugarcane in catchment
31 43 18	28 45 41	5	38	0	Mvc-038f.jpg	south	Rocks on edge of southern catchment boundary
31 41 44	28 45 56	6	39	24	Mvc-039f.jpg	north	Afforested catchment of Mhlathuze river, sugarcane
31 41 18	28 46 00	5	40	0	Mvc-040f.jpg	south	Grassland, bush on southern catchment boundary - no rocks
31 36 50	28 47 17	5	41	0	Mvc-041f.jpg	east	At turn-off to north (road nr D132): piece of Gum trees to northwest of roads
31 36 50	28 47 17	5	42		Mvc-042f.jpg	east	Notice board
31 33 17	28 47 48	6	43	23	Mvc-043f.jpg	north	Nkwaleni valley
31 33 17	28 47 48	6	44	22	Mvc-044f.jpg	south	Mhlatuzana river valley
31 33 16	28 48 38	5	45	21	Mvc-045f.jpg	north	Mhlatuzana river valley
31 33 16	28 48 38	5	46	21	Mvc-046f.jpg	north	Mhlatuzana river valley
31 33 40	28 48 42	3	47	0	Mvc-047f.jpg	down stream	River (Mhlatuzana river?)
31 33 40	28 48 42	3	48	0	Mvc-048f.jpg	up stream	River (Mhlatuzana river?)
31 39 43	28 48 18	7	49	20	Mvc-049f.jpg	down stream	River valley
31 39 43	28 48 18	7	50	19	Mvc-050f.jpg	up stream	Truck on bridge
31 39 43	28 48 18	7	51	0	Mvc-051f.jpg	up stream	Truck on bridge
31 39 43	28 48 18	7	52	0	Mvc-052f.jpg	up stream	River valley
31 44 45	28 44 52		53	0	Mvc-053f.jpg	up stream	W1H009 weir
31 44 45	28 44 52		54	18	Mvc-054f.jpg	up stream	south of bridge: grapefruit orchards (5-6 years old)
31 44 45	28 44 52		55	0	Mvc-055f.jpg	down stream	river valley
31 52 6	28 48 22		56	17	Mvc-056f.jpg	west	Lake Mpangeni
31 52 6	28 48 22		57	0	Mvc-057f.jpg	north	Catchment
31 51 6	28 47 37	10 or 0	58	0	Mvc-058f.jpg	up stream	river (Catchment of this river: sugarcane farming
31 51 6	28 47 37	10 or 0	59		Mvc-059f.jpg	down stream	river (Catchment of this river: sugarcane farming

Field trip to Nseleni river catchment,

Staff on field trip: Nina Snyman and Talita Germishuyse

Date: 22 July 1999

GPS Reading Long	Lat	Amount of satellites	Photo ID	Talita's camera	Filename of photo	Direction	Description
31 47 58	28 41 4	4	60	16	Mvc-060f.jpg	down stream	Heatonville Irrigation Scheme: Main canal
31 47 58	28 41 4	4	61	0	Mvc-061f.jpg	up stream	Heatonville Irrigation Scheme: Main canal
31 50 54	28 34 42	4	62	0	Mvc-062f.jpg	west	Catchment: forested grassland
31 49 25	28 36 47	4	63	15		west	Sugarcane with forested river courses
31 48 41	28 35 47	5	64	14	Mvc-064f.jpg	east	Forested catchment, with sugarcane
31 48 41	28 35 47	5	65	0	Mvc-065f.jpg	west	Natural veld: slow change from grassland to more thorn trees
31 44 45	28 36 24	4	66	13	Mvc-066f.jpg	west	Ntambanana: at road crossing
31 44 45	28 36 24	4	67	0	Mvc-067f.jpg	east	Catchment: forested natural veld and sugarcane
31 45 34	28 34 54	5	68	12	Mvc-068f.jpg	up stream	Nseleni river: dry river course
31 45 34	28 34 54	5	69	11	Mvc-069f.jpg	down stream	Nseleni river: dry river course
31 43 47	28 35 52	5	70	10	Mvc-070f.jpg	up stream	River course
31 43 47	28 35 52	5	71	9	Mvc-071f.jpg	down stream	River course
31 43 14	28 34 47	7	72	8	Mvc-072f.jpg	west	Dam
31 43 14	28 34 47	7	73	7	Mvc-073f.jpg	west	Catchment
31 42 40	28 34 02	6	74	6	Mvc-074f.jpg	west	Forested catchment in fore ground, grassland in background
31 40 08	28 33 38	7	75	5	Mvc-075f.jpg	south west	Catchment: grass, palms, newly planted plantation (Gum trees)
31 40 08	28 33 38	7	76	5	Mvc-076f.jpg	south west	Catchment: grass, palms, newly planted plantation (Gum trees)
31 40 08	28 33 38	7	77	4	Mvc-077f.jpg	north east	Catchment: forested, informal living
31 38 12	28 33 30	6	78	3	Mvc-078f.jpg	west	At cross roads, catchment of Mfuli (?) river
31 38 12	28 33 30	6	79	3	Mvc-079f.jpg	west	At cross roads, catchment of Mfuli (?) river
31 38 3	28 32 58	7	80	2	Mvc-080f.jpg	north	Nseleni river catchment
31 38 3	28 32 58	7	81	2	Mvc-081f.jpg	north	Nseleni river catchment
31 38 3	28 32 58	7	83	1	Mvc-083f.jpg	south	Mfuli river catchment (?)
31 38 3	28 32 58	7	84	2	Mvc-084f.jpg	north	Nseleni river catchment
31 38 3	28 32 58	7	85	2	Mvc-085f.jpg	north	Nseleni river catchment
31 38 3	28 32 58	7	86	2	Mvc-086f.jpg	north	Nseleni river catchment
31 40 23	28 33 07	7	87	24	Mvc-087f.jpg	north east	Catchment east of road: forested, catchment west of road: grassland
31 40 47	28 32 43	5	88	23	Mvc-088f.jpg	north west	Nseleni river tributary
31 40 47	28 32 43	5	89	22	Mvc-089f.jpg	north west	Nseleni river tributary
31 40 50	28 32 19	5	90	20	Mvc-090f.jpg	up stream	Nseleni river: dry river course
31 40 50	28 32 19	5	91	19	Mvc-091f.jpg	down stream	Nseleni river: dry river course
31 40 50	28 32 19	5	92	19	Mvc-092f.jpg	down stream	Nseleni river: dry river course
31 41 52	28 27 26	6	93	18	Mvc-093f.jpg	south	Land use in township: bare ground
31 41 52	28 27 26	6	94	18	Mvc-094f.jpg	south	Land use in township: bare ground
31 41 52	28 27 26	6	95	17	Mvc-095f.jpg	south	Land use in township: bare ground
31 39 45	28 34 32	4	96	16	Mvc-096f.jpg	up stream	River valley: rock layers at sides of river valley

31 39 45	28 34 32	4	97	15	Mvc-097f.jpg	down stream	River valley
31 39 45	28 34 32	4	98	16	Mvc-098f.jpg	up stream	River valley
31 39 45	28 34 32	4	99	15	Mvc-099f.jpg	down stream	River valley
31 40 12	28 35 38	5	100	0	Mvc-0100f.jpg	south	Catchment of Nseleni river
31 40 12	28 35 38	5	101	0	Mvc-0101f.jpg	north	Catchment of Nseleni river
31 41 26	28 36 20	6	102	0	Mvc-102f.jpg	south	Catchment: grass and bush
31 41 26	28 36 20	6	104	0	Mvc-104f.jpg	south	Catchment: grass and bush
31 41 26	28 36 20	6	105	0	Mvc-105f.jpg	south	Catchment: grass and bush
31 41 26	28 36 20	6	106	0	Mvc-106f.jpg	south	Catchment: grass and bush
31 41 26	28 36 20	6	107	0	Mvc-107f.jpg	south	Catchment: grass and bush
31 41 26	28 36 20	6	108	0	Mvc-108f.jpg	south	Catchment: grass and bush
31 43 31	28 37 11	5	109	0	Mvc-109f.jpg	north	Afforested catchment
31 43 31	28 37 11	5	110	0	Mvc-110f.jpg	south	Afforested catchment

APPENDIX 2

SATELLITE IMAGE PROCESSING

The satellite images were purchased for the identification of land use data on a smaller scale than the land use data which was available at the time of the study's research. It comprises of seven bands, in raster format, with a pixel resolution of 25 metres by 25 metres. This appendix lists the attributes of the different spectral bands, and provides a theoretical background of the classification methods used during construction of the land use model.

DETAILS OF THE TM SPECTRAL BANDS

THEORETICAL BACKGROUND OF CLASSIFICATION METHODS FOR:

- SUPERVISED CLASSIFICATION METHOD
- UNSUPERVISED CLASSIFICATION METHOD

DETAILS OF THE SATELLITE IMAGE

The seven bands cover the same frame using different filters. Each band promotes information on different features that exhibits reflective properties, listed in Table A2.1.

Table A2.1: Details of the different TM (Thematic Mapper) spectral bands (Source: Lillesand and Kiefer, 1994):

Band	Wave-length	Nominal spectral location	Principle Application
1	0.45-0.52	Blue	Designed for water body penetration, used for: - coastal water mapping - soil/vegetation discrimination, - forest type mapping, - cultural feature identification
2	0.52-0.6	Green	Designed to measure green reflectance peak of vegetation, used for: - vegetation discrimination - vigor assessment - cultural feature identification
3	0.63-0.69	Red	Used for identification of: - plant species (Identifies chlorophyll absorption region) - cultural features
4	0.76-0.9	Near infrared	Used for determination of : - vegetation types - vigor - biomass content - water bodies - soil moisture discrimination
5	1.55-1.75	Mid-infrared	Indicative of: - vegetation moisture content - soil moisture - difference between snow and clouds
6	10.4-12.5	Thermal infrared	Used in: - vegetation stress analysis - soil moisture discrimination - thermal mapping applications (?) - Associated with sensation of heat
7	2.08-2.35	Mid-infrared	Useful for: - discrimination of mineral and rock types - sensitive to vegetation moisture content

THEORETICAL BACKGROUND

Two different land use classification methods were investigated, i.e. a supervised classification method using maximum likelihood techniques and unsupervised classification method using a cluster analysis techniques. The classification methods are described first, followed by a description of the output from the analysis. The description of the theoretical background of the land use classification from satellite imagery were mainly taken from Eastman (1997).

The image frame consists of two original Landsat images, scanned on different dates. The two sides had to be investigated separately as the spectral reflectance of objects varies over time. The satellite image is shown in Figure 4.1 in the main text of the report.

Supervised classification of the satellite image

Supervised classification includes setting up a list of possible land cover classes and digitizing small areas where these land cover classes are known to exist. These known areas are called "training sites." From these training sites a *spectral signature* of each land cover class is identified. The supervised image classification is done by creating the statistical characteristics of each land cover class, or spectral signatures of each class, in each of the seven spectral bands. Each pixel in the image is then classified according to this spectral signatures. Land cover classes and training sites should be chosen with care, as to ensure that the spectral signatures of each class will be different from all other classes. It is also important to obtain training sites for *all* the different land uses.

After classification, there will be a number of pixels which belong to a class that differs from the surrounding pixels. These pixels belong to a class of their own, or have been miss classified. Although it depends on the mapping purposes of the classified land uses, it usually is necessary to have the whole image classified as "smooth" as possible. This is the case when the land uses classification is used for hydrological modelling, where the catchment is divided into hydrologically homogeneous subcatchments. This "smoothed" land use image can be obtained by passing a mode filter over the image. This filter replaces each pixel with the most frequently occurring class within a three by three window surrounding each pixel. This results in a filtering process of isolated classes and unclassified pixels.

The final step in the land use classification is the accuracy assessment. This involves field visits to another set of positions (which differs from the positions of the training sites) to verify the true land cover types. The ground truth information (the positions and the land cover classes) can be fed into a module which compares the true land cover classes with the assessed land cover classes and calculates the errors of omission, errors of commission and overall proportional errors.

Hard and soft classifiers

Several kinds of supervised classification can be done, that include "hard" and "soft" classifiers. Hard classifiers reach a "hard" decision about the class to which each pixel belongs. Soft classifiers do not make a "final" decision about the class that each pixel belongs to, but instead indicate the degree of membership of each pixel to each possible class. Both hard and soft classifiers use training sites for the purpose of classifying each pixel. Hard classifiers produce a single classified land cover map, while the output of soft classifiers is a set of images for each land cover class. Each of these images each indicate the degree to which all pixels belong to this land cover.

Hard classifiers

There are three distinctive classes of hard classifiers. Each makes use of a classification method based on training site information:

1. Classification on the basis of *minimum distance to means*, where each class is characterized by its mean position on each spectral band. Pixels are assigned to the class with the nearest mean spectral position to its own position. By only characterizing each class according to the mean band reflectance, it does not consider that some classes have more variance than other classes, which can lead to miss classification.
2. *Parallelepiped procedure* for classification, where each class are characterized by the range of expected values on each band. This range can be defined by the minimum and maximum values found in the training site data, or (more typically) by some standardized range of deviations from the mean (e.g. +/- 2 standard deviations).

3. *Maximum Likelihood procedure*, which is based on Bayesian probability theory. It uses the mean and variance/covariance data of the signatures to estimate the posterior probability that a pixel belongs to each class. This is the most powerful of the hard classifiers, taking into consideration the internal variance of each class, as well as co-variances with each of the other classes.

Soft classifiers

The three classes of soft classifiers are based on the following methods, which also make use of training sites:

1. Bayesian probability theory, which is an extension of the Maximum Likelihood classification procedure,
2. Dempster-Shafer theory, which is a variant of Bayesian probability theory that explicitly recognizes the possibility of ignorance, and
3. Fuzzy set theory and the Minimum distance to Mean classification procedure. IN this method the fuzzy set membership is determined by the distance of pixels from the spectral signature means.

Each of the methods produces a set of images, one for each land cover class, containing the likelihood that each pixel belongs to the land cover class.

After using a soft classifier to identify the image set, the soft results can be used to produce a hard classification. Different methods, to calculate the hard classification, are available for each of the soft classification procedures. In essence each method determines the class of each pixel by extracting the class to which the pixel most likely will belong.

Unsupervised classification of the satellite image

General logic

Unsupervised classification distinguishes between the major land cover classes in the image without prior knowledge of what they might be. These classification techniques fall under *cluster analysis*, as they search for clusters of pixels with the same reflectance characteristics in a multi band image. They generalize the land cover classes, as they are concerned with uncovering the *major* land cover classes and thus tend to ignore the low frequency land cover classes. There are almost as many approaches to clustering as there are image processing systems on the market. The primary unsupervised classification offered in IDRISI for Windows are unique, but it also offers a more common alternative (ISOCLUST).

CLUSTER

The CLUSTER module in IDRISI for Windows implements a special variant of Histogram Peak cluster analysis. The procedure can best be understood from the perspective of a single band. If one had a single band, the histogram of the reflectance values on that band would show a number of peaks and valleys. The peaks represent clusters of more frequent values associated with commonly occurring cover types.

The CLUSTER procedure searches for peaks by looking for cases where the frequency is higher than that of the immediate neighbours on either side. In the case of two bands, these peaks would be hills (two dimensional), and for three bands it would be spheres (three dimensional), etc. The concept can thus be extended to any number of bands. Once the peaks have been identified, each pixel can be assigned to its closest peak, with each such class being labelled as a cluster. It is the analyst's task to identify the land cover class of each cluster by looking at the cluster image and comparing it to ground truth
.features.

CLUSTER in IDRISI for Windows have been modified to work with the special case of three bands as described by a colour composite image. The reason for doing this is based largely on the fact that the procedure involved in creating the colour composite image is essentially the same as the first stage of multidimensional histogram generation in the clustering algorithm. Speed is greatly enhanced by not repeating this histogram generation step. If more than three bands of spectral data are available, Principal Component Analysis can assist in identifying the three bands with the most dominant contribution to the variation in the spectral reflectance. These are usually the red and near-infrared bands, along with a middle-infrared band.

APPENDIX 3

HYMAS VARIABLES AND VTI PARAMETERS

HYMAS was chosen as the basic modelling system for simulating surface run-off from the Mhlathuze River catchment. The VTI model in HYMAS was configured for the Mhlathuze and main tributaries during this project. This appendix describes the methods used in estimating the parameter values of the model for the Mhlathuze River catchment. The main attributes presented are :

- HYMAS PHYSIOGRAPHIC VARIABLES:
  - DESCRIPTIONS AND ESTIMATION METHODS
- VTI PARAMETERS
  - DESCRIPTIONS AND ESTIMATION METHODS

HYMAS PHYSIOGRAPHIC VARIABLES

In order to simulate the run-off from the HYMAS platform, the user needs to estimate 90 different physiographic variables for each subarea, from which the parameters of the different hydrological models in HYMAS are calculated. Some of these physiographic variables are also calculated from other variables, while many of the VTI parameters are also calculated from these parameters.

Some of the variables and parameters which need to be quantified do not have a clear description in the HYMAS manual (Hughes, 1994) and consequently a brief descriptions of the estimation methods for only these variables are presented in this appendix. The reader is referred to the HYMAS manual (Hughes, 1994) for a full description of the model and all the parameters and variables. The number code for each variable and parameter, as indicated follows the same notation as the manual.

Physiographical variables:

GIS parameters:

#1. The subarea number.

#2. The downstream subarea number.

#3. The catchment areas were determined in Arcview to the nearest km^2, from the 1:50 000 maps in the IB.

#5. Drainage density was determined from the lengths of all the rivers divided by the area of each subarea. The lengths of all available rivers, including the ones that are classified as non-perennial on the 1: 50 000 maps were taken into consideration.

#6. The Shreve Channel order was estimated for all rivers in each subarea, as indicated on the 1:50 000 topographical maps.

#7. The distance to the subarea outlet was derived along the main river bed from the middle of the subarea.

#8. The channel slope was determined from the change in elevation between the subarea centre and the catchment outlet, divided by the length of the river reach between these two points expressed as a percentage.

#12. The maximum dam storage (in m^3*1000) was estimated from the total area of all dams in each subarea by assuming an average depth of one metre.

#14 and #15. The A and B parameters in the area-volume relationship were estimated from the only available data at the Hilltop Balancing Dam. This dam is part of the Heatonville Irrigation Scheme. The derived values of A = 0.1, B = 1.1 were assumed for all subareas.

Channel characteristics:

These parameters are used to estimate the translation of water through the catchment. The values were estimated from field observations and photographs of river channels. All of these parameters are indexed so that they need to be given a value between zero and two.

#16. An index of the *structures in channels* where a value close to 2 indicates a fair amount of stones and boulders in the river reaches.

#17: An index of the *in-channel vegetation* where increasing amount of reeds, grass and trees will result in a value closer to 2.

#18: An index of the *cross section variation*: Variation in the shape of the cross section will need a value closer to 2.

#19: An index of the *degree of meandering*. . This was numerically calculated, by taking the length of the river divided by distance from the top end of the catchment to the bottom end. This calculation generally ranged between 1 and 3, and was re-scaled toa a value between 0 to 2.

#20. An index of the *channel grade* which describes the general channel characteristics which have not been taken into account in variables #16, #17, #18 and #19. A value close to 2 will indicate more roughness than a value closer to 0. This variable does not have a major impact (Smakhtin, 1997). A value of 1 was assumed for all subareas.

Soil characteristics:

The main source of soil data in the Mhlathuze catchment is the Land Types map of Richards Bay (2830) from a scale of 1:250 000. The soil types were derived from the main occurrence in each subarea.

Soil Types

The representative soil types were identified for each subarea and the parameters were derived on an area-weighted basis.

Soil Series

Each soil type consists of several soil series (in the study area up to 20 different soil series can be found in one soil type). Only the boundaries of the soil types (and not the boundaries of the soil series) are indicated on the 1:50 000 map. Between 1 and 5 representative soil series were selected for each soil type. These choices were based on the percentage area of each soil series in the soil type, and the occurrence of soil series on the terrain form. Soil series on the midslopes were mostly used. In some cases the soil type occurs mainly along the distinct catchment boundaries, in which case the soil series along the hill tops were selected. In other cases the soil type occurs mainly on the flood plains, where foot slope soil types were considered. The information for these selected soil series were listed for each soil type in each subarea. The soil depths and soil classification (variables #32 to #36) for each subarea were derived from this data.

Soil Profiles

Soil profiles that were dug in the region were used to estimate the macropore development, organic content, structural development and sand grade. Soil profiles located inside the subarea as well as soil profiles from other subareas, but from similar soil types, were considered. Two subareas did not have any soil profiles so estimates for these subareas were made from similar soil types in nearby subareas.

Estimates of parameters were also done on an area-weighted basis which takes the area of each soil series in the soil type into account. In the real world the boundaries of soil types do not overlap perfectly with subarea boundaries. When calculating area-weighted means of variables from each soil series in the soil type, the calculations did not consider the fact that some soil series could have been found on an area outside the subarea boundary. No information is available on the occurrence of soil series within each soil type, and this approximation had to be accepted.

Variables #22 to #26 defines the likely distribution of soil depths within a catchment, and are used to calculate #27, #28 and #94 (Hughes, 1994). The soil depths of soil series occurring in the catchment were used to estimate variables #22 to #26.

#29. The valley side mean soil depth were estimated by using the soil depth of the soil series with the biggest percentage area occurring on the valley sides of the rivers.

#30. The valley bottom soil depth were estimated by using the soil depth of the soil series with the biggest percentage area occurring on the valley bottom of a river, but not in the stream bed.

Variables #32 to #36 are used to calculate the hydraulic conductivity of the soil, which is a measurement of how fast the water moves through the soils. Variables #37 to #40 are used to correct the hydraulic conductivity to a minor extent.

#37. Macropore development (as defined for the estimation of this variable) are the pores in the soils, large enough to let water through the soil under gravity. This includes cracks in the soil, spaces left by movement of worms through the soil, spaces between larger stones, etc. In a forested area, the macropore development is expected to be higher than in a patch of grassland, because the biological life is promoted in the dense trees and ground cover (Smakhtin, 1997). This index ranges between zero and 2 where a close to 2 will indicate a better macropore development.

An estimation of the macropore development of each soil type was done from three different variables quantified for each soil profile: the soil texture, the soil structure and the soil grade. Different soil texture descriptions were assigned different macropore development values as shown in Table A3.1. The descriptions of profiles dug in the region were used to assign initial values to this parameter, but these initial values were adjusted to incorporate other factors: Factors taken into consideration with the estimation of macropore development were slopes (steep slopes will indicate a shallow soil with few macropores), soil types and depths, land use and agricultural practices.

Table A3.1: Soil texture descriptions and associated estimation of macropore development in the soil:

Soil texture description	Macropore development estimation
Many pores	1.8 (high macropore development)
Course triangular blocky	1.7
subangular blocky	1.5
weak medium subangular blocky	1.2
few pores	1
slightly firm	0.8
firm	0.5
massive	0.2 (low macropore development)

#38. An index of Organic content with a value between zero and 2, which specifies the amount of organic material in the soil. A value close to 2 indicates more organic content. An estimate for the organic content of the soil profiles were adjusted to estimate this index.

#39. Structural development a subjective index between zero and 2 where a better differentiated soil horizon indicates a better structural development of the soil, and will result in a value closer to 2. The structural development was estimated from the descriptions of the transition between the A and B horizons, as indicated in Table A3.2.

Table A3.2: Soil horizon description with associated estimation of structural development in the soil:

Description	Value
Abrupt smooth transition	1.8
clear smooth transition	1.5
gradual smooth transition	1.0
clear wavy transition	0.75
tonging transition	0.5
gradual wavy transition	0.3

#40. Sand grade: (An index between zero and 2). A courser sand in the soil structure will result in a larger value for the parameter (closer to 2), which in turn will raise the hydraulic conductivity. The estimates of the sand grade of the soil profiles (percentage course, medium and fine sand) were used to estimate the sand grade of each subarea on an area weighted basis.

Ground cover characteristic:

#41 to #45 are indexes between zero and 2 that describe the ground cover. Together they effects the runoff by up to about 4% (Smakhtin, 1997) and consequently, they were set to the mid-range value of one for all subareas and throughout all simulations. Some of these values were slightly changed during the calibration process.

#41 and #42. Surface compaction affects the infiltration rate of water into the soil (± 2-3 %). The winter compaction might be larger than the summer compaction due to less biological life and vegetation on the surface of the soils.

#43 and #44. Surface organic: The amount of litter and leaves on the ground. The number of dead leaves on the ground might increase during the drier winter months.

#45. Surface roughness: An overall indication of surface roughness which was not included in the surface compaction and organic.

Channel characteristics:

#58 and #59. Mean total flow width and Manning's n: Measurements of these variables was be done without taking the flood plain into account, and only for the main stream channel of the subareas. Estimates were done from photographs of the river beds taken in each of the different subareas. Values for Manning's n were estimated from Linsley and Franzini (1979).

Groundwater characteristic:

#60. The storativity indicates the amount of water stored in the aquifer and is assumed to be the same as the soil's porosity. This parameter was normally set between 0.001 or 0.002.

#61. The depth to the aquifer (in metres) was estimated by taking the mean of all measured borehole water depths in each subarea. The simulation period (from October 1982 to September 1992) overlap with the dates over which the water level measurements were taken.

#62. The aquifer transmissivity were adapted from values estimated for similar parameters during geohydrological studies by Kelbe and Germishuyse (1998).

Vegetation and Cover:

#64 to #73 are used to quantify the land use. Satellite imagery of the catchment were investigated to estimate these parameters (refer to Chapter 4).

General variables:

#78 to #85 are all redundant. All these variables should be set to 1 for all subareas to assure the smooth running of the model.

#86, #87 and #88 (coefficient A and B in the evaporation/rain relationship: Evap = Evap*A/Rain^B) are only used when modelling on a very detailed level to indicate less evaporation during rainy days than during hot summer days. The Mhlathuze catchment study assumed the default values of no change in evaporation due to rain.

#89 and #90. Summer and winter rain intensity distribution factor: The recommendation of the developers was to use a value of 8 hours to simulate the thunder storms which occurs in the Zululand area during summer. A value of 12 hours was recommended to simulate the more gently and evenly spread winter rains on rainy days. This recommendation from the developers was compared to hourly rainfall measured at the University of Zululand, for the 9 years 1988 to 1996. This investigation showed that the average number of hours that rain occurred on rainy days, during the summer months (Oct. - March) was 2 hours, and for the winter months (April to September) was 3 - 4 (3.5) hours. Considering only the big rain events (more than 10 mm per hour) gives the same results as when considering all rainfall events, from minimal rain (any amount of rain more than 0.1 mm per hour). During the calibration process, the initial estimates were adjusted to values of 4 and 6 hours for summer and winter rainfall respectively.

VTI PARAMETERS

Most of the VTI model's parameters are calculated from the physiographical variables defined in HYMAS. However, the calculated values of the parameters should always be checked for consistency. This section presents a discussion of the VTI parameters which are not calculated from other parameters. However, a description of some of the calculated parameters were added after a discussion with the developers, where these descriptions were unclear in the manual. Also refer to Appendix 4, which lists the calibrated values of the VTI parameters, indicating the parameters which are **not** calculated in **bold**.

The water usage demand must be specified for the different water components such as the river, the dams and the groundwater resources. The demands from dams are used to simulate irrigation. In catchments with informal subsistence farming an assumption was made that about 1% of a dam's capacity are used daily for irrigation and household demands. Monthly weighting factors were used to distribute the daily demand throughout the seasons. During the simulations, the daily rainfall are considered before any abstraction from the dams for irrigation purposes.

The evapotranspiration crop factors (#8 and #9) could not be established from the literature, as most definitions of crop factors in the literature differ from the evapotranspiration crop factor defined for the VTI simulations. Afforested subareas were assumed to have an evapotranspiration parameter value of 1.4 (Smakhtin, 1997).

The texture distribution factor (#32) is an important and sensitive parameter, and is normally set to 0.9, but can vary between 0.7 (a very low value) and 1 (a very high value). Initially the default of 0.9 was used for all subareas.

The planar slope (# 33) (indicated in Figure A3.1) is calculated from the catchment area, drainage density and catchment slope. This slope is used in calculating the groundwater movement. See Figure A3.1 and Figure A3.2. It indicates the percentage of the catchment where water can pass from the surface water component to the groundwater component.

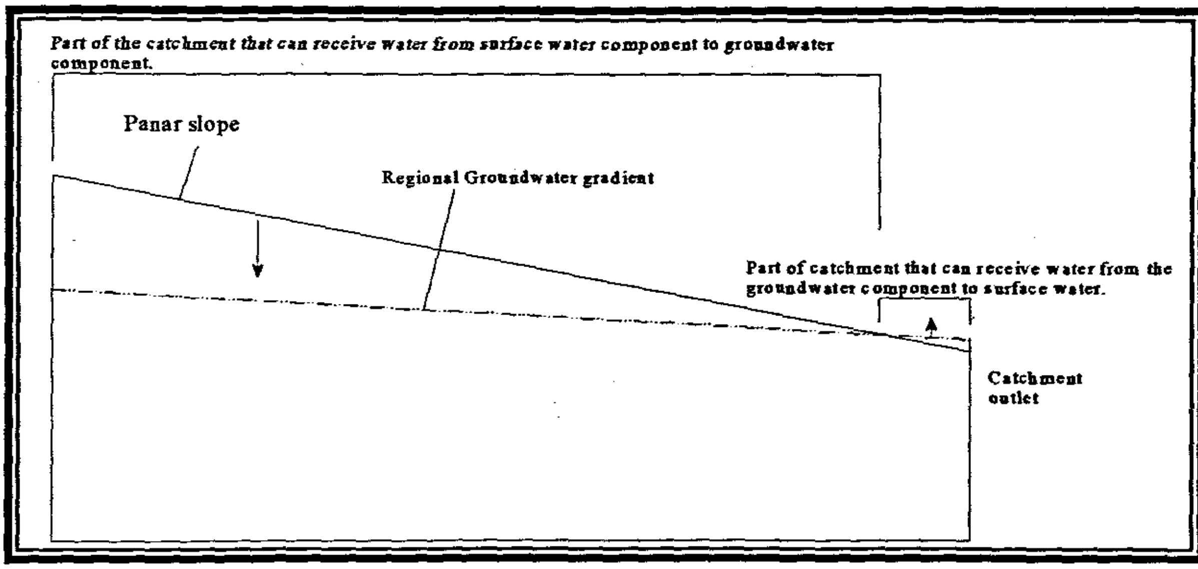

Figure A3.1 "Diagram showing relation between planar slope and regional groundwater gradient.

The value of the maximum depression storage (specified in mm) (#38) is normally set to 0.01 mm for all subareas, otherwise all flow might be held back in the river via this parameter. This is a very sensitive parameter.

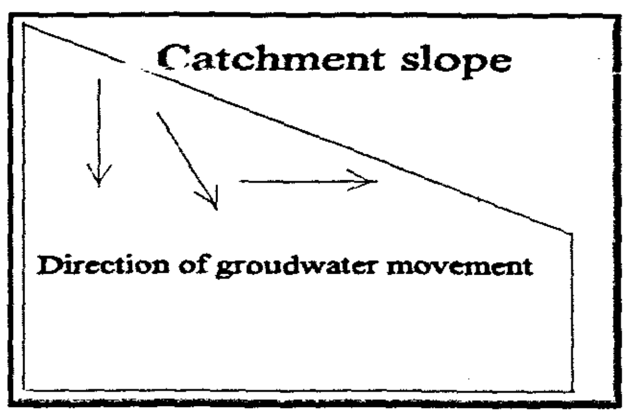

Figure A3.2: Direction of groundwater movement in relation to catchment slope.

The groundwater distribution vector parameters (#44 and #45) are used to route the groundwater according to the length of catchment borders where catchments neighbour each other. Groundwater can also be routed out of the system over the catchment boundaries, but this is not recommended, unless the strategic positions of faults clearly indicate this.

The groundwater drain vector (#46) (indicated in Figure A3.3) describes the direction into which the groundwater percolates (see Figure A3.2 and A3.3) and controls the component of the water which leaves the surface water and percolates down towards the groundwater component. A direction of zero (indicating horizontal flow) will result in springs, where the subsurface water becomes part of the surface flow (Figure A3.3). This is called springflow. A smaller flow direction than the catchment slope will thus result in the possibility of springs. If no springs occur in the subarea, the groundwater drain vector should be larger than the catchment slope. Specifying a groundwater drain vector slightly larger than the catchment slope (with very little difference between the two values) causes the subsurface water to take more time to percolate from the surface to the groundwater.

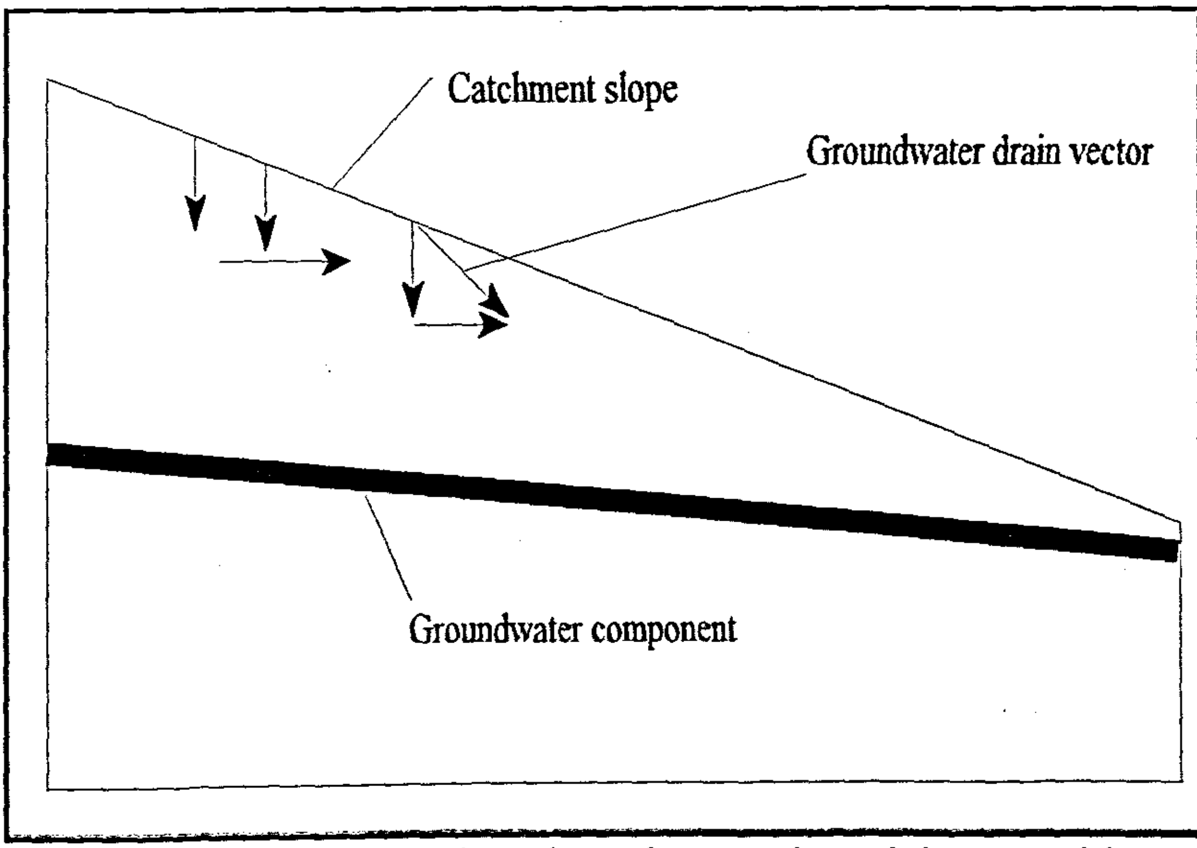

Figure A3.3: The relation between the catchment slope groundwater drain vector and the position of the groundwater component.

The maximum regional groundwater slope (#47) (see Figure A3.1) indicates the slope of the groundwater if no subsurface water is put into the groundwater, i.e. the rest water level slope. If the maximum regional groundwater slope (#47) has a value less than the groundwater drain vector (#46) (see Figure A3.3), i.e. the slope of rest water level of groundwater is less than the slope of general groundwater level, there will be a possibility for groundwater to seep through towards the surface of the subarea, and might be used by the vegetation of the subarea, or result in springs.

The maximum regional groundwater slope (#47) should always be slightly less than the planar slope (#33) for the surface water to drain through to the groundwater. If the planar slope and the maximum regional groundwater slope are very close to each other, it will result in a more responsive groundwater component (a more rapid rise and fall in the groundwater during a rainfall event). Figure A3.1 illustrates this.

Note 1: The difference between springflow and the water emerging from groundwater component to surface water component can be described as follows: when the water from the surface component seeps through the soil layers, it might happen that it can move along horizontal cracks or faults in the soil before it reaches the groundwater component. This water will then seep back to the surface water component as springflow.

Note 2: When negative groundwater depths are encountered during model simulations, it does not necessarily indicate groundwater that rises above the surface. In the VTI simulations it simply indicates the way that the groundwater gradient is calculated and functions.

The maximum depth to aquifer (#50) (specified in metres) and the initial depth to the aquifer (#53) refers to the groundwater level at the subarea outlet. See Figure A3.4. The maximum depth is the depth to the rest water level of the aquifer at the subarea outlet. It can be given a negative value if the groundwater level *in the simulations* generally remains above the ground and it is deemed necessary to allow the hydraulic gradient to increase as the groundwater level increase. This parameter was determined by considering the water levels measured at boreholes situated nearest to the catchment outlet of each subarea. Very few boreholes near catchment outlets with water level measurements were available. No negative values were specified initially, but due to negative groundwater depths found in the simulations (see *note 2* above), negative values were assigned to this parameter for some subareas.

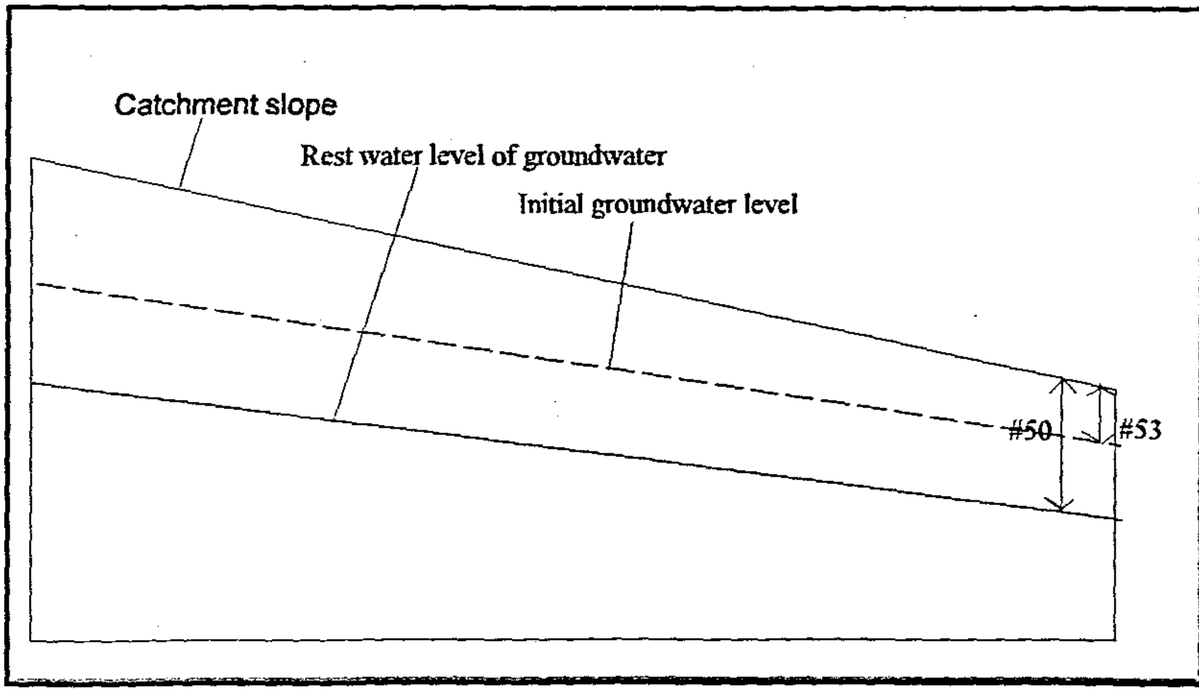

Figure A3.4. Relationship between catchment slope, rest water level and initial groundwater level, as well as parameter #50 and #53.

The initial depth to groundwater (#53) indicates the initial groundwater level, and refers to the groundwater level at the subarea outflow. This parameter only plays a roll during the initial time steps of the simulations. The value must be smaller than the value specified for parameter #50 (which is the rest water depth of groundwater at the catchment outlet). A negative value indicates that groundwater will initially contribute to the surface flow.

APPENDIX 4

ESTIMATED VALUES FOR THE VTI PARAMETERS

The VTI parameter values are estimated in HYMAS from the given physiographical variables, and adjusted during the calibration process. The final calibrated VTI parameters for the Goedertrouw, Mfuli, Nkwaleni and Richards Bay projects after consultations with prof. Denis Hughes, Institute for Water Research are listed here for the Mfuli, Nkwaleni and Richards Bay projects. The parameters for the Goedertrouw Dam and the Nsezi projects are listed for both the original calculations in HYMAS from the estimated variables of the catchments, as well as the calibrated parameters.

Values of parameters are for the present day conditions. The set of parameters for the virgin conditions of the catchment eliminates the simulation of the man made structures (i.e. the farm dams) and the demands on the water resources. The names of the variables that are indicated in **BOLD** are the parameters that are not calculated by HYMAS and needs to be estimated by the user. A description of the parameters and the estimation methods are given in Appendix 3.

ESTIMATED VALUES OF PARAMETERS: Mfuli project

nr	The VTI parameters: Mfuli	C1	C2	C3	C4	DC5
01	Downstream area number	3	3	4	5	0
02	Sub area [km^2]	226	42	127	173	92
03	Sub area shape (L/W ratio)	1	1.5	2	0.8	0.6
04	Mean sub area slope [%]	0.1	0.1	0.1	0.1	0.06
05	A in evaporation reduction factor	1	1	1	1	1
06	Summer B in evap. reduction factor	0	0	0	0	0
07	Winter B in evap. reduction factor	0	0	0	0	0
08	**Evapotranspiration cropfactor (summer)**	1.3	1.1	0.9	0.9	1
09	**Evapotranspiration cropfactor (winter)**	1.3	1.1	0.9	0.9	1
10	Summer proportion vegetation cover	0.67	0.67	0.4	0.4	0.456
11	Winter proportion vegetation cover	0.67	0.67	0.4	0.4	0.456
12	Summer LAI	2.9	2.9	1.45	1.45	1.8
13	Winter LAI	2.9	2.9	1.45	1.45	1.8
14	Summer canopy capacity [mm]	1.119	1.119	1.413	1.413	0.533
15	Winter canopy capacity [mm]	1.119	1.119	1.413	1.413	0.533
16	Summer storm duration factor [hr]	4	4	4	4	4
17	Winter storm duration factor [hr]	8	8	8	8	8
18	Intensity runoff parameters (summer)	0	0	0	0	0
19	Intensity runoff parameter (winter)	0	0	0	0	0
20	Summer infil. curve K	0.598	0.598	0.598	0.598	0.598
21	Winter infil. curve K	0.598	0.598	0.598	0.598	0.598
22	Infil. curve K variability	0.009	0.009	0.009	0.009	0.009
23	Summer infil. curve C	158.112	158.112	158.112	158.112	158.112
24	Winter infil. curve C	158.112	158.112	158.112	158.112	158.112
25	Infil. curve C variability	101.97	101.97	101.97	101.97	101.97
26	Upper soil store [mm]	66.3	66.3	66.3	66.3	66.3
27	Lower soil store [mm]	302.77	302.77	302.77	402.22	402.22
28	FC/porosity ratio	0.611	0.611	0.611	0.611	0.611
29	Slope/bottom soil depth ratio	0.714	0.714	0.714	0.714	0.714
30	Mean soil hydraulic conductivity [mm/hr]	14.417	14.417	14.417	14.417	14.417

nr	The VTI parameters: Mfuli	C1	C2	C3	C4	DC5
31	Mean aquifer hydraulic conductivity [mm/hr]	0.08	0.08	0.08	0.08	0.08
32	**Texture distribution factor**	0.8	0.8	0.8	0.8	0.8
33	Effective planar slope	0.041	0.054	0.041	0.035	0.026
34	**Direct demand from river [Ml/day]**	0	0	0	10	16.6
35	Runoff curve lambda (summer)	0	0	0	0	0
36	Runoff curve lambda (winter)	0	0	0	0	0
37	SD of the moisture content distribution	0.141	0.141	0.141	0.125	0.125
38	**Maximum depression storage [mm]**	.01	.01	.01	.01	.01
39	Maximum dam storage [m^3*1000]	52	3	0	0	10
40	Catchment above dams [%]	0.07	0.08	0	0	0.001
41	A in area-volume relationship	0.1	0.1	0	0	0.1
42	B in area-volume relationship	1.1	1.1	0	0	1.1
43	**Demand from dams [Ml/day]**	0	0	0	0	0
44	**1st Groundwater distribution vector**	3.8	3.8	4.5	5.5	0.5
45	**2nd Groundwater distribution vector**	3.5	4.2	4.5	5.5	0.5
46	**Groundwater drain vector (fract.)**	50	50	50	50	50
47	**Maximum regional groundwater slope (fract.)**	0.039	0.052	0.039	0.033	0.024
48	Aquifer storativity	0.005	0.005	0.005	0.005	0.005
49	Aquifer transmissivity [m^2/day]	20	20	20	20	20
50	**Maximum depth to aquifer [m]**	10	10	10	10	10
51	**Groundwater demand [Ml/day]**	0	0	0	0	0
52	**Initial percolation store (fract.)**	0.1	0.1	0.1	0.1	0.1
53	**Initial depth to groundwater [m]**	**1**	**1**	**1**	**1**	**1**
54	Sub area routing K (summer)	5.277	2.402	3.587	4.631	4.651
55	Sub area routing K (winter)	4.991	2.228	3.587	4.623	4.601
56	Sub area routing n	0.7	0.7	0.7	0.7	0.7
57	**Channel loss parameter (power)**	.8	.8	.8	.8	.8
58	Flow infiltration area [km^2]	0.68	0.055	0.75	0.6	0.24
59	Mannings 'n'/√slope	0.38	0.32	0.32	0.43	0.55
60	Channel infiltration curve K	0.627	0.627	0.627	0.627	0.627

nr	The VTI parameters: Mfuli	C1	C2	C3	C4	DC5
61	Channel infiltration curve C	185.602	185.602	185.602	185.602	185.602
62	**Channel infiltration, storage power**	2	2	2	2	2
63	Channel routing delay	14.528	4.704	4.994	4.053	1.182
64	Channel routing K	0	0	0	0	0

ESTIMATED VALUES OF PARAMETERS: Nkwaleni project

nr	The VTI parameters: Nkwaleni	D1	D2	D3	E4	E5
01	Downstream area number	3	1	5	5	0
02	Sub area [km^2]	206	70	200	175	74
03	Sub area shape (L/W ratio)	1.5	1	0.8	2.5	1.6
04	Mean sub area slope [%]	0.051	0.079	0.02	0.078	0.05
05	A in evaporation reduction factor	1	1	1	1	1
06	Summer B in evap. reduction factor	0	0	0	0	0
07	Winter B in evap. reduction factor	0	0	0	0	0
08	**Evapotranspiration cropfactor (summer)**	1	1	1	1	1
09	**Evapotranspiration cropfactor (winter)**	1	1	1	1	1
10	Summer proportion vegetation cover	0.575	0.464	0.519	0.575	0.575
11	Winter proportion vegetation cover	0.575	0.464	0.519	0.575	0.575
12	Summer LAI	2.375	1.75	2.075	2.425	2.425
13	Winter LAI	2.375	1.75	2.075	2.425	2.425
14	Summer canopy capacity [mm]	0.839	0.522	0.688	0.839	0.839
15	Winter canopy capacity [mm]	0.839	0.522	0.688	0.839	0.839
16	Summer storm duration factor [hr]	4	4	4	4	4
17	Winter storm duration factor [hr]	6	6	6	6	6
18	Intensity runoff parameters (summer)	0	0	0	0	0
19	Intensity runoff parameter (winter)	0	0	0	0	0
20	Summer infil. curve K	0.573	0.573	0.573	0.573	0.573
21	Winter infil. curve K	0.573	0.573	0.573	0.573	0.573
22	Infil. curve K variability	0.007	0.007	0.007	0.007	0.007
23	Summer infil. curve C	148.512	148.512	148.512	148.512	148.512
24	Winter infil. curve C	148.512	148.512	148.512	148.512	148.512
25	Infil. curve C variability	100.98	100.98	100.98	100.98	100.98

nr	The VTI parameters: Nkwaleni	D1	D2	D3	E4	E5
26	Upper soil store [mm]	66.675	66.675	66.675	66.675	66.675
27	Lower soil store [mm]	302.26	244.475	302.26	288.925	335.598
28	FC/porosity ratio	0.643	0.643	0.643	0.643	0.643
29	Slope/bottom soil depth ratio	0.769	0.769	0.769	0.769	0.769
30	Mean soil hydraulic conductivity [mm/hr]	12.224	12.224	12.224	12.224	12.224
31	Mean aquifer hydraulic conductivity [mm/hr]	0.08	0.08	0.08	0.08	0.08
32	**Texture distribution factor**	0.85	0.85	0.85	0.85	0.85
33	Effective planar slope	0.021	0.035	0.008	0.035	0.028
34	**Direct demand from river [Ml/day]**	120	0	0	30	0
35	Runoff curve lambda (summer)	0	0	0	0	0
36	Runoff curve lambda (winter)	0	0	0	0	0
37	SD of the moisture content distribution	0.154	0.17	0.154	0.016	0.149
38	**Maximum depression storage [mm]**	0.01	0.01	0.01	0.01	0.01
39	Maximum dam storage [m^3*1000]	567	0	511	57.7	0
40	Catchment above dams [%]	0.35	0	0.1	0.025	0
41	A in area-volume relationship	0.1	0	0.1	0.1	0.1
42	B in area-volume relationship	1.1	0	1.1	1.1	1.1
43	**Demand from dams [Ml/day]**	0	0	0	0	0
44	**1st Groundwater distribution vector**	3.5	1.5	5.5	5.5	0.5
45	**2nd Groundwater distribution vector**	3.5	1.5	5.5	5.5	0.5
46	**Groundwater drain vector (fract.)**	50.09	50.09	50.09	50.09	50.09
47	**Maximum regional groundwater slope (fract.)**	0.016	0.03	0.004	0.03	0.023
48	Aquifer storativity	0.005	0.005	0.005	0.005	0.005
49	Aquifer transmissivity [m^2/day]	25	25	25	25	25
50	**Maximum depth to aquifer [m]**	10	10	10	10	10
51	**Groundwater demand [Ml/day]**	0	0	0	0	0
52	**Initial percolation store (fract.)**	0.1	0.1	0.1	0.1	0.1
53	**Initial depth to groundwater [m]**	**1**	**1**	**1**	**1**	**1**
54	Sub area routing K (summer)	11.873	2.004	10.442	6.71	10.241
55	Sub area routing K (winter)	11.873	2.004	10.442	6.71	10.241

nr	The VTI parameters: Nkwaleni	D1	D2	D3	E4	E5
56	Sub area routing n	0.7	0.7	0.7	0.7	0.7
57	**Channel loss parameter (power)**	.8	.8	.8	.8	.8
58	Flow infiltration area [km^2]	1.735	0.075	0. 76	0.21	0.48
59	Mannings 'n'/√slope	1.1	0.35	0.85	0.7	1.35
60	Channel infiltration curve K	0.584	0.584	0.584	0.584	0.584
61	Channel infiltration curve C	149.877	149.877	149.877	149.877	149.877
62	***Channel infiltration, storage power***	2	2	2	2	2
63	Channel routing delay	17.488	12.619	8.863	11.734	0
64	Channel routing K	0	0	0	0	0

VALUES OF PARAMETERS: Richards Bay project

nr	The VTI parameters: Richards Bay	F1	F2	F3
01	Downstream area number	2	3	0
02	Sub area [km^2]	51	73	70
03	Sub area shape (L/W ratio)	1.5	2.5	2.0
04	Mean sub area slope [%]	0.06	0.035	0.02
05	A in evaporation reduction factor	1	1	1
06	Summer B in evap. reduction factor	0	0	0
07	Winter B in evap. reduction factor	0	0	0
08	**Evapotranspiration cropfactor (summer)**	1	1	1
09	**Evapotranspiration cropfactor (winter)**	1	1	1
10	Summer proportion vegetation cover	0.575	0.558	0.567
11	Winter proportion vegetation cover	0.575	0.558	0.733
12	Summer LAI	2.425	2.375	2.2
13	Winter LAI	2.425	2.375	2.2
14	Summer canopy capacity [mm]	0.839	0.792	0.815
15	Winter canopy capacity [mm]	0.839	0.792	1.348
16	Summer storm duration factor [hr]	3	3	3
17	Winter storm duration factor [hr]	6	6	6
18	Intensity runoff parameters (summer)	0	0	0
19	Intensity runoff parameter (winter)	0	0	0

nr	**The VTI parameters: Richards Bay**	**F1**	**F2**	**F3**
20	Summer infil. curve K	0.675	0.675	0.675
21	Winter infil. curve K	0.675	0.675	0.675
22	Infil. curve K variability	0.011	0.011	0.011
23	Summer infil. curve C	212.063	212.063	212.063
24	Winter infil. curve C	212.063	212.063	212.063
25	Infil. curve C variability	98.719	98.719	98.719
26	Upper soil store [mm]	61.65	61.65	61.65
27	Lower soil store [mm]	308.25	369.9	439.377
28	FC/porosity ratio	0.459	0.459	0.459
29	Slope/bottom soil depth ratio	0.9	0.9	0.9
30	Mean soil hydraulic conductivity [mm/hr]	34.758	34.758	34.758
31	Mean aquifer hydraulic conductivity [mm/hr]	0.12	0.2	0.25
32	**Texture distribution factor**	0.8	0.8	0.8
33	Effective planar slope	0.036	0.021	0.015
34	**Direct demand from river [Ml/day]**	0	21.5	0
35	Runoff curve lambda (summer)	0	0	0
36	Runoff curve lambda (winter)	0	0	0
37	SD of the moisture content distribution	0.15	0.15	0.15
38	**Maximum depression storage [mm]**	0.01	.01	.01
39	Maximum dam storage [m^3*1000]	0	0	0
40	Catchment above dams [%]	0	0	0
41	A in area-volume relationship	0.1	0.1	0.1
42	B in area-volume relationship	1.1	1.1	1.1
43	**Demand from dams [Ml/day]**	0	0	0
44	**1st Groundwater distribution vector**	0.5	0.7	0.5
45	**2nd Groundwater distribution vector**	2.5	3.3	0.5
46	**Groundwater drain vector (fract.)**	90.03	90.03	90.03
47	**Maximum regional groundwater slope (fract.)**	0.03	0.015	0.01
48	Aquifer storativity	0.01	0.01	0.01

nr	**The VTI parameters: Richards Bay**	F1	F2	F3
49	Aquifer transmissivity [m^2/day]	100	100	100
50	**Maximum depth to aquifer [m]**	10	10	10
51	**Groundwater demand [Ml/day]**	0	0	0
52	**Initial percolation store (fract.)**	0.3	0.3	0.3
53	**Initial depth to groundwater [m]**	**1**	**1**	**1**
54	Sub area routing K (summer)	4.843	9.033	22.059
55	Sub area routing K (winter)	4.843	8.813	23.155
56	Sub area routing n	0.7	0.7	0.7
57	**Channel loss parameter (power)**	.8	.8	.8
58	Flow infiltration area [km^2]	0.167	0.475	0.1
59	Mannings 'n'/√slope	0.76	0.862	0.487
60	Channel infiltration curve K	0.652	0.652	0.652
61	Channel infiltration curve C	197.182	197.182	197.182
62	**Channel infiltration, storage power**	2	2	2
63	Channel routing delay	7.387	2.179	0.664
64	Channel routing K	0	0	0

VALUES OF PARAMETERS: Goedertrouw project

nr	The VTI parameter: Goedertrouw	Estimations based on catchment knowledge							Calibrated parameters						
	Subarea number:	A1	A2	B3	B4	B5	B6	B7	A1	A2	B3	B4	B5	B6	B7
1	Downstream subarea number	2	3	7	3	7	7	0	2	3	7	3	7	7	0
	Area (km^2)	309	315	248	29	34	153	193	309	315	248	29	34	153	193
3	Subarea shape (L/W ratio)	2.9	3.4	2	3.8	12.9	2.8	0.5	2	1.5	0.8	1.5	1.5	2	0.8
4	Mean subarea slope (%)	0.038	0.025	0.08	0.061	0.044	0.091	0.099	0.05	0.06	0.12	0.08	0.05	0.1	0.1
5	A in evaporation reduction ratio (A/rain^B)	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	B in evap reduction ratio (A/rain^B): summer	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	B in evap reduction ratio (A/rain^B): winter	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	**Evapotranspiration cropfactor (summer)**	1.3	1.4	1.3	1.5	1.5	1.3	1.3	1	1.1	1	1.2	1.2	1	1
9	**Evapotranspiration cropfactor (winter)**	1	1.3	1	1.5	1.5	1	1	1	1.1	1	1.2	1.2	1	1
10	Proportion veg. cover: summer	0.436	0.436	0.436	0.547	0.547	0.436	0.528	0.542	0.542	0.542	0.611	0.611	0.514	0.611
11	Proportion veg. cover: winter	0.408	0.408	0.408	0.539	0.539	0.408	0.528	0.542	0.542	0.542	0.611	0.611	0.514	0.611
12	Leaf area index: summer	1.55	1.55	1.55	2.275	2.275	1.55	2.1	2.125	2.125	2.125	2.575	2.575	1.975	2.55
13	Leaf area index: winter	1.45	1.45	1.45	2.25	2.25	1.45	2.1	2.125	2.125	2.125	2.575	2.575	1.975	2.55
14	Canopy capacity: summer (mm)	0.489	0.489	0.489	0.761	0.761	0.489	0.71	0.746	0.746	0.746	0.944	0.944	0.674	0.944
15	Canopy capacity: winter (mm)	0.43	0.43	0.43	0.739	0.739	0.43	0.71	0.746	0.746	0.746	0.944	0.944	0.674	0.944
16	Storm duration factor : summer (hrs)	2	2	2	2	2	2	2	4	4	4	4	4	4	4
17	Storm duration factor: winter (hrs)	4	4	4	4	4	4	4	6	6	6	6	6	6	6
18	Not used								-	-	-	-	-	-	-
19	Not used								-	-	-	-	-	-	-
20	Infiltration curve K: summer	0.612	0.651	0.614	0.613	0.645	0.61	0.696	0.576	0.576	0.576	0.576	0.576	0.576	0.576
21	Infiltration curve K: Winter	0.59	0.609	0.592	0.591	0.621	0.588	0.671	0.576	0.576	0.576	0.576	0.576	0.576	0.576
22	Infiltration curve K variability	0.009	0.009	0.008	0.009	0.013	0.007	0.013	0.007	0.007	0.007	0.007	0.007	0.007	0.007

23	Infiltration curve C: summer	151.575	161.078	160.078	159.059	184.008	158.139	207.456	148.921	148.921	148.921	148.921	148.921	148.921	148.921
24	Infiltration curve C: Winter	148.755	158.517	157.114	156.155	180.63	135.595	203.658	148.921	148.921	148.921	148.921	148.921	148.921	148.921
25	Infiltration curve C variability	93.378	109.089	96.947	101.479	100.766	85.928	102.485	101.475	101.475	101.475	101.475	101.475	101.475	101.475
26	Upper soil store (mm)	65.415	72.495	62.22	63.195	62.212	64.92	60.18	67.8	67.8	67.8	67.8	67.8	67.8	67.8
27	Lower soil store (mm)	194.064	275.481	199.934	244.354	248.85	212.072	140.42	305.1	305.1	305.1	305.1	305.1	305.1	305.1
28	Field Capacity/poricity ratio (soil moisture content)	0.632	0.569	0.642	0.64	0.545	0.684	0.504	0.633	0.633	0.633	0.633	0.633	0.633	0.633
29	Slope/valley soil depth ratio	0.791	0.827	0.642	0.986	1.188	0.811	0.728	0.833	0.833	0.833	0.833	0.833	0.833	0.833
30	Mean soil hydraulic cond. (mm/hrs)	13.13	**33.908**	10.891	10.742	15.571	11.103	**32.538**	14.026	14.026	14.026	14.026	14.026	14.026	14.026
31	Mean aquifer hydraulic cond. (mm/hrs)	0.208	0.139	0.139	0.417	0.417	0.104	0.139	0.08	0.08	0.08	0.08	0.08	0.08	0.08
32	Texture distribution factor	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.085	0.085	0.085	0.085	0.085	0.085	0.085
33	Effective planar slope	0.016	0.01	0.027	0.037	0.026	0.036	0.039	0.021	0.023	0.04	0.049	0.03	0.04	0.039
34	Direct demand from river [Ml/day]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	Not used								0	0	0	0	0	0	0
36	Not used								0	0	0	0	0	0	0
37	Stand Deviation of the moisture content distribution	0.177	0.14	0.144	0.192	0.21	0.197	0.169	0.157	0.157	0.16	0.166	0.166	0.16	0.16
38	**Maximum depression storage [mm]**	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
39	Maximum dam storage [m3*1000]	7	0	0	4	18	0	166	7	0	0	4	18	0	166
40	Catchment above dams [%]	0.01	0	0	0.01	0.03	0	0.01	0.01	0	0	0.01	0.03	0	0.01
41	A in area-volume relationship	0.1	0	0	0.1	0.1	0	0.1	0.1	0	0	0.1	0.1	0	0.1
42	B in area-volume relationship	1.1	0	0	1.1	1.1	0	1.1	1.1	0	0	1.1	1.1	0	1.1
43	Demand from dams [Ml/day]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	**1st Groundwater distribution vector**	1.7	3.7	7.5	3.5	4.3	3.5	0.5	3.8	3.8	6.4	3.5	7.5	7.5	0.5
45	**2nd Groundwater distribution vector**	0.3	0.3	7.5	3.5	7.7	7.5	0.5	0.2	0.2	7.6	3.5	7.5	7.5	0.5
46	Groundwater drain vector (fract.)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.19	0.21	0.39	0.47	0.28	0.38	0.37
47	Maximum regional groundwater slope (fract.)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	50.04	50.04	50.04	50.04	50.04	50.04	50.04
48	Aquifer storativity	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.005

49	Aquifer transmissivity [m2/day]	50	50	50	50	50	50	50	15	15	15	15	15	15	15
50	**Maximum depth to aquifer [m]**	50	100	100	50	50	50	50	10	10	10	10	10	10	10
51	**Groundwater demand [Ml/day]**	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	Initial percolation store (fract.)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	Initial depth to groundwater [m]	1	1	1	1	1	1	1	1	1	1	1	1	1	1
54	Sub area routing K (summer)	7.107	5.364	4.944	2.075	2.554	3.277	5.059	6.575	4.165	4.165	2.449	3.697	3.156	5.228
55	Sub area routing K (winter)	7.017	5.281	4.813	2.061	2.523	3.257	5.059	6.512	4.13	4.639	2.437	3.672	3.144	5.228
56	Sub area routing n	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
57	**Channel loss parameter (power)**	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
58	Flow infiltration area [km2]	0.574	1.11	0.904	0.05	0.1	0.101		0.574	1.11	0.904	0.05	0.1	0.101	0.376
59	Mannings n/ slope	0.469	0.277	0.375	0.206	0.257	0.378	0.444	0.45	0.25	0.35	0.36	0.36	0.35	0.43
60	Channel infiltration curve K	0.612	0.631	0.614	0.613	0.645	0.61	0.696	0.609	0.631	0.614	0.613	0.645	0.61	0.696
61	Channel infiltration curve C	151.575	161.361	160.078	159.059	184.008	138.139	207.456	151.575	161.361	160.078	159.059	184.008	138.139	207.456
62	**Channel infiltration, storage power**	2	2	2	2	2	2	2	2	2	2	2	2	2	2
63	Channel routing delay	11.326	7.761	3.835	4.006	2.527	4.381	1.979	11.326	7.761	3.835	4.006	2.527	4.381	1.979
64	Channel routing K	3.51	3.835	2.972	1.48	2.455	2.703	1.637	0	0	0	0	0	0	0

VALUES OF PARAMETERS: Nseleni project

	The VTI parameters: Nsezi	Estimations based on catchment knowledge									
nr	Subarea number:	G1	G2	G3	G4	H5	H6	H7	H8	H9	H10
1	Downstream subarea number	2	4	4	5	7	7	10	9	10	0
2	Area (Dec.Degrees)	111	106	35	48	72	112	23	52	137	52
2	Area (km^2)	120	115	38	52	77	121	25	56	148	56
3	Subarea shape (L/W ratio)	5.25	3.726	1.044	6.025	2.128	1.986	6.864	4.458	1.09	1.004
4	Mean subarea slope (%)	0.121	0.051	0.078	0.09	0.076	0.078	0.065	0.073	0.009	0.009
5	A in evaporation reduction ratio (A/rain^B)	1	1	1	1	1	1	1	1	1	1
6	B in evap reduction ratio (A/rain^B): summer	0	0	0	0	0	0	0	0	0	0
7	B in evap reduction ratio (A/rain^B): winter	0	0	0	0	0	0	0	0	0	0
8	Evapotranspiration cropfactor (summer)	1.4	1.3	1.5	1.4	1.4	1.4	1.4	1.4	1.5	1.5
9	Evapotranspiration cropfactor (winter)	1.1	1	1.5	1	1	1	1	1	1.5	1.5
10	Proportion veg. cover: summer	0.65	0.622	0.636	0.539	0.497	0.456	0.525	0.622	0.678	0.678
11	Proportion veg. cover: winter	0.503	0.475	0.558	0.503	0.419	0.378	0.447	0.544	0.628	0.628
12	Leaf area index: summer	2.875	2.7	2.775	2.3	2.1	1.8	2.2	2.55	3.1	3.1
13	Leaf area index: winter	2.15	2.1	2.4	2.175	1.725	1.425	1.825	2.175	2.85	2.85
14	Canopy capacity: summer (mm)	1.065	0.978	1.021	0.739	0.632	0.533	0.702	0.978	1.156	1.156
15	Canopy capacity: winter (mm)	0.646	0.578	0.792	0.646	0.453	0.37	0.514	0.754	0.995	0.995
16	Storm duration factor : summer (hrs)	2	2	2	2	2	2	2	2	2	2
17	Storm duration factor: winter (hrs)	4	4	4	4	4	4	4	4	4	4
18	Not used	-	-	-	-	-	-	-	-	-	
19	Not used	-	-	-	-	-	-	-	-	-	
20	Infiltration curve K: summer	0.599	0.577	0.551	0.559	0.577	0.549	0.617	0.609	0.676	0.723
21	Infiltration curve K: Winter	0.605	0.583	0.556	0.564	0.583	0.555	0.623	0.615	0.683	0.73
22	Infiltration curve K variability	0.011	0.009	0.002	0.002	0.003	0.006	0.014	0.008	0.008	0.008
23	Infiltration curve C: summer	166.155	146.397	114.073	123.702	149.718	108.179	180.875	169.664	209.723	239.168
24	Infiltration curve C: Winter	166.95	147.093	114.617	124.269	150.399	108.695	181.737	170.471	210.728	240.305
25	Infiltration curve C variability	97.305	94.208	78.861	81.484	101.985	78.215	100.827	90.026	88.92	90.232

	The VTI parameters: Nsezi	Estimations based on changes to Goedertrouw project									
nr	Subarea number:	G1	G2	G3	G4	H5	H6	H7	H8	H9	H10
1	Downstream subarea number	2	4	4	5	7	7	10	9	10	0
2	Area (Dec.Degrees)	120	115	38	52						
2	Area (km^2)	120	115	38	52	77	121	25	56	148	56
3	Subarea shape (L/W ratio)	2	2	0.75	2	2	0.8	0.8	1	0.6	0.6
4	Mean subarea slope (%)	0.1	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.01	0.01
5	A in evaporation reduction ratio (A/rain^B)	1	1	1	1	1	1	1	1	1	1
6	B in evap reduction ratio (A/rain^B): summer	0	0	0	0	0	0	0	0	0	0
7	B in evap reduction ratio (A/rain^B): winter	0	0	0	0	0	0	0	0	0	0
8	Evapotranspiration cropfactor (summer)	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.2	1.2
9	Evapotranspiration cropfactor (winter)	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.2	1.2
10	Proportion veg. cover: summer	0.75	0.75	0.75	0.5	0.5	0.5	0.5	0.5	0.75	0.75
11	Proportion veg. cover: winter	0.75	0.75	0.75	0.5	0.5	0.5	0.5	0.5	0.75	0.75
12	Leaf area index: summer	2.8	2.8	2.8	2	2	2	2	2	3	3
13	Leaf area index: winter	2.8	2.8	2.8	2	2	2	2	2	3	3
14	Canopy capacity: summer (mm)	1.065	0.978	1.021	0.739	0.632	0.533	0.702	0.978	1.156	1.156
15	Canopy capacity: winter (mm)	0.646	0.578	0.792	0.646	0.453	0.37	0.514	0.754	0.995	0.995
16	Storm duration factor : summer (hrs)	4	4	4	4	4	4	4	4	4	4
17	Storm duration factor: winter (hrs)	6	6	6	6	6	6	6	6	6	6
18	Not used	-	-	-	-	-	-	-	-	-	-
19	Not used	-	-	-	-	-	-	-	-	-	-
20	Infiltration curve K: summer	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
21	Infiltration curve K: Winter	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
22	Infiltration curve K variability	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
23	Infiltration curve C: summer	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654
24	Infiltration curve C: Winter	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654	160.7654
25	Infiltration curve C variability	90.2063	90.2063	90.2063	90.2063	90.2063	90.2063	90.2063	90.2063	90.2063	90.2063

26	Upper soil store (mm)	53.488	64.02	65.438	65.55	67.958	68.542	61.837	63.6	65.613	64.502	63.054 8	63.054 8	63.054 8	63.054 8	63.054 8	63.054 8	63.054 8	63.054 8	63.054 8	63.054 8
27	Lower soil store (mm)	112.16 1	113.10 2	115.60 6	135.47	120.05 8	146.2 4	65.548	129.32	489.39	525.40 4	195.22 83	195.22 83	195.22 83	195.22 83	195.22 83	195.22 83	195.22 83	195.22 83	195.22 83	195.22 83
28	Field Capacity/poricity ratio (soil moisture content)	0.58	0.652	0.754	0.733	0.634	0.733	0.537	0.57	0.51	0.41	0.6116	0.6116	0.6116	0.6116	0.6116	0.6116	0.6116	0.6116	0.6116	0.6116
29	Slope/valley soil depth ratio	0.527	0.843	0.857	0.8	0.637	1.009	0.559	0.667	0.51	1.213	0.7622	0.7622	0.7622	0.7622	0.7622	0.7622	0.7622	0.7622	0.7622	0.7622
30	Mean soil hydraulic cond. (mm/hrs)	16.679	11.507	7.17	6.096	14.104	8.74	20.387	19.671	25	25	15.435 4	15.435 4	15.435 4	15.435 4	15.435 4	15.435 4	15.435 4	15.435 4	15.435 4	15.435 4
31	Mean aquifer hydraulic cond. (mm/hrs)	0.139	0.139	0.083	0.069	0.104	0.139	0.139	0.104	0.104	0.208	0.1228	0.1228	0.1228	0.1228	0.1228	0.1228	0.1228	0.1228	0.1228	0.1228
32	Texture distribution factor	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
33	Effective planar slope	0.054	0.24	0.046	0.051	0.042	0.039	0.041	0.042	0.006	0.007	0.054	0.24	0.046	0.051	0.042	0.039	0.041	0.042	0.006	0.007
34	Direct demand from river [Ml/day]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	Not used	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	Not used	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	Stand Deviation of the moisture content distribution	0.198	0.262	0.301	0.282	0.223	0.276	0.201	0.191	0.113	0.099	0.2	0.25	0.3	0.25	0.2	0.25	0.2	0.075	0.01	0.01
38	Maximum depression storage [mm]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
39	Maximum dam storage [m3*1000]	124	428	46	140	198	404	0	217	142	834	124	428	46	140	198	404	0	217	142	834
40	Catchment above dams [%]	0.28	0.45	0.07	0.2	0.12	0.13	0	1	0.25	1	0.28	0.45	0.07	0.2	0.12	0.13	0	1	0.25	1
41	A in area-volume relationship	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
42	B in area-volume relationship	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
43	Demand from dams [Ml/day]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	1st Groundwater distribution vector	2.5	4.5	2.1	5.5	7.7	5.3	10.5	3.2	7.3	10	2.5	4.5	2.1	5.5	7.7	5.3	10.5	3.2	7.3	10
45	2nd Groundwater distribution vector	2.5	4.5	4.9	5.5	9.3	7.7	10.5	9.8	10.7	10	2.5	4.5	4.9	5.5	9.3	7.7	10.5	9.8	10.7	10
46	Groundwater drain vector (fract.)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
47	Maximum regional groundwater slope (fract.)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.001	0.001	50	50	50	50	50	50	50	50	50	50
48	Aquifer storativity	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
49	Aquifer transmissivity [m2/day]	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
50	Maximum depth to aquifer [m]	10	10	10	20	15	15	15	15	15	5	10	10	10	20	15	15	15	15	15	5
51	Groundwater demand [Ml/day]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	Initial percolation store (fract.)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
53	Initial depth to groundwater [m]	10	10	10	10	10	10	10	10	10	5	10	10	10	10	10	10	10	10	10	5
54	Sub area routing K (summer)	3.488	7.16	5.792	4.22	6.34	6.288	8.555	4.923	32.859	27.414	3.488	7.16	5.792	4.22	6.34	6.288	8.555	4.923	20	15
55	Sub area routing K (winter)	3.488	6.84 5	5.656	4.157	6.175	6.133	8.427	4.747	31.659	26.069	3.488	6.845	5.656	4.157	6.175	6.133	8.427	4.747	20	15

56	Sub area routing n	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
57	Channel loss parameter (power)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
58	Flow infiltration area [km2]	0.075	0.062	0.019	0.053	0.051	0.078	0.393	0.032	0.064	0.525	0.075	0.062	0.019	0.053	0.051	0.078	0.393	0.032	0.064	0.525
59	Mannings n/ slope	0.552	1.103	1.494	0.753	1.198	0.975	2.368	0.0805	7.906	1.45	0.552	1.103	1.494	0.753	1.198	0.975	2	0.0805	3	1.45
60	Channel infiltration curve K	0.599	0.577	0.551	0.559	0.577	0.549	0.617	0.609	0.676	0.723	0.599	0.577	0.551	0.559	0.577	0.549	0.617	0.609	0.676	0.723
61	Channel infiltration curve C	166.15 5	146.39 7	114.07 3	123.70 2	149.71 8	108.17 9	180.87 5	169.66 4	209.72 3	239.16 8	166.15 5	146.39 7	114.07 3	123.70 2	149.71 8	108.17 9	180.87 5	169.66 4	209.72 3	239.16 8
62	Channel infiltration, storage power	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
63	Channel routing delay	19.303	21.371	0	0	19.003	0	7.34	10.875	8.371	2.772	19.303	21.371	0	0	19.003	0	7.34	10.875	8.371	1.36
64	Channel routing K	values > 0										0	0	0	0	0	0	0	0	0	0

APPENDIX 5

FLOW MODEL PARAMETER ESTIMATIONS DONE BY RESEARCHERS FROM DIFFERENT BACKGROUNDS

For the surface water simulations of the Goedertrouw Dam catchment, parameter estimations of the HYMAS VTI model were done separately by two different people to assess the level of knowledge and experience need to apply the model:

The *model applier*: the researcher who applied the HYMAS VTI model to the Mhlatuze catchment, and has a good background knowledge of the hydrological characteristics of the catchment. Experience with the model was limited to two weeks in-house training at IWR, where the model was developed.

The *model developer*: the researcher who developed the HYMAS and the VTI model, and thus has a sound knowledge of the model and its application.

The model developer accepted the catchment delineation prepared by the model applier and then adjusted some parameters in the calibration procedure. This section discusses the details of the changes in parameters, and investigate the reasons for the change. A description of the parameters is given in Appendix 3, and the list of parameter values is provided in Appendix 4.

The set of variables and parameters which needs to be estimated for the HYMAS VTI simulation software comprises of the physiographic variables in the main HYMAS component, and the VTI parameters. Only the changes in the VTI parameters are discussed in this section, as these are the parameters used in the VTI simulation runs. In the following discussion of each parameter, those parameters that are calculated from other parameters are indicated by inserting "(calculated)" in the description. IN some cases, these may be changed manually. A description of the difference (if any) between the two sets of parameters, and the possible reasons for the changes made to the estimated values by the model developer, are also provided:

#1: Downstream subarea number: Unchanged.

Some **GIS parameters** were changed as regarded necessary by the model developer. Changes to the GIS parameters lead to different default values for some parameters, e.g. the planar slopes (see parameter #33) which in turn lead to different estimations for some groundwater parameters. (See parameter #47).

#2: Subarea area (km^2): Unchanged.

#3: Subarea shape (Length/width ratio) (Calculated): A value of 12.9 was considered to high and was changed to 1.5 for subarea 5 . All other values were changed to vary between 0 and 3, a range which are not indicated in the manual.

#4: Mean subarea slope (%): (Changed) After the model developer inspected the contours of the catchment, changes was made to the values of some subareas to reflect the high slopes evident in the area.

The **evaporation reduction** factors were left at the default. **Evapotranspiration** factors were changed according to model knowledge.

#5: A in evaporation reduction factor ($A/rain^B$): Default excepted (1).

#6& 7: B in evaporation reduction factor ($A/rain^B$) for summer and winter: Default excepted (0).

#8 & 9: Summer and winter evapotranspiration crop factor: The definition of this crop factor are different to any other crop factor in the literature, and made it's estimation difficult. Values were made proportionally smaller than the values estimated by the model applier. This reduction in values was based purely on prior knowledge of the model.

Parameters related to the **vegetation cover** of the catchment were not changed by the model developer. The calculated values were excepted, as the model developer had no data to verify these values.

#10 & 11: Summer and winter proportion vegetation cover (calculated): Values were not changed.

#12 & 13: Summer and winter leave area index (calculated): Values were not changed.

#14 & 15: Summer and winter canopy capacity (Calculated): Values were not changed.

Storm duration factors: The changes to values are purely based on experience and knowledge of the model.

#16 & 17: Summer and winter storm duration factor (hrs): These values were doubled, although the model applier's estimations were based on hourly rainfall measurements over a 9 year observation period.

#18 & 19: Summer and winter intensity run-off parameter: not used.

Parameters related to the **soil and soil moisture content** are calculated by the VTI model from various physiographic variables. The model applier left the parameter values at the calculated values, as done by HYMAS. The model developer choose a unique value for each of these parameters and assigned this value for the parameter to each of the subareas.

#20 & 21: Summer and winter infiltration curve K (Infiltration rate = K * C * time $^{(K-1)}$) (Calculated): The calculated values (varying around 0.634) were all changed to 0.599.

#22: K variability (Calculated): The calculated values (varying around 0.009) were all fixed to

0.009, for all subareas.

#23 & 24: Summer and winter infiltration curve C (Infiltration rate = K * C * time $^{(K-1)}$) (Calculated): The calculated values (varying around 165.8) were all fixed to 160.27.

#25: C variability (Calculated): The calculated values (varying around 98.58) were all fixed to 110.78, for all subareas.

#26 & 27: Upper and lower soil store (mm): (Calculated): The calculated values for the upper soil store (varying around 64 and 216 respectively) were all changed to 68.325 for all subareas. The lower soil store were changed to 235 (subarea 1 and 2) and 209.35 (subareas 3 to 7).

#28: Field Capacity/Porosity ratio (Calculated):The calculated values (varying around 0.6) were all fixed to 0.599, for all subareas.

#29: Slope/Valley soil depth ratio (Calculated): The calculated values (varying around 0.85) were all fixed to 0.833, for all subareas.

#30: Mean soil hydraulic conductivity (mm/hr) (Calculated): The calculated values varies around 12 for subareas 1, 3, 4, 5 and 6, but have exceptionally high values for subareas 2 and 7 (which values, 34 and 32 respectively). These high values were questioned by the model developer. The parameters were assigned a value of 18.981, for all subareas, which is close to the mean of the original values of the parameter for all 7 subareas.

#31: Mean aquifer hydraulic conductivity (mm/hr) (Calculated): The calculated values (varying around 0.2) were all changed to 0.115, for all subareas.

#32: Texture distribution factor: A default value of 0.9 were assigned to all subareas by the model applier. These were changed to 0.85 for all subareas.

#33: Effective planar slope (calculated): Values were used as calculated by HYMAS VTI model.

However, due to changes made by the model developer to the GIS parameters, the planar slopes used by the developer differ from those used by the model applier.

#34: Direct demand from the river (Ml/day): No demand from the river.

#35 & 36: Summer and winter run-off curve lambda are not used.

#37: Standard deviation of the moisture content distribution (Calculated): The calculated values (varying around 0.17) were all changed to 0.159, for all subareas.

#38: Maximum depression storage (mm): Values were left at the default value of 0.01.

Parameters related to **farm dams** were estimated by the model applier and specified in the physiographic variables file. These estimations were accepted by the model developer.

#39: Maximum dam storage (m^3 * 1000)(Specified in physiographic variables file): Accepted values as estimated.

#40: % catchment area above dams (Specified in physiographic variables file): Unchanged.

#41 & #42: A and B in area-volume relationship (Dam surface = A*Dam volume^B) (Specified in physiographic variables file): Unchanged.

#43: Demand from dams (Ml/day): No major demands from dams.

Groundwater parameters were initially estimated by the model applier from the descriptions in the HYMAS manual, but the full definition of each parameter and the relationships between parameters only became clear to the model applier after a lengthy discussion with the model developer. This discussion was only possible after the model applier had estimated the groundwater parameters. The full descriptions of the groundwater parameters are given (with illustrations) in Appendix 3.

Calculated values of the groundwater parameters are not true reflections of estimations, so that it is necessary to reconsider all calculated parameters when estimating these parameters.

Some groundwater parameters (e.g. the maximum and initial depths to the aquifer and the maximum regional groundwater slope) cannot be estimated on the basis of common concepts, but must be determined on the roll that they play in the functions controlling the simulations. Example: a negative maximum depth to the aquifer will in reality imply submerge creating wetlands. This does not necessarily apply to the simulations in the VTI model. Here a negative maximum groundwater depth controls the way in which the hydraulic gradient is calculated (it increases as the groundwater level rises). This implies that the VTI's simulations of the groundwater levels will generally not be compatible with any observed water levels in the catchment. The groundwater component in the VTI model is there as a tool to manipulate the different water components in the simulations. The surface water component is the major issue which must be simulated "correctly".

#44 & #45: Groundwater distribution vectors: They were assigned some values by the model applier to indicated that groundwater seeps out of the catchment. This was changed by the model developer so that all groundwater would stay inside the catchment. There are no clear evidence that major faults stretch over catchment boundaries which would let major parts of the groundwater component into adjacent catchments.

#46: Groundwater drain vector (Fraction) (Calculated): These values were assigned lower values to confirm with the relationship to catchment slope (which were also changed by the model developer).

#47: Maximum regional groundwater slope (Fraction) : In addition to the parameter description given in the HYMAS manual, these values must be within a range of 0.003 less than the planar slope (see # 33). The reason for this is to make the groundwater become more responsive to a rainfall event (i.e. to have a more rapid rise and fall during a rainfall event). Due to misunderstanding of the parameter's function by the model applier, the values of this parameter was changed from an estimated 0.15 to 50.15 for all subareas.

#48: Aquifer storativity: This parameter needs to be estimated. Initial recommendations from the developers indicated that this parameter should have value of 0.001 or 0.002. The model developer however changed this to 0.005 to decrease the fluctuations in the groundwater levels.

#49: Aquifer transmissivity (m^2/day): This value was decreased from 50 to 10 for all subareas. This leads to less water to be removed from the groundwater component.

#50: Maximum depth to aquifer (m): Initially these values were estimated from borehole water levels in the vicinity of subarea outlets (where available), but values were changed to fit in with the way the functions in the VTI model simulates the different water components. As the groundwater depths tends to stay negative during initial simulations, this value was made negative for some subareas.

#51: Groundwater demand (Ml/day): No demand on groundwater component.

#52: Initial perculation store (fraction):This parameter is "calibrated" after a few runs of the model, and the model developer changed this value accordingly.

#53: Initial depth to the Groundwater (m): This parameter is "calibrated" after a few runs of the model, and the model developer changed this value accordingly.

Parameters related to **channel routing, channel infiltration and channel losses** were left at the default values as calculated by HYMAS. According to the model developer, the channel routing, infiltration and losses should not be regarded as important in the upper reaches of the Mhlatuze river (upstream from the Goedertrouw Dam) due to the soil types found in this region, but should be regarded more important downstream from the Goedertrouw Dam. The catchment upstream from the Goedertrouw Dam comprises of large areas of Dwyka Group and Basement Complex lithology, which are weathered and fractured soil types with relatively low expected borehole yields (DWAF, 1994).

#54 & 55: Summer and winter subarea routing K (Calculated): Routing parameter in the non-linear storage discharge function $S = K.Q^n$. Values used by the model developer are throughout all subareas slightly less than those used by the model applier.

#56 Subarea routing n (Calculated): Used default of 0.7 for all subareas.

#57 Channel losses parameter (Calculated): Used default of 0.8 for all subareas.

#58: Flow infiltration area (km^2) (Calculated): Used calculated values.

#59: Manning n/sqrt(slope) (calculated): Used calculated values.

#60 & 61: Channel infiltration curve K and C (Calculated): Used calculated values.

#62: Channel infiltration - storage power: Used default value of 2.

#63: Channel routing delay (hr) (Calculated): Used calculated values.

#64: Channel routing K (calculated): Used calculated values.

Conclusions:

Catchment characteristics respond to surface water run-off in a complex way. The VTI model tries to simulate this process in a complex way. Many parameters are interdependent and thus some parameters had to be changed by the model developer simply to conform to changes made in other parameters.

In the comparative study, some changes were made due to a misunderstanding of parameters by the model applier. A sound background of the operation of a simulation model is essential for application of a model, in order for the simulation to be regarded as a good reflection of the hydrological processes in the catchment. To apply a hydrological model, it is also necessary to have a sound understanding of the general processes that dominates the behaviour of a catchment's hydrology.

Some of the parameter changes in this project were made due to catchment characteristics which were misjudged by the model applier. These changes will be discussed with the model developers in order to gain a better understanding of the "interpretation" of catchment characteristics by the model to improve its application.

A study on the estimation of parameters should include an analysis of the sensitivity of each parameter. If a change is made in a "sensitive parameter", major changes are reflected in the simulated hydrograph. Changes in each parameter will result in changes to different aspects of the hydrograph. A full description of the sensitivity of parameters should include the kind of change in the simulated hydrograph, or in terms of the interaction between the different water components.

Sensitivity of parameters can change as a water resource simulation package is applied to different river catchments, and it is up to the discretion of the user of a simulation model to find the sensitive parameters for a certain model when applied to a certain catchment.