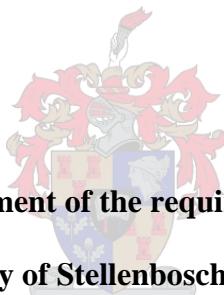


**SPATIAL DECISION SUPPORT SYSTEM FOR HYDROGEOLOGICAL STUDIES
IN TABLE MOUNTAIN GROUP AQUIFERS, WESTERN CAPE PROVINCE,
SOUTH AFRICA**

**ANDISWA MLISA, B.Sc. HONS
STUDENT NUMBER 14254980**



**Thesis presented in partial fulfilment of the requirements for the degree of Master of
Natural Sciences at the University of Stellenbosch**

Supervisor: Mr A. van Niekerk

December 2007

Department of Geology, Geography & Environmental Studies

DECLARATION

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

Signature: _____

Date: _____

Copyright ©2007 Stellenbosch University
All rights reserved

ABSTRACT

The Western Cape province of South Africa is a water scarce area with a Mediterranean climate. The majority of rainfall occurs in the cold winter months and the area experiences hot and dry summers. Studies done to investigate various water supply and water demand management options for the City of Cape Town, concluded that the Table Mountain Group (TMG) aquifer has the potential of yielding high volumes (estimated at 70Mm³/a) of good quality water, but that further research about this source as a potential augmentation supply to the City of Cape Town was necessary before extraction could commence.

The aim of the study is to develop a spatial decision support system (SDSS) to be used by a hydrogeology project team, which includes hydrogeologists, environmentalists, ecologists, engineers and other stakeholders. The Table Mountain Group Aquifer (TMGA) SDSS is meant to be a decision support tool, but should also raise awareness about the use of spatial data and information and its capabilities for earth science and other multidisciplinary applications.

By means of team discussions and interviews data, spatial analysis and data manipulation requirements were determined. Based on these requirements, four spatial analysis tools were developed. The spatial tool named “Borehole Analysis” analyses stratigraphic information obtained from existing boreholes and hydrogeological point data. The tool determines what groundwater use and monitoring has been undertaken in the area of interest. The “Topographic Analysis” tool identifies any topographical (e.g. rivers) and cadastral (e.g. farm boundaries) data within a certain distance from a possible borehole site. The “Sensitive Area Analysis” tool addresses queries with respect to sensitive areas, such as wetlands, statutory protected areas and private nature reserves. The “Image Classification” tool gives the team members an opportunity to use band ratios during image interpretation.

The TMGA SDSS was developed using TNTmips v70, Extensible Markup Language (XML) and Spatial Manipulation Language (SML) and can be run on TNTAtlas v70, which is a free software.

The TMGA SDSS enables the team members to have equal and ready access to data acquired by other members. This was found to support intra- and interdisciplinary conversation and facilitate understanding of how the data is being (or could be) used. It also contributes to

levels of confidence in decision-making and supports a holistic approach to project design and implementation.

Keywords: decision-making, geographic information system (GIS), spatial decision support systems (SDSS), spatial manipulation language (SML)

OPSOMMING

Die Wes-Kaap provinsie van Suid-Afrika is ‘n waterskaars gebied met ‘n Mediterreense klimaat. Reënval vind meestal tydens die koue wintermaande plaas en die gebied ondervind warm droë somermaande. Ondersoeke na verskeie watervoorsienings- en aanvraagbestuursopsies vir die Stad Kaapstad, het bevind dat die Tafelberg Groep (TMG) akwifer die potensiaal het om hoë volumes (beraam op $70\text{Mm}^3/\text{j}$) van hoë gehalte water te lewer, maar dat verdere navorsing oor dié bron as potensiële aanvullings bron vir die Stad Kaapstad nodig is voordat onttrekking kan begin.

Die doel van die studie was om ‘n prototipe Ruimtelike Besluit Ondersteuningsisteem (RBOS) te ontwikkel wat deur die projekspan gebruik kan word. Die projekspan bestaan uit hidrogeoloë, omgewingskundiges, ekoloë, ingenieurs en ander aandeelhouers wat op ‘n hidrogeologieprojek werk. Die RBOS is bedoel om beide as ‘n besluitnemingondersteuningsinstrument en ook as ‘n bewusmakingsinstrument te wees oor die gebruik van ruimtelike data en inligting en sy geskiktheid vir natuurwetenskaplike en multidissiplinêre toepassings.

Die studie het gebruikersvereistes vasgestel d.m.v. groepbesprekings en onderhoude om die data, ruimtelike analise en data transformasie-benodighede van die projek vas te stel. Gebaseer op hierdie benodighede is vier ruimtelike analise-instrumente ontwikkel. Die ruimtelike instrument genaamd “Borehole Analysis” ontleed stratgrafiese informasie bekom van bestaande boorgate en hidrogeologiese puntdaten. Die instrument gee die gebruiker ‘n aanduiding van die grondwatergebruik en monitering wat in ‘n ondersoekgebied onderneem is. Die “Topographic Analysis” ruimtelike instrument identifiseer enige topografiese (byvoorbeeld riviere) en kadastrale (byvoorbeeld plase) data binne ‘n sekere afstand van ‘n moontlike boorgatposisie. Die “Sensitive Analysis” ruimtelike instrument adresseer navrae in verband met sensitiewe gebiede, soos vleie, staatsbeskermde areas en private natuurreservate. Die “Image Classification” ruimtelike instrument bied die groeplede die geleentheid om die beeldratio’s te gebruik gedurende beeldinterpretasie.

Die TMGA RBOS is ontwikkel deur gebruik te maak van TNTmips v70, “Extensible Markup Language” (XML) en “Spatial Manipulation Language” (SML) en dit word verskaf op TNTAtlas v70 sagteware wat verniet is.

Die TMGA RBOS maak dit moontlik vir spanlede om gelyke en vinnige toegang tot ander lede se data te verkry. Dit ondersteun intra-en interdisiplinêre interaksie en fasiliteer begrip van hoe die data gebruik (of moontlik) gebruik kan word. Dit verhoog selfvertroue in besluitneming en ondersteun ‘n holistiese benadering tot projekontwerp en implementasie.

Sleutelwoorde: besluitneming, geografiese inligting stelsels (GIS), ruimtelike besluit ondersteuningsisteem (RBOS), “Spatial Manipulation Language” (SML)

ACKNOWLEDGEMENTS

I would like to thank the following people who have made it possible for me to finish this thesis:

Rowena Hay, for your time and always knowing what to say and do when I seem to have lost direction and hope.

Kornelius Riemann, for your quiet support and time, especially your formatting skills.

Chris, Ruth and Michael, for allowing me to take so much of Rowena's time from you.

My family, for your support and understanding when I could not make family time.

Colleen de Wet, for making sense of all the yellow-pad messages and opening locked gates.

Rob Harris and Phila Sibandze for your programming support.

TMGAA and WRC ECO projects teams for making this project possible.

Umvoto staff, for your support throughout.

All the friends and colleagues I have met and who assisted during the implementation of this project.

ABBREVIATIONS

API	Application Programming Interfaces
AML	Arc Macro Language
AVSWAT	Arc View Soil and Water Analysis Tool
BHU	Broad Habitat Units
CAD	Computer Assisted Design
CAPE	Cape Action Plan for the Environment
CCWR	Computing Centre for Water Research
CDSM	Chief Directorate Surveys and Mapping
CFR	Cape Floristic Region
CGER	Commission on Geosciences, Environment and Resources
CGS	Council of Geoscience
COGO	Co-ordinate geometry
CVA	Change Vector Analysis
DEM	Digital Elevation Model
DGMS	Dialogue Generation and Management System
DN	Digital Numbers
DWAF	Department of Water Affairs and Forestry
ETM+	Enhanced Thematic Mapper Plus
EIA	Environmental Impact Assessment
ESGWM	Expert System for Groundwater Modelling
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System
DGMS	Dialogue Generation and Management System
GPS	Global Positioning System
GSM	Gravel, Sand and Mud
HTML	Hypertext Markup Language
ISO	International Organisation for Standardization
JPEG	Joint Photographic Experts Group
KBR	Kellogg Brown and Root
Mamsl	Metres above mean sea level
MAP	Mean Annual Precipitation
MRI	Mountain Research Initiative
NBI	National Botanical Institute
NDVI	Normalized Difference Vegetation Index
NGDB	National Groundwater Database
ODBC	Open Database Connectivity
RBOS	Ruimtelijke Besluit Onderstueningsisteem
RTD	Research and Technology Demonstration
SABS	South African Bureau of Standards
SDSS	Spatial Decision Support System

SKEP	Karoo Environmental Plan
SML	Spatial Manipulation Language
STEP	Subtropical Thicket Ecological Plan
SWAT	Soil and Water Analysis Tool
TCI	Tasseled Cap Index
TMG	Table Mountain Group
TMGA	Table Mountain Group Aquifer
TMGAA	Table Mountain Group Aquifer Alliance
TMGA SSDS	Table Mountain Group Aquifer Spatial Decision Support System
WGS	World Geodetic System
WMA	Water Management Areas
WCSA	Western Cape System Analysis
XML	Extensive Markup Language

CONTENTS

	Page
Declaration	ii
Abstract	iii
Opsomming	v
Acknowledgements	vii
Abbreviations	viii
Contents	x
List of Tables	xiii
List of Figures	xiii
CHAPTER 1: COLLABORATIVE DECISIONS ABOUT WATER	1
1.1 Background to Current Surface and Groundwater Investigations in the Western Cape	1
1.2 Towards Collaborative Decision-making	4
1.3 Aims and Objectives	6
1.4 Description of the Study Area	7
1.4.1 Biophysical Environment	7
1.4.2 Socio-economic Environment	11
1.5 Research Design and Methodology	11
CHAPTER 2: DEVELOPING SPATIAL DECISION SUPPORT SYSTEMS	14
2.1 Spatial Decision-making and GIS	14
2.2 Spatial Decision Support Systems	15
2.2.1 SDSS Architecture	16
2.2.2 Technologies for Developing SDSS	19
2.3 SDSS Applications	20
2.4 Conclusion	21
CHAPTER 3: REQUIREMENTS ANALYSIS	23
3.1 Introduction	23
3.2 Decision-makers	24
3.3 Data Requirements	25
3.4 Spatial Analytical Requirements	27
3.5 Operation Requirements	29
3.5.1 Data Access	30

3.5.2	Data Sharing	31
3.6	Conclusion	32
CHAPTER 4: DATA ACQUISITION AND PREPARATION		33
4.1	Data Acquisition	34
4.1.1	Topographic and Cadastral Data	36
4.1.2	Cadastral and Infrastructure Data	36
4.1.3	Infrastructure Data	37
4.1.4	Hydrological Data	37
4.1.5	Hydroclimatology Data	37
4.1.6	Climatic Time series	38
4.1.7	Aerial Photography and Satellite Imagery	38
4.1.8	Regional Geology and Structural Data	39
4.1.9	Ecological Data	40
4.1.10	Vegetation Indices	41
4.1.11	Point Source Hydrocensus and Monitoring Data	41
4.1.12	Point Source Ecological, Botanical and Monitoring Data	42
4.1.13	Other Data	42
4.2	Data Preprocessing	43
4.2.1	Detection and Correction of Errors	43
4.2.2	Re-projection, Transformation and Generalization	44
4.2.3	Edge Matching and Rubber-sheeting	45
4.3	Metadata	46
4.4	Conclusion	47
CHAPTER 5: TMGA SPATIAL DECISION SUPPORT SYSTEM		48
5.1	GIS and User Interface	48
5.1.1	Atlas Interface	48
5.1.2	Dialogue Window	54
5.2	Spatial Analytical Tools	55
5.2.1	Site Selection	56
5.2.2	Borehole Analysis	60
5.2.3	Topographic Analysis	69
5.2.4	Sensitive Area Analysis	75
5.2.5	Image Classification	78
5.3	Dissemination	81
5.4	Conclusion	82

CHAPTER 6: TMGA SDSS EVALUATION	83
6.1 Evaluation Process	83
6.1.1 Accuracy of the Database	83
6.1.2 Efficiency of the System	84
6.1.3 Effectiveness in Serving the Larger Purpose	84
6.2 Project Team Evaluation	84
6.2.1 Site Selection and Area of Analysis	85
6.2.2 Borehole Analysis Tool	85
6.2.3 Topographic Analysis Tool	86
6.2.4 Sensitive Area Analysis Tool	86
6.2.5 Image Classification	87
6.2.6 Display of Information and Results	87
6.3 Technical Evaluation and challenges	87
6.3.1 Sensitive Area Analysis Tool	87
6.3.2 Display of Information and Results	88
6.4 Conclusion	89
CHAPTER 7: CONCLUSION AND RECOMMENDATIONS	90
7.1 Conclusion	90
7.2 Recommendations	92
REFERENCES	93
Appendix A: Data Catalogue	102
Appendix B: Questionnaire and Interviews	109
Appendix C: Database Management Protocol	113
Appendix D: Details of Data Layers	124
Appendix E: Metadata Template	127
Appendix F: SML Script	128

LIST OF TABLES

Table 1-1	Lithostratigraphic units of the Table Mountain Group	9
Table 3-1	Decision-makers' expertise	27
Table 3-2	Available data-sharing formats	32
Table 4-1	Landsat 7 ETM+ characteristics	38
Table 5-1	Raster data check-list	49
Table 5-2	Vector data check-list	49

LIST OF FIGURES

Figure 1-1	Table Mountain Group groundwater projects	2
Figure 1-2	Project study area	8
Figure 1-3	Research methodology	13
Figure 2-1	The dialogue interface system	17
Figure 2-2	Technology levels for developing spatial decision support systems	19
Figure 3-1	Requirement analysis	23
Figure 4-1	The data stream – the process of data encoding and editing	34
Figure 4-2	Examples of spatial error in vector data	43
Figure 5-1	Table Mountain Group aquifer spatial decision support system (TMGA SDSS)	51
Figure 5-2	Feature scale display control	52
Figure 5-3	Digital Atlas window	53
Figure 5-4	Geotoolbox window	54
Figure 5-5	Spatial analytical routines	56
Figure 5-6	Top of dialogue window defining the area of interest	57
Figure 5-7	Input point routine for site selection	58
Figure 5-8	Results of possible borehole site and buffer area	60
Figure 5-9	Dialogue window with the Borehole Analysis Tool	61
Figure 5-10	Borehole Analysis subroutine – lithology of the possible borehole point	62
Figure 5-11	Borehole Analysis subroutine – monitoring points within area of analysis	63
Figure 5-12	Results of the second section of the Borehole Analysis Tool showing point streams found and the lithology they start in	65
Figure 5-13	Borehole Analysis subroutine – stratigraphic information and monitoring points within study area	66
Figure 5-14	Borehole Analysis subroutine – climate stations and gauges within study area	68
Figure 5-15	Topographic Analysis Tool window	70
Figure 5-16	Topographic Analysis subroutine – roads and rivers within analysis area	71
Figure 5-17	Topographic Analysis Tool results of roads and perennial rivers	72
Figure 5-18	Topographic Analysis subroutine – dams and farms within analysis area	73
Figure 5-19	Topographic Analysis subroutine – towns within analysis and study area	74
Figure 5-20	Sensitive Area Analysis Tool window	75
Figure 5-21	Sensitive Area Analysis routine	76
Figure 5-22	Results of Sensitive Area Analysis Tool query for provincial nature reserves	77
Figure 5-23	Image Classification Analysis Tool	78
Figure 5-24	Image Classification subroutine – pre-defined and user defined ratios	79
Figure 5-25	Image Classification subroutine – true and false colour composite	80

CHAPTER 1: COLLABORATIVE DECISIONS ABOUT WATER

1.1 BACKGROUND TO CURRENT SURFACE AND GROUNDWATER INVESTIGATIONS IN THE WESTERN CAPE

The Western Cape province of South Africa is a water scarce area with a Mediterranean climate, i.e., the majority of rainfall occurs in the cold winter months and the area experiences hot and dry summers. This means that sufficient storage has to be provided during winter to cater for dry summer months as well as to provide assurance of supply, particularly in the event that the winter rains are low or a drought is experienced.

When the winter rainfall is low, water shortages can occur. Since the late 1990s surface water sources have been insufficient to meet the growth in water demand of the City of Cape Town (Cape Metropolitan Council 2001). Even though discussions to investigate groundwater in the Table Mountain Group (TMG) aquifer system started as early as the 1970s (Joubert 1970), a firm proposal to investigate groundwater as a potential source of large-scale supply to the City of Cape Town was first raised in the early 1990s as part of the Western Cape Systems Analysis (WCSA) project, after the prediction that the Cape Town Metropolitan Region (CMR) would “exhaust the local conventional water resources within the next two to five decades” (Alexander 1985: 75). Continental (e.g. De Wit & Stankiewicz 2006) and regional analyses of the future impacts of climate change predict a reduced streamflow supply and increased urban and agricultural demand, which result in a “permanent inability to meet the 1:50 year supply yield in the CMR, with the consequence that the frequency of supply failure will be greater than expected” (New 2002: 1). The stresses of looming water scarcity and also water-quality degradation have particularly serious developmental implications for Cape Town because the future economic growth of the area is dependent on a high-quality environment (Quick 1995).

Throughout the 1990s a number of projects focussing on groundwater from the TMG aquifers were undertaken in the Western Cape province (Figure 1-1). These projects included resource evaluation studies, namely Citrusdal Artesian Groundwater Exploration (CAGE)(Hartnady & Hay 2000; 2001; 2002a-e; Hay & Hartnady 2002; Mlisa & Hartnady 2003), the Deep Artesian Groundwater Exploration in the Greater Oudtshoorn District for Bulk Water Supply (DAGEOS)(Umvoto 2005), as well as actual wellfield development and management projects, e.g. the Water Source Development and Management Plan of the Greater Hermanus Area (Hay & Riemann 2002; Hay, Hartnady & Riemann 2002).

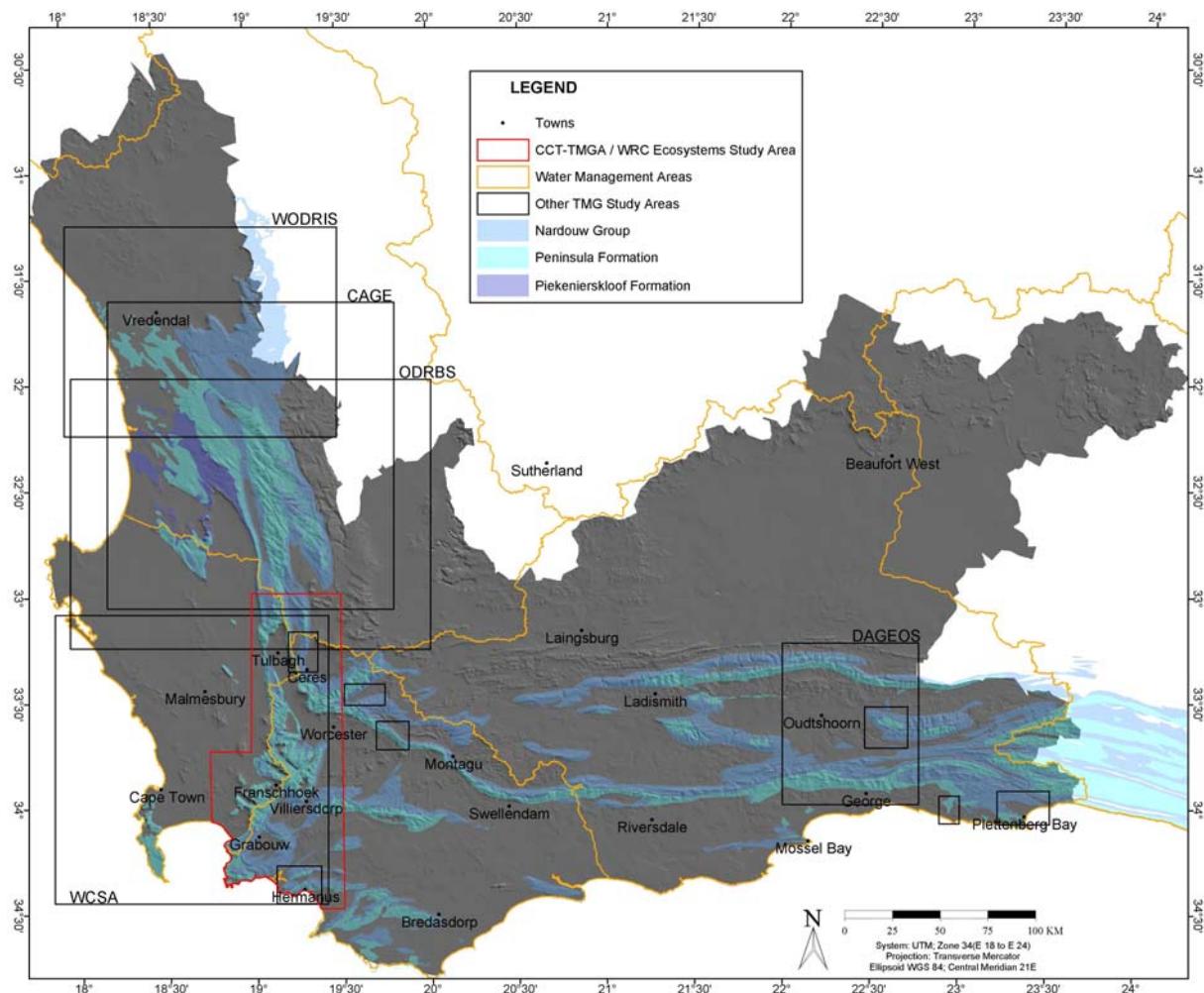


Figure 1-1 Table Mountain Group groundwater projects

[Western Cape Systems Analysis (WCSA); Western Cape Olifants/Doring River Irrigation Study (WODRIS); Citrusdal Artesian Groundwater Exploration (CAGE); Olifants Doring River Basin Study (ODRBS); Deep Artesian Groundwater Exploration in the Greater Oudtshoorn District for Bulk Water Supply (DAGEOS)]

In 2000 and 2001 two major studies were initiated to investigate various water supply and water demand management options for the City of Cape Town. One of the options considered was the TMG aquifer. The studies concluded that the TMG has the potential of yielding high volumes (estimated at 70Mm³/a) (City of Cape Town, CMC Administration 2002) of good quality water and that further research about this source as a potential augmentation supply to the City of Cape Town was necessary before extraction could commence.

As a result a project titled the *Table Mountain Group Aquifer Feasibility Study and Pilot Project* (hereafter the TMGA project) was initiated by the City of Cape Town in 2002. Its aim is to determine the feasibility of large-scale abstraction of the TMG groundwater supply for use by the City of Cape Town (City of Cape Town, CMC Administration 2002). Another project funded by the Water Research Commission (WRC) within the same study domain,

entitled *Ecological and Environmental Impacts of Large-volume Groundwater Abstraction in the Table Mountain Group (TMG) Aquifer Systems* (hereafter the WRC ECO project), is investigating the possible environmental impacts of exploiting the TMG aquifer systems (Brown et al. 2003).

In the inception report of the TMGA Project, the Table Mountain Group Aquifer Alliance's (TMGAA) rationale of the pilot phase is clearly expressed:

“The intention is then to seriously stress the aquifer system by continuous pumping at a rate that is close to the limit of predicted sustainability, and to closely observe the behaviour of the surface- and groundwater system in both the near- and far-field regions around the abstraction site. The period of this Performance Evaluation stage should be at least one hydrological cycle covering both wet and dry seasons, (but preferably more)” (City of Cape Town 2004a: C-53).

It is therefore clear that the natural system covered by the current TMGA exploratory phase is not restricted just to the immediate environs of the future pilot phase abstraction site, but incorporates the surrounding “near- and far-field regions” in which the wider “behaviour of the surface- and groundwater system” can be observed and monitored (Hartnady 2005: Appendix D). The TMGA Project area therefore constitutes a “natural laboratory”, i.e. a “... carefully chosen (area) ... where representative behaviours can be investigated in appropriate context and detail and with the appropriate complement of expertise and instrumentation” (Commission on Geosciences, Environment and Resources (CGER) 2001: 154).

The pilot phase concept of the TMGA Project is of a holistic “research-and-technology-demonstration” (RTD) project for an environmental impact assessment (EIA) of an unprecedented kind (Hartnady 2005: Appendix D). This RTD-EIA approach to the TMGA pilot phase, involves scientific and technical considerations that extend beyond the field of applied hydrogeology, and in this multidisciplinary context the “natural laboratory” concept is particularly relevant, as the following extract indicates:

“Designating specific areas for special scrutiny has several advantages. It facilitates the coordination of activities across multiple groups of investigators, encouraging the types of multidisciplinary studies that are often essential to understanding complex processes and system behaviours. It also provides a long-

term basis for capitalizing on field-based research. If the investigations are well directed and the data properly analyzed and archived, then the return on previous research investments can be compounded as more data are collected. Each observational study within the natural laboratory adds to the database, improving the context for future work.

This co-ordinated, multidisciplinary approach is especially desirable when field operations are logically complicated and expensive, as in the collection of spatially dense data sets and the monitoring of phenomena over extended time intervals. Synoptic studies of natural laboratories furnish an important observational base for developing theoretical and numerical models of complex natural systems, and they yield the essential data by which these models are ultimately validated. They also provide the facilities for involving students and teachers in participating in field-based research ...” (CGER 2001: 154).

In addition to facilitating multidisciplinary interaction, the natural laboratory approach is also a “key element in the dialogue between observational and newly developed modelling approaches” (Cloetingh, Ziegler & Cornu 2004: 07554) in the emergent discipline of earth system science, which treats the whole planet as an integrated, interacting system, whose study must transcend disciplinary boundaries.

1.2 TOWARDS COLLABORATIVE DECISION-MAKING

According to Malczewski (1997), any decision-making problem falls within the range from completely structured to unstructured. Structured decisions occur when the decision-maker can structure the problem and these decisions can be programmed and be solved by computers. On the other hand, unstructured decisions occur when the decision-maker is unable to structure the problem and has to solve the problem without the assistance of a computer.

Because in most cases semi-structured decision problems are spatially related, a concept known as spatial decision support systems (SDSS) evolved as a field of research, development and practice parallel to decision support systems (DSS) during the late 1970s and 1980s. SDSS could be defined as an interactive, computer-based system designed to support a user or group of users in increasing effectiveness of decision-making whilst solving a semi-structured spatial decision problem (Malczewski 1997). Its development has been

associated with the need to expand geographic information systems (GIS) capabilities for handling complex, ill-defined, spatial decision problems.

GIS provides database management systems, graphic display of spatial data and tabular reporting capabilities. SDSS provides a framework for integrating GIS capabilities, analytical modelling capabilities and the decision-makers' expert knowledge (Densham 1990). SDSS has been used in numerous projects for supporting decision-making; these projects include land and water management (Dutta 2002), regional transportation (Stevens & Thompson 1996) and evacuation planning (De Silva 2000). The inclusion of GIS in DSS enables visualization, which has been found to be important, as people make decisions based on what things look like (Johnson & Lachman 2001). Once the data and information have been made easily accessible and presented in a format that all users understand, it is easier for the decision-makers to apply their expert knowledge in solving the problem (Urban 2003).

The project teams of the TMGA and WRC ECO projects are multidisciplinary and include hydrogeologists, environmentalists, ecologists, engineers and other stakeholders. Although the teams have common purposes for each project, members from different disciplines have different priorities. For example, an optimum drilling site according to a hydrogeologist could also have been identified by ecologists as a highly sensitive area. Such conflicts arise because each scientist uses different data sets and tools to inform his/her opinions or decisions. Scientists also collect and keep their own spatial data sets, which often leads to duplication.

Conflicts and data duplication can be limited by making all data sets and decision tools available to the full team. Team members need to know what data is available to be able to determine what data still needs to be collected. They also need to know what analyses can be undertaken on the existing data. This means that the data need to be structured and managed in such a way that each team member can have access to view and analyse all available datasets, even from remote locations. Data integration is the process by which different data within a GIS are made compatible with each other, so that extraction, visualization, generalization and statistical and spatial analysis may be accomplished (Tyson 1999). Integration of spatial data and information has the following advantages:

- A broader range of operations can be performed on integrated information than on disparate sets of data;
- Data sets are made spatially consistent;

- Duplication of effort is reduced (if one team has collected the data, there is no need for another team to again collect the same data);
- An interdisciplinary perspective to problem solving is promoted (where one disciplinary specialist can provide useful data to another specialist discipline).

Much of the data used in both projects are spatially orientated. It therefore makes sense to use a GIS to input, store, manage, analyse and present the data. It has been shown that GIS enables more effective decision-making because it facilitates communication of concerns and insights between disciplines and individuals as well as opportunities for consensus problem definition and solving (De Silva 2000). This is critical for non-partisan decision-making in the resource management context, as it increases efficiency and effectiveness, and reduces risk.

It is, however, a fact that not all team members are GIS literate or have the time or desire to be trained in GIS. The data and tools should therefore be presented so as to support decision-making for all experts, irrespective of their GIS proficiency.

1.3 AIMS AND OBJECTIVES

The aim of the study is to design and implement a spatial decision support system for the multidisciplinary teams of the TMGA and WRC ECO projects, hereafter referred to as TMGA SDSS. In addition, the TMGA SDSS could be used as an educational or awareness tool for earth scientists in the usage of GIS and spatial data to improve effectiveness in decision-making.

To meet the project aim, the following objectives were identified:

- Review similar applications in the literature.
- Survey and document user requirements.
- Document a database management protocol based on the user requirements with special emphasis on data sharing, access, and intellectual property issues.
- Determine and tabularise data availability.
- Collate available spatial and temporal data.
- Construct a digital atlas of available data.
- Design and develop spatial analytical tools and a user interface.

- Evaluate and document feedback from the project team, to be used to refine the SDSS and to make recommendations for further work.

There is a significant body of knowledge and data available for the study domain. It is however widely dispersed between different institutions and individuals. These individuals and institutions are variably involved in both the TMGA and the WRC ECO projects but the use and knowledge of the potential of GIS technology in both routine data processing and more complex analysis is limited except for select individuals.

However, both team members have an extensive knowledge of the study area, this will help with the analysis of the data.

1.4 DESCRIPTION OF THE STUDY AREA

The study domain forms part of the Western Cape Systems Analysis (WCSA) area (Figure 1-2), and focuses on the region along the south-eastern boundary. The study extends the geographic area of interest to include a wider region of TMG outcrop that was formerly excluded from the earlier 1994 WCSA study (City of Cape Town, CMC Administration 2002). The area covers the upper Berg, upper Riviersonderend, middle Breede and Steenbras/Palmiet River catchment areas.

1.4.1 Biophysical Environment

The study area includes some of the highest rainfall zones in South Africa. The range of precipitation patterns over the higher mountain terrain varies from 200 to 3400mm/a. The predominantly high-lying catchments (H10E, H10J, H10K, G10A, G10B, H60A) receive between 2000 and 3400mm/a. Even the lower lying areas of these catchments receive more than 500mm/a (City of Cape Town, CMC Administration 2002).

In general the regions of high rainfall coincide with topographically elevated mountain chains, mainly underlain by erosionally resistant, but highly fractured TMG rocks. The catchments that receive the greatest amount of rain comprise between 44% and 76% of Peninsula Formation outcrop (City of Cape Town, CMC Administration 2004b).

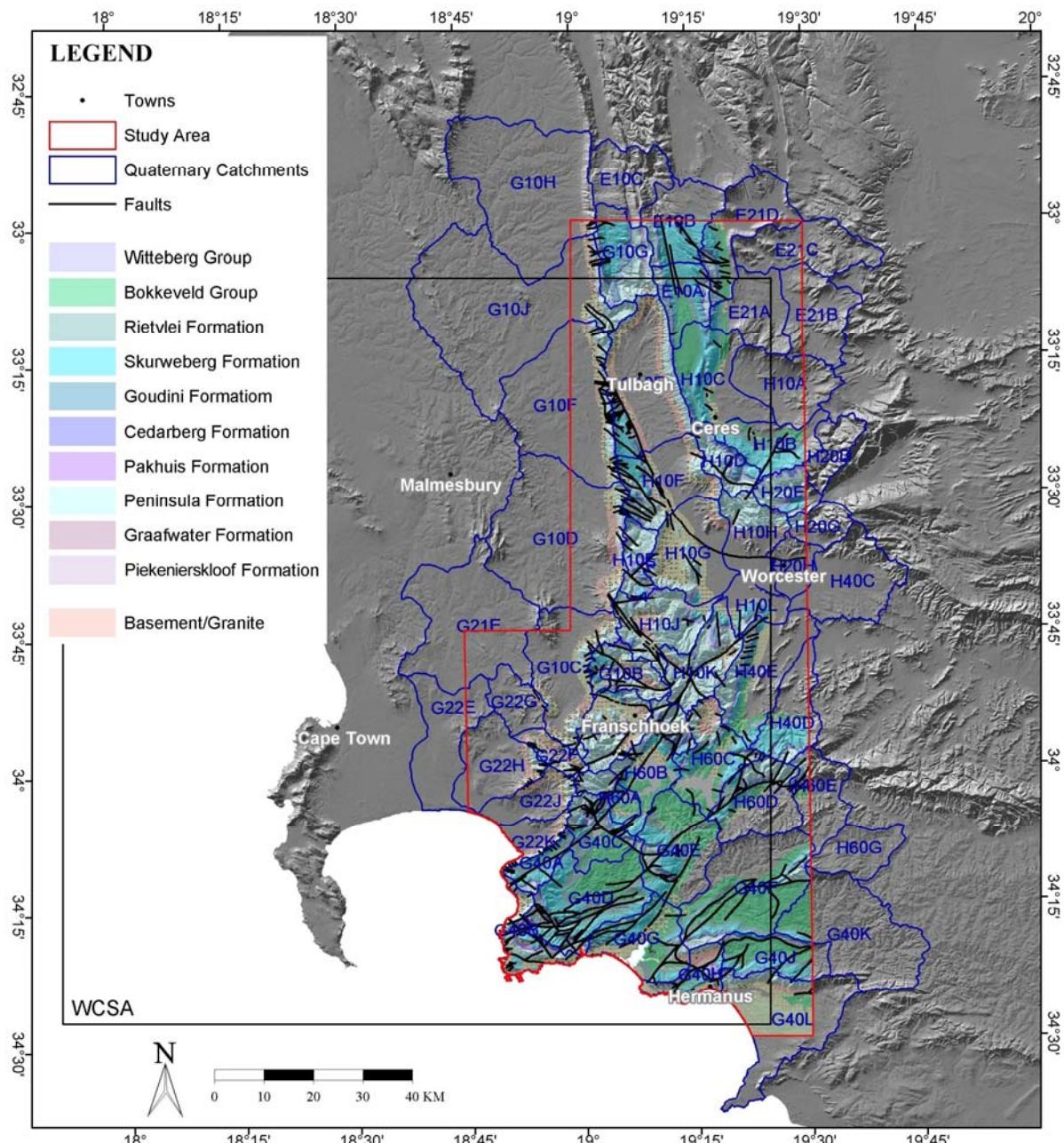


Figure 1-2 Project study area

The Peninsula Formation is one of the eight formations that constitute the TMG (Table 1.1). The TMG consists of three major fractured-rock sandstone aquifers, i.e. Piekenierskloof, Peninsula and Skurweberg formations, separated by shale-bearing units, which locally act as confining layers for groundwater flow (City of Cape Town, CMC Administration 2004b).

Table 1-1 Lithostratigraphic units of the Table Mountain Group

Formation	Lithology (rock type)	Hydrostratigraphy
Rietvlei	Feldspathic sandstone	Aquifer (limited)
Skurweberg	Quartz sandstone	Aquifer
Goudini	Silty sandstone, siltstone	
Cedarberg	Shale, siltstone	Meso-aquitard
Pakhuis	Diamictite shale	
Peninsula	Quartz sandstone	Aquifer
Graafwater	Impure sandstone, shale	Meso-aquitard
Piekenierskloof	Quartz sandstone, conglomerate, shale	Aquifer (limited)

Source: Adapted from Mlisa & Hartnady (2003: 2)

The Peninsula Formation constitutes the middle aquifer in the TMG. It is approximately 550m thick in the Cape Peninsula area and reaches approximately 1300m in the Citrusdal region. It is the topographically dominant unit in the TMG, underlying most of the high mountain ranges. It is also the most hydrogeologically important, having the largest extent in the areas of maximum precipitation and recharge potential and greatest sub-surface volume of permeable fractured rock (City of Cape Town, CMC Administration 2002).

The study area is located within the "syntaxial zone" where N/S-trending folds of the western branch of the Cape Fold Belt interfere with the NE/SW- to E/W-trending folds of the southern branch of the belt (City of Cape Town, CMC Administration 2002). Significant fault and fracture structures with a wide range of orientations also occur throughout the area, the most conspicuous of which is the Worcester Fault near the northern boundary of the study area. This major faulting and fracturing penetrates the TMG to great depths and forms an interconnected network of preferred flow paths for groundwater. This network constitutes the TMG aquifers, which are "secondary" or fractured-rock aquifers.

The vegetation of the study area belongs to the Cape Floral Kingdom, the smallest and most threatened of the world's six floral kingdoms. Particularly high levels of plant endemism mark the Cape Floral Kingdom. The area is home to 1406 Red Data Book species, the highest known concentration in the world. As a result of its combination of species richness and vulnerability to processes that threaten its biodiversity, the Cape Floristic Region (CFR) is

recognized globally as a biodiversity hotspot of global significance (Cowling et al. 2002) and eight sites have been included as part of the CFR which was declared a World Heritage Site.

The fynbos biome contributes more than 80% of species to the Cape Floristic Region (Ninham Shand 2004). The Boland Mountain Complex in which the study area occurs supports some of the finest examples of mountain fynbos in the Western Cape. Over 1 600 plant species, including several locally rare and otherwise threatened plant species as well as more than 150 endemic plants.

The study area is covered by a number of provincial, local authority and private nature reserves, of major importance being the Kogelberg Biosphere Reserve (KBR). The KBR was proclaimed in 1998 as South Africa's first entry to the UNESCO-MAB programme (UNESCO-MAB 2006c). It is described as the "floristic heart of the smallest of the world's floral kingdoms" (UNESCO-MAB 2006c). More than 80% of the KBR consists of mountainous landscape, ranging from high mountain peaks (Kogelberg Peak at 1266m) and deep valleys to lower mountain slopes and gentle hills. It is indeed a mountain biosphere reserve, albeit with a coastal setting and a maritime, Mediterranean-type climate. Consequently it is deemed (Hartnady 2005) to be an appropriate location for interaction with-and learning from-projects co-ordinated by the Mountain Research Initiative (MRI)(Becker & Bugmann 2001; Reasoner et al. 2002), in which mountain biosphere reserves are used as monitoring sites for assessing the impact of global change (Beniston 2003).

Because of the role of aquifer storage as a low-pass filter for the effective separation of short-term fluctuations from long-term climatic trends, groundwater monitoring is the most likely key to the MRI objectives. Due to the importance of orographic control over precipitation and the topographic prominence of the TMG fractured-rock aquifers in high-mountain recharge areas, the Palmiet River drainage system in the KBR appears to be an ideal experimental catchment (Hartnady 2005). Like many other mountain source zones in other parts of the world (Wiesmann et al. 2000), it functions as a natural "water tower" for its foot-zones and adjoining lowland areas, including a major part of the City of Cape Town's supply system. Because more than half the world's population depends on mountains for drinking water, mountain regions-the so-called "Water Towers for the 21st Century" (Messerli, Vivenzio & Weingartner 2004) are crucial to the long-term monitoring of global climate change, which is a threat both to regional water-resource sustainability and to the conservation of the unique flora and fauna of the Cape Floristic Region World Heritage Site.

The rugged terrain of the area covered by mountain fynbos provides valuable sanctuary to a wide range of mammals, including dassies and baboons. The area has limited anthropogenic disturbances to the habitat. The disturbances that do occur include agriculture (e.g. deciduous fruits and grapes along the lower slopes), commercial plantations, and holiday and tourist facilities.

1.4.2 Socio-economic Environment

The study area falls within the boundaries of thirteen municipalities, which in turn are situated within the Berg and Breede Water Management Areas (WMA). According to Ninham Shand (2004), water scarcity in both the Berg and the Breede WMA is seen as a threat to the potential growth of agriculture and limits large industrial development.

The predominant land-use within the study area is nature conservation. The nature conservation types include statutorily protected areas, provincial nature reserves, and the KBR. The other major land-use types are agriculture, plantation forestry and recreational use, particularly in the form of hiking trails, mountain biking and wilderness areas.

There is a great deal of information about the heritage of early inhabitants of the CFR dating back thousands of years. Evidence in the form of rock paintings, caves, burial sites and artefacts are well preserved. No sites of historical significance have been specifically identified in the study, though archaeological material such as stone artefacts and rock art may be present (Ninham Shand 2004).

The study area represents the diversity of scientists involved in the project and also highlights the different priorities or data needs of each discipline.

1.5 RESEARCH DESIGN AND METHODOLOGY

Though the system to be developed by the study will support both quantitative and qualitative methods, the research will follow qualitative research methods. Qualitative research methods have been developed in the social sciences to enable researchers to study social and cultural phenomena. According to McBride & Schostak (2005), qualitative research pays greater attention to individual cases and the human understanding of features in those cases. In qualitative research, the researcher attempts to understand people in terms of how they define their world (Mouton 2005).

The present study aimed to develop a spatial decision support system. The study conducted a user requirements analysis by means of interviews and discussions with the project team members. The interviews and discussions focused on what the various disciplines involved in the study required in terms of data to be acquired for the project and also requirements with regards to spatial analysis. These requirements formed the framework for the spatial decision support capabilities.

The research design and methodology (Figure 1-3) of the study comprised a literature review of similar studies, the application methodologies, findings, and determining what lessons could be learnt for this study. The literature study, discussed in Chapter 2, was followed by user requirements analysis.

The user requirements are discussed in Chapter 3 of the thesis. The chapter looks at the methodology used, presents the results and discusses what these requirements mean to the project and how they were to be met. The requirements were two fold, data requirements and spatial analysis requirements. The result of the analysis outputs a document with the details of the requirements. Based on user requirements, data were then acquired from different specified sources and imported into the GIS system. Acquisition and collation of the acquired data, which is discussed in Chapter 4, included data cleaning and validation to prepare the for input into the digital atlas. The results of data acquisition and collation also outputs two documents, a data catalogue and metadata catalogue for all datasets acquired. The data acquired and the development of spatial analytical tools forms part of the development of the SDSS. The SDSS design and implementation is discussed in Chapter 5. The design and implementation also involves the development of a digital atlas and user interface. Once the digital atlas had been built, a user interface and spatial analysis tools were created using a spatial manipulation language to link to the spatial decision support system. Chapter 6 deals with evaluation and dissemination of the spatial decision support system. The evaluation process included workshops where the SDSS was presented to the project team who are specialists to be using the project for their comments and review. The results of the evaluation process were then implemented as the final step of development of the Table Mountain Group Aquifer (TMGA) SDSS. In the final chapter the project conclusions are outlined and recommendations for further work are made.

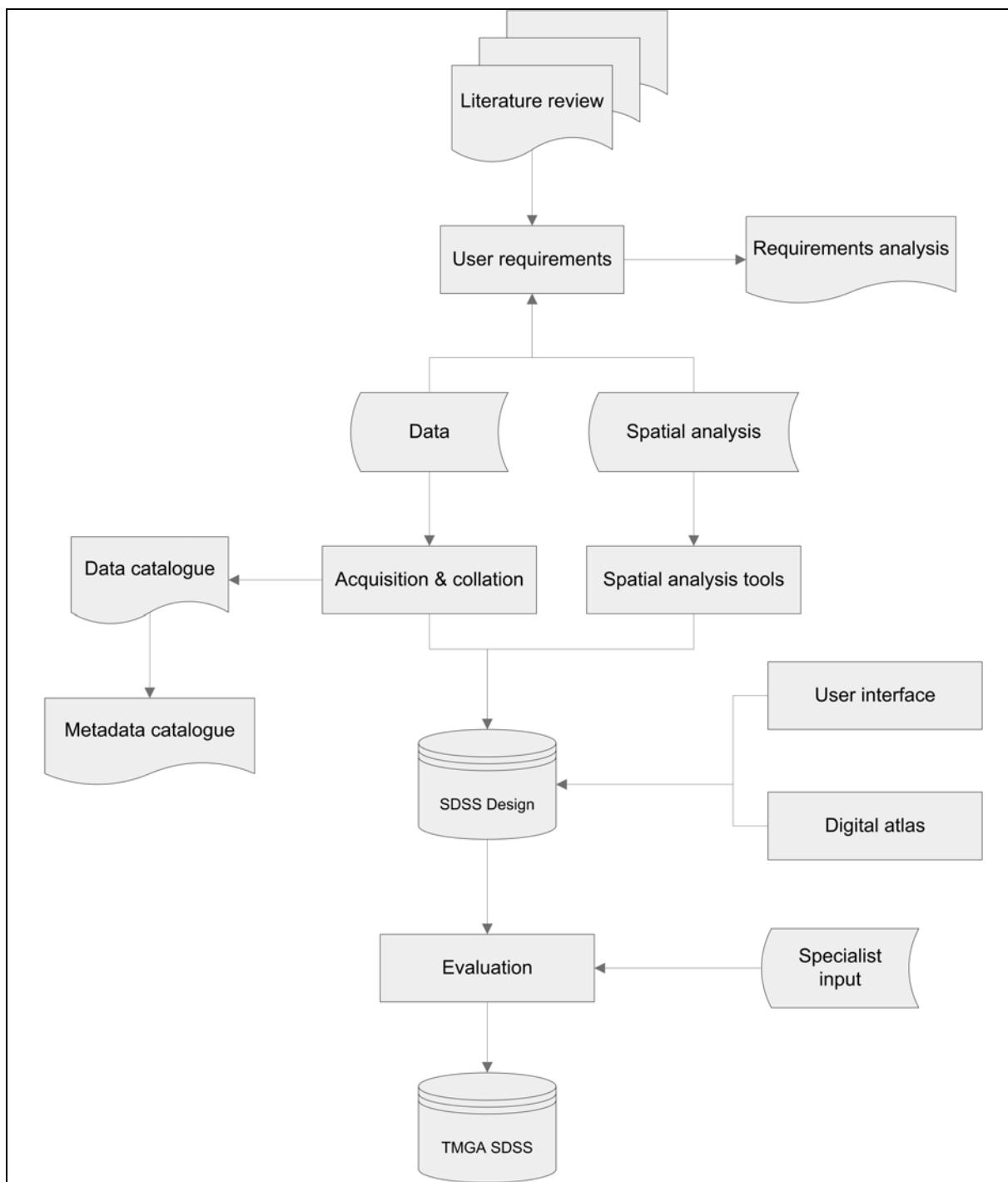


Figure 1-3 Research methodology

In the next chapter, spatial decision support systems are defined and a review of studies where SDSS have been applied is provided.

CHAPTER 2: DEVELOPING SPATIAL DECISION SUPPORT SYSTEMS

2.1 SPATIAL DECISION-MAKING AND GIS

Spatial problems typically involve a set of geographically defined alternatives from which the decision-makers can choose a preferred option. These preferences are related to the relative importance of evaluation criteria and decision consequences and these decisions are often surrounded by uncertainty (Malczewski 1997).

The focus in more recent research in GIS has been to understand the social benefit of the technology rather than the initial focus on technical issues (Stevens & Thompson 1996). This includes the idea that support for better informed decision-making is in itself a social benefit. Sprague & Ralph (1980) suggest that the decision-making process should be structured into three major phases: intelligence, design and choice.

The *intelligence phase* involves searching the environment for conditions calling for decisions as a way to define the problem and it therefore requires an exploratory analysis of the decision situation. The *intelligence phase* involves data acquisition, storage, retrieval, manipulation, analysis capabilities and effective presentation of information for decision-makers. A GIS can help in co-ordinating decision situation analysis through its ability to acquire, integrate and explore large amounts of diverse data and information from a wide range of sources. GIS can also effectively present information in a comprehensible form for decision-makers.

GIS are described as systems that support the process of designing and evaluating spatial decision problems. Some authors even suggest that GIS is a decision support system (Keenan 2004). However, commercially available GIS lacks the kinds of spatial analysis and modelling capabilities required in the *design phase* of the decision-making process as this involves inventing, developing and analysing a set of decision alternatives for the problem identified in the intelligence phase (Keenan 2004). GIS is capable of generating a set of alternative decisions based on the spatial relationship principles of connectivity, contiguity, proximity and the overlay methods. In the current GIS environment, however, models for generating decision alternatives operate in the background, detached from a decision-maker's insight and qualifications and therefore without the added value of this intelligence.

The third process of decision-making, the *choice phase*, involves selecting a particular alternative from those available. In this phase, specific decision rules defined by the decision-

maker are used to evaluate and rank these alternatives (Ascough et al. 2002). In general, GIS do not provide a mechanism for flexible incorporation of the decision-maker's preferences into the decision-making process. Therefore current GIS have limited capabilities for supporting the design and choice phases of the decision-making process and provide a very static modelling environment, thus reducing their scope as decision support tools.

2.2 SPATIAL DECISION SUPPORT SYSTEMS

The notion of spatial decision support systems (SDSS) was derived from the concept of decision support systems (DSS) in the 1970s and has evolved since then. There are a variety of definitions of DSS in published work, but most of these works agree that DSS are tools to support decision-making when addressing problems that are not well structured.

DSS, according to Sprague & Ralph (1980), should provide integration and regeneration of information. This supports the exploratory nature of the decision-making process and allows the development of alternatives by using information system technology to increase the effectiveness of decision-makers. Hall, Bowerman & Feick(s.d) outline the six characteristics of DSS as:

- explicit design to solve ill-structured problems;
- problem solving in an interactive and recursive manner;
- ability to combine analytical models with data in a flexible manner;
- support for a variety of decision-making styles and levels of decision-making;
- user interface that is both powerful and easy to use; and
- ability to explore different alternatives.

Decision-makers have indicated that inaccessible spatial data and especially difficulties in synthesising and viewing various recommendations or solution scenarios are primary obstacles to spatial problem solving using normal DSS (Ascough et al. 2002).

As SDSS follow on DSS, they also necessarily have the same characteristics as outlined by Sprague & Ralph (1980), as well as additional capabilities outlined by Densham (1990) as:

- providing mechanisms for the input of spatial data;
- allowing the representation of spatial relations and structures;

- including spatial and geographical analysis techniques; and
- providing output in different spatial forms, including maps and tabular reports.

When the spatial element is included with DSS, spatial information processing and management are possible, hence SDSS. SDSS make an important contribution to incorporating the spatial dimension in the decision-making process, which has great significance in areas related to conservation and natural resource management (Segrera, Ponce-Hernandez & Arcia 2003). GIS provide database management systems, graphical display and tabular reporting capabilities, and work well for supporting structured decisions. But over and above the GIS capabilities, SDSS provide analytical modelling capabilities and decision-maker's expect knowledge (Densham 1990).

2.2.1 SDSS Architecture

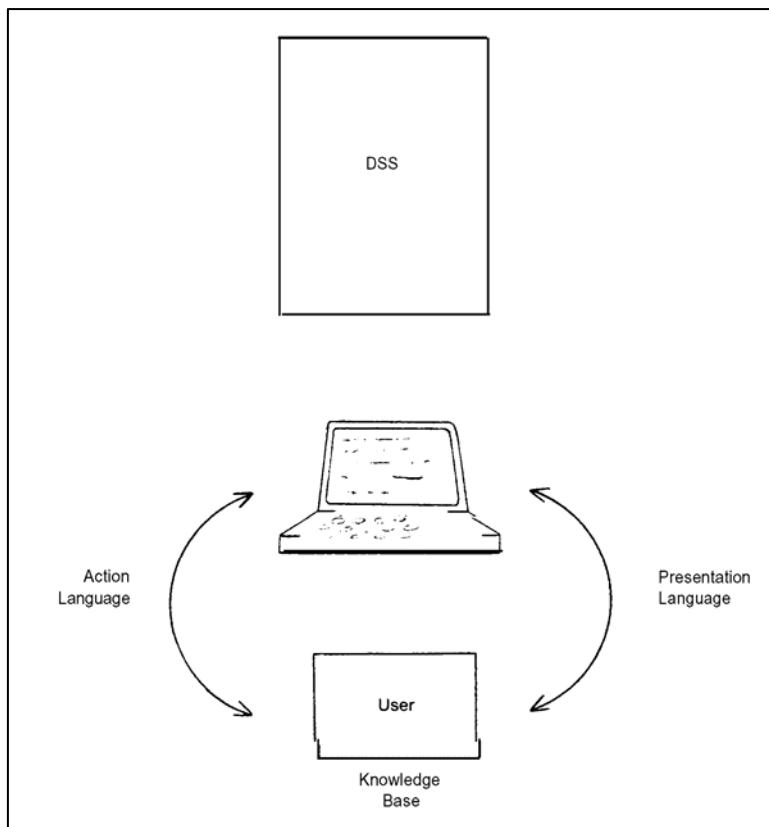
Segrera, Ponce-Hernandez & Arcia (2003) suggest that an SDSS requires four major operations to support decision-making: data input, database management, analysis and presentation. They further suggest five key modules for SDSS architecture to enable the system to meet its major operation requirements. These requirements are:

- a database management system;
- analytical procedures in a model-based management system;
- a screen generator;
- a report generator; and
- a user interface.

The last three components could be summarised as a dialogue generation and management system (DGMS) (Malczewski 1997). Much of the power, flexibility and usability characteristics of an SDSS are derived from the capabilities in the DGMS. The user interface should provide support to decision-makers through all phases of decision-making and is the key to successful use of any DSS (Ascough et al. 2002). It includes all input/output methods by which data are entered, queried and results are displayed by an SDSS. It enables a dynamically interactive session between the user and the system.

Sprague & Ralph (1980) divide the dialogue interface into three parts, as shown in Figure 2-1. The action language represents how the user can communicate with the system, either by

using a keyboard or voice commands. The display language represents what the users see, including options such as display screen or printer. The knowledge base consists of what the user needs to bring in order to use the system effectively. The knowledge may be in the user's head (expert knowledge) or in a user's manual. The effectiveness of the user interface will depend on the strength of the capabilities in each of these areas.



Source: Sprague & Ralph (1980: 18)

Figure 2-1 The dialogue interface system

In designing the user interface Fedra (1995) and Ascough et al. (2002) list a number of specific issues for consideration. The interface should:

- be accessible, implying that appropriate real-world metaphors are used so that users unfamiliar with the system can use intuition to know the purpose of a particular screen or icon;
- provide a variety of dialogue styles, such as command lines, pull-down menus and dialogues that are of benefit to the user;

- be flexible, user-friendly and consistent to allow the decision-maker to recover from unintended and adverse actions, e.g. the availability of cancel and undo options;
- be interactive to ensure efficiency of information flow from the user to the system and vice versa, which allows the user to define and explore the problem in response to immediate answers from the system;
- be process-driven, thereby allowing the user to be aware of the tasks they are carrying out, e.g. showing active icons differently to indicate active processing; and
- have visualization capabilities either in the form of graphical and or tabular display.

The model-based management system includes tools for generating value structure, preference modelling, and multi-attribute or multi-objective decision rules (Ascough et al. 2002). This implies that the decision-maker could recommend alternative solutions for formal analysis. The system must have capabilities for modelling uncertainty in the form of data uncertainty, decision rule uncertainty, sensitivity analysis and error propagation analysis. According to Sprague & Ralph (1980) and Batty & Densham (1996), the model-based management system must also be capable of cataloguing and maintaining a wide range of models supporting all levels of decision-makers and must support mechanisms for storing, linking and accessing models. The types of models include analytical models, which have capabilities to handle goal seeking, optimisation, simulation and ‘what if’ scenarios and statistics, and forecasting models, which look at exploratory and confirmatory spatial data analysis, time series and geostatistics.

According to Densham (1990), there are two approaches to incorporation of analytical models in geoprocessing systems. One is to develop libraries of analytical sub-routines, which permits large numbers of models to be made accessible very quickly, because existing programs can be pasted into a system. This is, however, wasteful in terms of replicated code. The second approach is to develop a model-based management system, which could consist of small pieces of code, each of which solves a step in the algorithm. As some steps are common to several algorithms, they can be shared, hence reducing the amount of code and making updating easy.

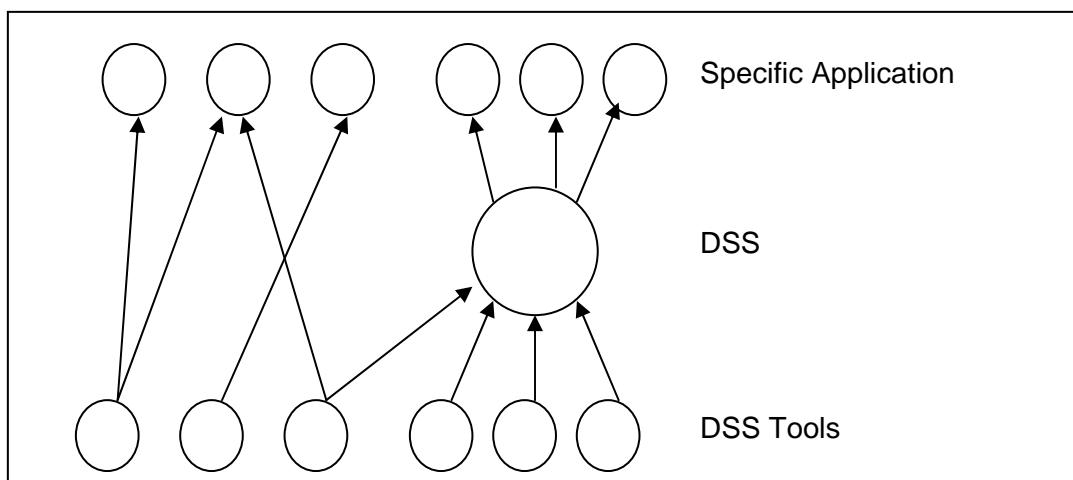
The third level of architecture is the database and management system. According to Densham (1990) and Malczewski (1997), a database for an SDSS must support cartographic display, spatial query and analytical modelling by integrating three types of data, viz.

locational (e.g. co-ordinates and chains), topological (attribute-bearing objects, e.g. points, lines, polygons and the relationship between them) and thematic (attributes of the topological objects). The database must permit the user to construct complex spatial relations between all three types of data.

The database management system could either be a relational, hierarchical, network or object-orientated data model, depending on the data and application. It must have capabilities for managing internal and external databases for data acquisition, storage, retrieval, manipulation, directory, queries and integration.

2.2.2 Technologies for Developing SDSS

The SDSS technology ranges from simple, specific applications to broadly applicable systems. Three levels of technology framework are defined in the literature (Keenan 2004) (see Figure 2-2).



Source: Adapted from Keenan (2004: 5)

Figure 2-2 Technology levels for developing spatial decision support systems

The first level is the system that actually does the work, which can be referred to as the specific DSS. The system addresses a specific problem and its characteristics make it significantly different from others. Examples of such a system include GeoMed (Carver et al. 1998) and IDRISI decision support (Malczewski 1997).

The second technology level is a DSS generator. This is a set of related hardware and software modules, which provides a set of capabilities to implement the specific DSS.

Examples are GIS (e.g. ARC/INFO, ArcView, MapInfo, TNTmips); database packages (e.g. dBase, MS Access); decision analysis and optimisation software; statistical and geospatial software; and simulation software.

The third and most fundamental level of technology applied to the development of DSS is the DSS tools. This is a set of mutually compatible hardware and software items, which facilitate the development of both DSS generators and specific DSS. Examples include: procedural programming languages and code libraries (e.g. Arc Macro Language (AML) scripting tool of ARC/INFO, Spatial Manipulation Language (SML) scripting tool for TNTmips); visual programming languages; inter-application communication software (e.g. open database connectivity (ODBC)); application programming interfaces (API); applets; visual interfaces, graphics and colour subroutines; and simulation languages and software.

2.3 SDSS APPLICATIONS

Spatial decision support systems have been applied in numerous studies from different disciplines with the aim of making the decision-making process effective.

Sekkouri & Ouazar (2002) implemented the Expert System for Groundwater Modelling (ESGWM), an intelligent spatial data preparation system for groundwater modelling. The DSS integrates six main elements: a user interface, database management system, GIS, knowledge base component, parameter estimation tools and models. The major feature of the ESGWM component is the knowledge base, which contains a variety of alternatives for choosing an adequate model and estimating the necessary aquifer parameters. The user is guided through an interactive user interface to operate linked tools (databases, GIS, aquifer parameter tools and numerical models) in order to prepare all required input data.

Sinske & Zietsman (2004) developed an SDSS for pipe-break susceptibility analysis of a municipal water-distribution system. The system architecture is composed of four main subsystems: object query browser for object-orientated analysis, user services, data services and operation services. The functionality of the user interface of the system allowed different levels of access to different levels of users. This ensures that the decision-maker views only what is relevant to solving his/her particular problem. The results can be presented as graphs or thematic maps. The SDSS can give a municipality valuable insight into the specific pipe-break causes, and preventive maintenance can thus be carried out more effectively. The tool

was built so that it can be extended to model other possible causes of pipe-break, though not yet implemented due to lack of available data.

Scott, Goodrich & Levick (2003) developed a management tool to help estimate groundwater demand from riparian vegetation and how the groundwater use will likely change with different management strategies. The tool allowed the user to change vegetation cover within the riparian corridor and allowed for incorporation of new, longer-term measurements. The user-friendly interface allows for easy manipulation of data and would make it possible to communicate results to management agencies and the public. The SDSS is aimed at enabling users to better understand how natural and human-induced change will alter groundwater use in the future.

Dutta (2002) presents the development of AVSWAT (ArcView-SWAT). This SDSS tool is an integration of soil and water analysis tool (SWAT) and ArcView GIS software along with a spatial analysts extension. The SWAT model is able to model both the hydrology and water quality of a watershed; it has eight major model components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides and agricultural management. Because SWAT needs a great amount of time, expertise and cost for acquiring data, running the model and analysing the results, the inclusion of a GIS technology was important. The interactive tools of GIS enable exchange of data between the model and GIS, and the exchange is fully automatic. To perform this, the SDSS entails the use of three key components: preprocessor generation of sub-basin topographic parameter and input parameters; editing processor of input data sets and execution of simulation; and postprocessor viewing of graphical data and tabular results.

2.4 CONCLUSION

According to Keenan (1997), SDSS makes an important contribution to incorporating the spatial dimension in the decision-making process, which has great significance for the management of natural resources. One such natural resource is groundwater and some of the studies above indicate the use of SDSS in this field.

The review of previous studies has provided the guidance as to what capabilities the SDSS must have. These capabilities can be achieved by following suggestions made for SDSS architecture and the use of proper technology. The technology to be used by the study is dependent on user requirements, as different technologies have specific capabilities. The

present study begins with user requirements analysis as the means of deciding what technology to use in order to meet the spatial decision support architecture and therefore fulfil SDSS capabilities.

CHAPTER 3: REQUIREMENTS ANALYSIS

3.1 INTRODUCTION

In any development activity, before the building of an application one needs to know what it must do (Hughes 2005). The inclusion of user input or requirements added to specialist insight will specify how the system is required to perform.

The documenting of these requirements provides a mechanism for all interested parties to discuss what the system should be designed to achieve, and also allows for various conflicting requirements to be analysed and discussed (Assero 2003). Requirements are also needed to confirm whether the goals of the development activity were achieved or not.

The specification document for requirements analysis should contain information about the business process, system users, user data and information requirements, data processing and analysis requirements, and the operational requirements (Hughes 2005). Figure 3-1 gives an outline of this chapter.

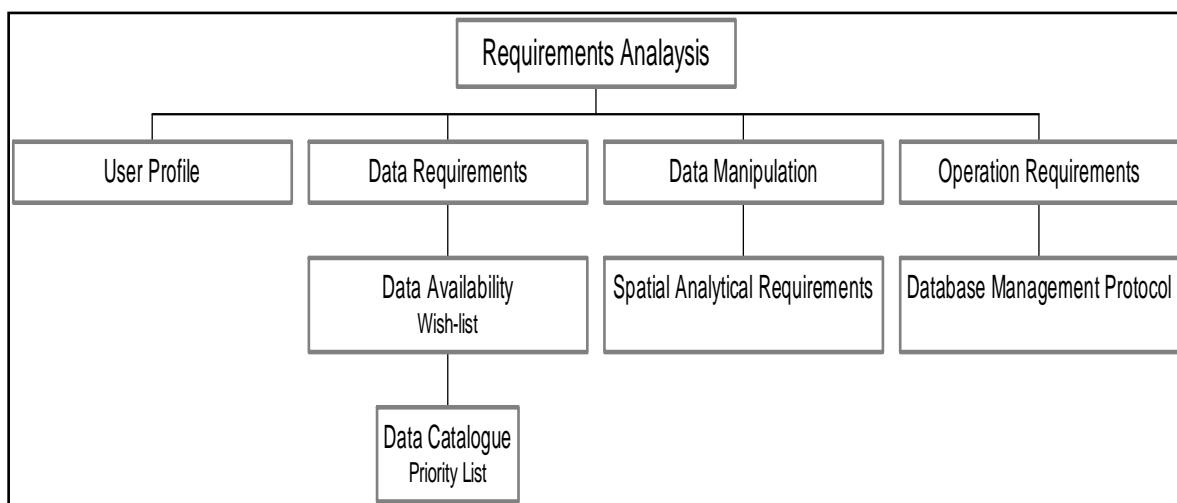


Figure 3-1 Requirement analysis

Requirements may be gathered by a variety of methods. Mouton (2005) lists four data collection methods and describes the specific types of gathering under each method. These methods are: (1) observation, (2) interviewing, (3) testing and selecting and (4) analysing texts. Because questionnaires are always subject to misinterpretation and users are not always aware of their specific needs (Bernhardsen 2002), interviews were conducted to gather

requirements. Different interviewing methods were used depending on which part of the requirements analysis was being carried out. These are discussed in detail in this chapter.

3.2 DECISION-MAKERS

During requirements gathering, system users must be identified before data and other system requirements are established, as the users will be providing the data and system requirements. Once the users have been identified, they must be described, allocated roles and responsibilities (Hughes 2005). According to Sprague & Ralph (1980), there are five evolving roles in DSS. These are the:

- *manager or user* - the person faced with the problem or decision;
- *intermediary* - assists the user to interact with the SDSS;
- *SDSS builder or facilitator* - assembles the necessary capabilities from the SDSS generator to build the specific SDSS with which the user interacts;
- *technical supporter* - develops additional information system capabilities or components when they are needed as part of the generator; and
- *toolsmith* - develops new technology, new languages, new hardware and software and improves the efficiency of linkages between systems.

One person may assume several roles, or more than one person may be required to fill a role. The appropriate role assignment depends on the nature of the problem, how comfortable the individual is with computer equipment, language and concepts, and also the strength of the technology, particularly its degree of user-friendliness.

For this study the last three roles – the SDSS builder, the technical support and the toolsmith – were grouped into one, named the database operator in this project. The project teams of both the WRC ECO and TMGA projects were identified as the users or decision-makers of the TMGA SDSS. These teams are made up of the following companies, each with different specialist expertise: Umvoto Africa (Pty) Ltd, Ninham Shand Inc., CSIR-Environmentek, Southern Waters Ecological Research and Consulting cc, Stellenbosch University Botany Department, and Kellogg Brown and Root (KBR). The decision-makers provide an appropriate blend of regional and international expertise and experience in hydrogeology, terrestrial and aquatic ecology, hydrology, engineering and environmental sciences.

The knowledge of GIS varies from user to user. Some of the users have very little knowledge of GIS in terms of how it works and what it could be used for. In most cases the experts have in-house GIS departments and therefore see no need to be fully able to use the GIS themselves. This can unintentionally limit their understanding of how the technology can be used to their advantage. If this limitation were to be overcome, the in-house GIS departments could play an intermediary role, where necessary.

3.3 DATA REQUIREMENTS

Once the users have been defined, the next step is to look at what information or resources the user is dependent upon in order to perform his or her tasks (Hughes 2005). Spatial data requirements analysis includes both defining data needed and identifying what data are available and their sources.

To carry out data requirements, semi-structured focus group interviewing was done. Through project team discussion, a preliminary data catalogue or wish-list was compiled for data that might be needed for the projects (see Appendix A). At the same time, availability and source information were added where known. Data may be grouped into two categories, primary and secondary data (Heywood, Cornelius & Carver 2002). Primary data is data collected by the team itself whilst another individual or organisation collects secondary data. The latter data category is normally obtained from published sources. In GIS all primary and secondary geographical data have three modes or dimensions (Veregin 1998):

- Temporal, which provides a record of when the data were collected.
- Thematic, which describes the character of the real-world feature to which the data refer. Thematic data is often referred to as non-spatial or attribute data.
- Spatial, can be regarded as the values or character strings that convey to the user the information about the location of the feature.

When acquiring data all three modes of dimension have to be taken into account.

Once the data acquisition process was underway, the wish-list was edited after evaluating whether the available data were suitable for the project or not, and also identifying which data will not be needed, e.g. the initial data requirement list had both the 1:250 000 and 1:50 000 geology map sheets. It was later found that the 1:50 000 map sheets are available for use by the project, therefore there was no need to acquire the 1:250 000 sheets.

The secondary data required were:

- cadastral data;
- infrastructure data;
- topographic and digital elevation model (DEM) data;
- hydrological data;
- hydroclimatology data;
- regional geology data;
- structural geology data;
- environmental data;
- aerial photography;
- satellite imagery; and
- climatic time series.

In terms of primary data, the following were required:

- point source hydrocensus and monitoring data;
- hydrological records for rivers;
- downhole logs, including geophysical logs, drill core description and borehole video;
- point source ecological, specifically vegetation, data; and
- pump test data.

The data required by the users are linked to each user's brief or scope as per the project at hand. Table 3.1 gives a summary of what the users' roles in the hydrogeology projects and their data requirements are.

Table 3-1 Decision-makers' expertise

Scientist	Scope or brief	Data Requirements
Hydrogeologist	Regional geology analysis Borehole siting Water resource evaluation Groundwater modelling Groundwater – surface water interaction	Geology Topography Cadastral data Rainfall Temperature River reaches Monitoring data
Hydrologist	Surface water flow Groundwater – surface water interaction Stream-flow reduction	River reaches Rainfall Land-use Monitoring data
Terrestrial and aquatic ecologist	Botanical study Ecological impacts	Protected areas Sensitive areas Land-use Borehole sites Monitoring data
Engineer	Infrastructure planning Cost calculation	Borehole sites Borehole yield Reservoirs Cadastral data
Environmentalist	Public participation Environmental impact assessment (EIA) process	Protected areas Cadastral data Results of all above

3.4 SPATIAL ANALYTICAL REQUIREMENTS

In the GIS context there is a difference between data, information and knowledge. Data are observations we make from observation of the real world and are collected as facts or evidence (Heywood, Cornelius & Carver 2002). Hence data are the individual record elements in a spatial database. Once the data are processed to give them meaning and context, information is derived. Knowledge is the understanding of possible consequences based on the information derived from the data and a specific line of reasoning followed by the GIS user (Stevens & Thompson 1996). The GIS technician may generate data and information but the GIS user generates knowledge.

Through GIS technology users are constantly transforming spatial data from one level to another, and with each transformation new information is obtained. Data transformation refers to the reconfiguration of a single entity, or a whole set of data. Transformation may involve changing the projection of a map layer or converting data from one data structure to another, e.g. from vector to raster type. Data may be transformed from one data structure to another to prepare them for data analysis. Heywood, Cornelius & Carver 2002 classifies GIS analysis procedures into three types:

- Storage and retrieval operations, e.g. data presentation capabilities.
- Constrained queries that allow the user to discern patterns in the data.
- Modelling procedures, or functions, for prediction purposes.

Bernhardsen (2002) outlines four various levels at which data may be analysed.

- Data in attribute tables are sorted for use in other computer programs or for presentation in reports.
- Arithmetic, Boolean and statistical operations are performed in attribute tables.
- Operations are performed on geometric data, either in search mode or for computational purposes.
- Geometry and attribute tables are used together to compile new sets of data based on original and derived attributes and/or on geographical relationships.

In all these levels, the operations used may be logical, arithmetic, geometric, statistical, or a combination of two or more of these operation types. The operation analysis may be carried out on point, line and or area data and may involve considerations of proximity or of changes over time.

In most cases user requirements have not actually been established so as to ensure that the information gathered from the data transformation will be useful for decision-making. The decision support environment is a way of telling the GIS user what processes and data analysis will in fact be useful (Stevens & Thompson 1996).

The spatial analytical requirements considered what analytical processes the decision-makers would like to have available on the spatial database. Spatial analytical requirements were gathered via individual interviews or as part of team meetings. In cases of individual

interviews the experts in the team were divided according to discipline and a member of each discipline was interviewed, either via the telephone or personally. Out of all the questions asked of users (see Appendix B), the main question was: What kind of information would you like to get from the spatial database (GIS) without having to ask a GIS operator to do any work for you? In other words, what questions would you like independently to ask the GIS to answer for you in order to assist with the decision-making process?

The results of the analysis ranged from basic to advanced GIS operations (Appendix B). The answers given by the users overlapped in most cases, especially with regards to proximity analysis, i.e. where is something located relative to something else? Other requirements put forward were on the user-friendly side, e.g. the spatial database must have a Help function to assist the user on how to use the system.

Even though the majority of experts showed an interest in this project, there were also some who felt that it is something that will not be useful to them. From their own perspective they are more interested in hardcopy maps and hardcopy tables, not in working with computers. A requirement therefore was derived that the SDSS must provide a means for printing results. These decision-makers will be able to get assistance from the intermediate role players, meaning that their in-house GIS personnel must be able to make use of the system. Lack of proper data, whether because of the scale available or simply a lack of data were expressed as a major constraint by most experts, especially the ecologist. Other experts requested that they first see how the SDSS worked before they would volunteer suggestions about data transformation requirements. In general this attitude arose from a lack of understanding of GIS use and capabilities as well as a disinclination to explore them until motivated further, possibly by the results of this project.

3.5 OPERATION REQUIREMENTS

Even though one of the SDSS aims is to make sure data are stored in a database and users are able to query and run analyses on a need-to-know basis, there are cases where access to individual datasets is required. In certain cases the decision-maker may need to use the dataset in a programme that is not linked to the SDSS, in which case the user has to have access to the dataset. Also, because the WRC ECO and TMGA projects are ongoing, new data will be gathered and have to be incorporated into the SDSS.

Operations requirements were collected through the use of semi-structured focus group interviews. An operations requirement considers how the user wants the system to handle data issues; these are the constraints and rules for the use of the system. The main difference between constraints and rules is that constraints are unchangeable, while rules are discussed and agreed upon (Hughes 2005). In a multidisciplinary team, working at different locations with different software, the aspect of data handling, e.g. data sharing, becomes critical to integrated problem conceptualisation and solving. The challenges of data sharing include ensuring access to users of different levels of skill, insight and security clearance, updating and quality control of additional data and metadata, and respecting copyright and intellectual property rights.

To address operational requirements, a management protocol document (Appendix C) was prepared based on team discussion. The following paragraphs summarize this document.

3.5.1 Data Access

There is often uncertainty about the exact meaning of the terms ‘copyright’ and ‘intellectual property rights’ with respect to the way in which such rights operate and how they can be exploited. According to Du Plessis (2001), intellectual property rights describe all the intangible rights, which exist to protect ideas, inventions, creations and their commercial value. Copyright, on the other hand, is the right created by statute to provide protection to the authors of a range of work and forms part of the intangible rights within the group referred to as intellectual property rights.

A number of datasets have copyright for publishing, distribution or changing. The copyright holder is usually, but not always, identical with the owner. For example, these copyrights may specify that data purchased for use on a particular project cannot be used outside of that project; or can be used generally by the organization that has purchased that dataset but cannot be distributed outside of the organisation. The existing copyright for each dataset has to be specified within the metadata and has to be respected and acknowledged in the data-sharing process.

Available datasets would be provided to the team on request; they have to be submitted using a prescribed form. Copyright and ownership have to be acknowledged and respected when using the data, even if the data are not restricted for further distribution. Special care must be taken when using restricted data, referring to datasets that may have other restrictions for

publishing, like cave locations, co-ordinates of archaeological sites (e.g. rock paintings) and co-ordinates for rare plant species. These datasets can only be made available when the purpose of use is specified.

3.5.2 Data Sharing

As the number of GIS packages and users of GIS increase, so do the number of formats available for GIS data. This makes data sharing difficult and means that data created in one system is not always easily read by another system (Heywood, Cornelius & Carver 2002). To solve this problem, GIS system vendors have included data conversion functions in the software. The users may now agree on which formats to exchange the data as per their GIS software requirements.

Data sharing within the project tends to be two-sided: users who request data and users who provide new data to be incorporated into the SDSS. Depending upon the sources of datasets to be incorporated, different requirements and responsibilities for quality control were specified. The requirements focused on data formats and compulsory fields for metadata. An emphasis was put on some of the issues discussed under data access (Section 3.5.1) and on the importance of metadata. The protocol stated an acceptable level of quality for data to be included in the spatial database based on issues such as data completeness, correct GPS co-ordinates, georeferencing, correct attributes and metadata. As most of these datasets would be received from experts themselves, a statement on level of usability was required.

Possible formats for sharing individual data files were stipulated (Table 3.2). The user is required to specify the format, when requesting the data. The same data formats are to be used for data to be incorporated into the database. The SDSS was built using TNTmips® and TNTatlas®, which are TNT products developed by MicroImages.

Table 3-2 Available data-sharing formats

Table Formats	DBase III / IV		
Vector Formats	Arc/Info “Coverage”	Arc/Info “Export” (E00)	ArcView “Shapefile”
Raster Formats	GEOTIFF / TIFF /MRSID /JPEG (incl. Georeference header-file)	Arc/Info BIL/BIP	ERDAS-IMG
Projection	UTM/Gauss Conformal	Geographic WGS84	Latitude/Longitude WGS84 (GPS data only)

3.6 CONCLUSION

Requirements analysis gave both the project team and spatial database designer information and an understanding of what the system is required to do. The process also allowed the project team to seriously consider what GIS means to them and what their expectations were. The project team was able to register lack of data or availability of suitable data once they began to think spatially. The spatial database designer learnt that there is no such thing as a simple data transformation step, and that user requirements must control the data transformation to be performed by the GIS technician.

The next chapters will look at how the user requirements were implemented into a spatial decision support system.

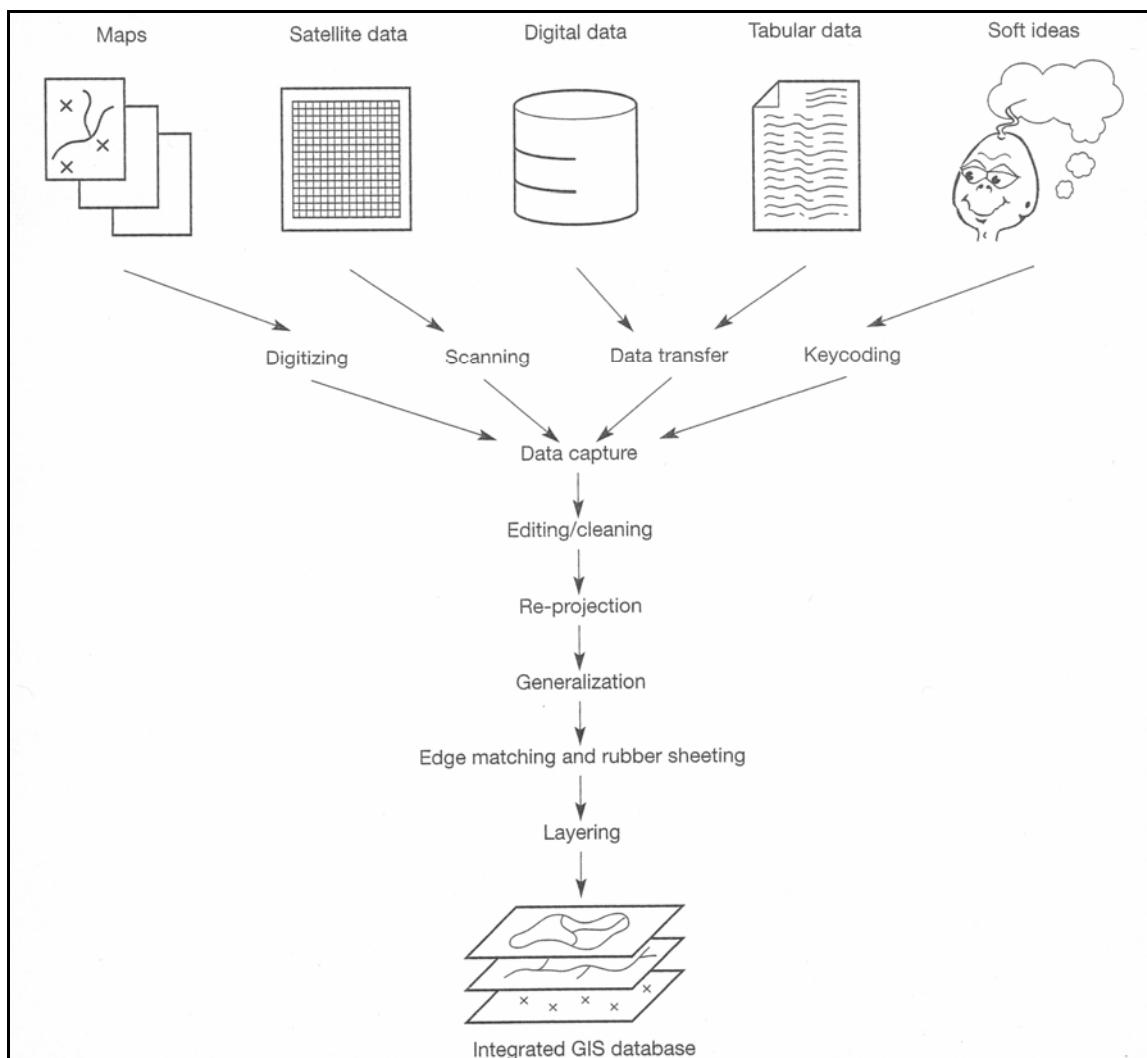
CHAPTER 4: DATA ACQUISITION AND PREPARATION

The first step after establishing user requirements in the development of a spatial database for a GIS is to acquire the data and to input it into the system (Star & Estes 1990). Through the establishment of policies on data sharing and access to information like the Promotion of Access to Information Act (No 2 of 2000) and the Policy on the Pricing for Spatial Information (2002) and the Spatial Data Infrastructure Act (No 54 of 2003), data is becoming available for less cost of effort and access to data providers is more transparent. Though the models that use the data are important to support decision-making activities, a large amount of investment will still be needed in collecting, converting and storing the new data (Bernahardsen 2002).

The process of data acquisition, preprocessing and storing is summarised in Figure 4-1. Data to be input into a GIS are typically acquired in different formats. Some data are received in graphic and tabular format. These would include maps and photography, records from site visits, related non-spatial information from both hard copy and digital files. Other data are received in digital format. These would include digital spatial data such as computer records of farm boundaries and remotely sensed imagery.

Often these data sets will require manual or automated preprocessing prior to data encoding, for example scanning of hard copy maps, digitizing of specific data needed for analysis, manual entering of attribute information from tabular records and numerical rectification algorithms to convert data to a standard georeferencing system.

A crucial and sometimes overlooked issue during data acquisition is that of metadata. Obtaining information about the accuracy, currency, georeferencing systems and other information about the data is very important, and this information is known as metadata.



Source: Heywood, Cornelius & Carver (2002: 90)

Figure 4-1 The data stream – the process of data encoding and editing

4.1 DATA ACQUISITION

Two types of data to be input into a GIS can be identified as spatial and attribute data. A variety of data sources exist for both spatial and attribute data and the most common are:

- hard copy maps;
- aerial photographs;
- remotely-sensed imagery;
- point data samples from surveys;
- existing digital data; and
- textual or tabular data.

In any project, it is best to find out if the required data exists before starting on creating the data. The difficulty is knowing where to look, what to do when one finds the data one requires and how to get it into the GIS (Clarke 1999). Places to look include data custodians, whom are normally government departments; map agencies; commercial data companies; experts in the field of interest; leaders of previous projects carried out in the relevant study area; and the World Wide Web. When the location of the data has been established, the user must ask the following questions:

- What data are available?
- What will the data cost?
- On what media will the data be supplied?
- What format will the data be in and will it have metadata?

Once the data have been acquired, the encoding process occurs. Encoding is the process of getting data into a computer or GIS. There are at least four basic procedures for encoding data into a GIS (Tyson 1999) (see Figure 4-1). These are:

- digitizing;
- scanning;
- GPS and entry of co-ordinates using co-ordinate geometry; and
- import and conversion of existing data.

Scanning and digitizing are the most used methods of capturing existing hardcopy maps into digital form. Scanning automatically converts the analogue map into a computer readable form. The scanned map can be used digitally as a background image or be converted to vector data by an automated process or by a digitizing process, using a digitizing board or on-screen digitizing as is available on the latest GIS systems. An increasing amount of data is collected in the field using a global positioning system (GPS) or co-ordinate geometry (COGO) procedures. The COGO procedure involves entering, from survey data, the explicit measurement of features from some known monument. This method is normally used for creating very precise cartographic definitions of property, but not for natural resource applications. In natural resource applications a GPS is preferably used. A GPS will collect individual points, lines and areas in any combination necessary for the project. Location data and associated attribute data can be transferred to a GIS (GISWEB 2006).

Though data may be available for a project, it might be in a format that the project's GIS cannot read. Data conversion methods have allowed users to be able to convert the existing data for input in their GIS. For example, many GIS packages can now read shapefiles and computed assisted design (CAD) files. Similarly, CAD files can be converted to vector or raster, and the reverse is also true. New data can be created using these conversion methods.

Based on user data requirements, data to be input in the GIS for the SDSS were acquired from different sources and in different formats. The acquired data may be grouped in the thirteen categories set out in the following sections.

4.1.1 Topographic and Cadastral Data

The topographic data acquired comprised contour lines at 20metre interval and spot heights. The data were acquired in shapefile format as lines and points respectively at a scale of 1:50 000 from Chief Directorate Surveys and Mapping (CDSM) in Mowbray, Cape Town. The data were received as 15 individual files as per each 1:50 000 topographic sheet.

The contour-vector objects were transformed to a raster format, rectangular-grid arrays of terrain heights, through a surface-fitting operation, which involves interpolation to a regular grid using a minimum curvature method. A two-dimensional (2D) cubic spline function is applied iteratively to fit a smooth surface to the set of input elevation values, so that the final result has a minimum amount of curvature. The DEM has 20 x 20m cell size, and a vertical resolution of approximately 5m. The image has been checked to ensure that there are no linear edge artefacts at the junctions between map sheets.

Apart from this primary DEM product, GIS maps of slope and aspect have also been produced in the expectation that they will prove useful to other TMGA project tasks, especially during later phases of the study.

4.1.2 Cadastral and Infrastructure Data

The cadastral data were requested from the Department of Land Affairs, Surveyor General's Office in Cape Town and from the Demarcation Board website. The 1:50 000 digital data provided by the Surveyor General were in feature-file format that had to be converted to shape file before the data could be imported into the GIS. The acquired cadastral data included farm boundaries, municipal boundaries and towns. The attribute data associated with the farm and municipal boundaries gave the registered number of each polygon. The

disadvantage is that no names were allocated, only the codes. Though this makes sense in terms of databases and especially since things like farm names change a lot, it was still found not to be user-friendly to have only the codes. The data both from the Surveyor General and the Demarcation Board did not contain any metadata, especially in terms of the currency of the data and how the boundaries were captured.

4.1.3 Infrastructure Data

Data acquired included 1:50 000 roads, railway lines, and dams from CDSM in Mowbray. The data were received in shapefile format. The attribute data give information about the codes and/or names of the features and the version of each feature in the file. The metadata is given in the attribute tables. This information includes the version number of the feature and the year of capture. Other infrastructure data to be used in the later stages of the project, like power lines, still need to be captured

4.1.4 Hydrological Data

The acquired data included rivers captured at 1:50 000 scale by the CDSM in Mowbray. The rivers are classified as being either perennial or non-perennial.

The drainage network of the selected area covers 57 quaternary catchments in the G and H primary drainage basins, of which only 29 are considered relevant for the study. The polygon file included attribute tables with precipitation and run-off information. These datasets were acquired from the CD accompanying the published report *Surface Water Resources of South Africa 1990* (Midgley, Pitman & Middleton 1994).

4.1.5 Hydroclimatology Data

Hydroclimatology data refer to spatial distribution of mean annual data. The Computing Centre for Water Research (CCWR) provided gridded mean annual precipitation (MAP) and related monthly hydroclimatic data for the project area. Compared to the previously published maps (Midgley, Pitman & Middleton 1994), this data provides a better resolution of precipitation patterns over the higher mountain terrain. The range varies from ≈ 200 to 3 400mm/a.

4.1.6 Climatic Time series

Climatic time series refers to climate data that is four-dimensional. The daily records of minimum and maximum temperature, and rainfall for the years 2001 and 2002 for official weather stations in and close to the study area were acquired from the South African Weather Bureau. The list comprises 37 weather stations at altitudes between 4masl and 747masl.

4.1.7 Aerial Photography and Satellite Imagery

Digital JPEG copies were acquired of a set of 1:10 000-scale colour aerial photos covering a key portion of the TMG Project area from the Department of Water Affairs and Forestry. Additional aerial photographs were acquired from CDSM in MrSid format. In addition, selected orthophotos (1:10 000 scale) out of the complete set of acquired orthophotos the study area were scanned and georeferenced to create raster copies.

The acquisition of satellite imagery was restricted to Landsat data, as ASTER imagery covering the study area were not available. Two scenes, path 175 row 083 and path 175 row 084, of Landsat 7 enhanced thematic mapper plus (ETM+) imagery were acquired. The ETM+ has seven multi-spectral bands with 30m-pixel resolution and a higher resolution, 15m, in the panchromatic band (Table 4.1).

Table 4-1 Landsat 7 ETM+ characteristics

Swath width:	185 kilometres	
Repeat coverage interval:	16 days (233 orbits)	
Altitude:	705 kilometres	
Band Number	Spectral Range (microns)	Ground Resolution (m)
1	0.45 to 0.515	30
2	0.525 to 0.605	30
3	0.63 to 0.690	30
4	0.75 to 0.90	30
5	1.55 to 1.75	30
6	10.40 to 12.5	60
7	2.09 to 2.35	30
Panchromatic	0.52 to 0.90	15

Source: NASA (1999:)

Imagery of different dates were acquired given the different needs of the project team. For change vector analysis (CVA), to map locations of vegetation associated with groundwater discharge, end dry-season (March) and end wet-season (July) imagery for the year 2001 were required by the team, but due to cloud cover acquired imagery dated March 2001 and September 2002. These images still had clouds in certain places, so for geological and structural mapping, November 2001 imagery were acquired.

4.1.8 Regional Geology and Structural Data

Existing geological mapping data, at a scale of 1:250 000, covering neighbouring parts of the Worcester sheet 3219 (Gresse 1997) and the Cape Town sheet 3218 (Theron et al. 1992) were acquired through digitally scanned images of these maps.

The 1:250 000 maps were found to be of regional scale and maps at a more detailed scale were required for the project. Shape-file format coverages (area polygons) of the different lithostratigraphic units within and immediately adjacent to the TMG, and of the major structural features in the region (line vectors, e.g. faults; and point vectors, e.g. dip and strike), were obtained from official mapping conducted at 1:50 000 scale by the Council of Geoscience (CGS). This data were collated and supplied to the TMG Project by the CGS under a special contract, as the 1:50 000 geological maps of the area were only available in field-sheet format. The data were received in 15 individual 1:50 000 vector polygon sheets.

Structural geological data were acquired in two ways, the first, the 1:50 000 fault lines, were received from the CGS with the vector geological maps. The second method of capture was via remote sensing. The remote sensing structural interpretation involved data collection through aerial photographic interpretation (API), Landsat 7 ETM+ image processing and interpretation, DEM and their derivative products, and fracture analysis by way of conventional structural geological techniques. The fracture-trace analysis was conducted at 1: 100 000 scale and at 1: 40 000 scale from Landsat. In addition, a comparative lineament study based on variously sun-shaded DEMs was undertaken to augment the Landsat-based interpretations. Later in the project a 1:10 000 fracture lineament capture was undertaken from the orthorectified imagery.

4.1.9 Ecological Data

The spatial layers, available without copyright constraints for the general Cape Action Plan for the Environment (CAPE) data sets and the Succulent Karoo Environmental Plan (SKEP) component of the CAPE project, were downloaded from <http://cpu.uwc.ac.za>. No information has been added or removed from the metadata sets as yet, although the input to the database prepared for this project comprises only a subset of the CAPE data.

There are three different data sets:

- Statutory protected areas:
 - Provincial nature reserves;
 - Local authority reserve core;
 - Protected nature environment;
 - Private nature reserves;
 - Biosphere reserves;
 - Mountain catchment areas;
 - National Heritage Sites; and
 - Other areas, listed in the CAPE data catalogue, such as marine reserves and national parks, are not located in the study domain and, hence, not incorporated.
- Ecological sensitive areas:
 - SKEP lower vertebrates, which are subdivided into amphibians, reptiles and bony fish;
 - SKEP expert plant;
 - SKEP expert fish;
 - Sensitive wetland areas, containing separate spatial layers for dams, lagoons, rivers, vleis, salt pans and small vleis;
 - SKEP planning domain spatial layer, which is subdivided into Hantam-, Tanqua-, South Karoo and Roggeveld;
 - SKEP geographic priorities; and

- Other areas, listed in the SKEP data catalogue, such as mammals, birds, reptiles, amphibians, invertebrates, insects, are not located in the study domain and, hence, not incorporated.
- Classification maps, comprising
 - Broad habitat units (BHU);
 - Untransformed land; and
 - Irreplaceability values.

In addition, the vegetation classification, produced by the National Botanical Institute (NBI), was acquired and incorporated into the GIS database to supplement the BHU mapping obtained from CAPE.

The Subtropical Thicket Ecological Plan (STEP) data are outside the study domain but provide interesting perspectives on other TMG domains. These data are not yet web-served. Thus it has not been possible to access these data but it is expected that they will become available.

4.1.10 Vegetation Indices

Image processing applications for vegetation monitoring were conducted, using the satellite images mentioned in Section 4.1.17. The normalized difference vegetation index (NDVI) uses band 3 and band 4 of Landsat 7 ETM satellite; the tasseled cap index (TCI) uses all Landsat 7 ETM bands except for the panchromatic band and produces the brightness, greenness, and wetness images; and change vector analysis (CVA), which calculates the magnitude and direction of change between two images, either for different seasons or different years. CVA also enables the production of negative or positive vegetation anomalies, which may indicate groundwater occurrence.

4.1.11 Point Source Hydrocensus and Monitoring Data

Regular hydrocensus surveys will feed vital information into the upcoming EIA process as well as the ongoing long-term monitoring programme (City of Cape Town, CMC administration 2006). Hydrocensus data are acquired through field surveys undertaken at six-monthly intervals, to coincide roughly with the start and middle of the hydrological year in the Western Cape region, i.e. around October/November and April/May, respectively.

Four pertinent data series for analysis of the hydrocensus results are water levels, flow, temperature and water quality. Oxygen and hydrogen isotope measurements have also been obtained. The hydrocensus began with the collation of all publicly available data sets and a preliminary review thereof. The data were collected from the National Groundwater Database (NGDB) of the Department of Water Affairs and Forestry and from the Berg River Hydrocensus. It was followed by a field verification of selected data sets during April 2003. The field verification also included collection of new sites. The point source data coverage include, boreholes, springs, streams and seep zones. The hydrocensus will continue for the duration of the project until an expanded and detailed monitoring programme starts, which is anticipated to begin before the exploration phase of the TMGA project.

4.1.12 Point Source Ecological, Botanical and Monitoring Data

The ecological data are based on measurements of macroinvertebrates and diatoms. The macroinvertebrate samples were collected on roughly a six-week basis starting from July 2004. Nine monitoring points were selected in the two streams in Purgatory catchment and five monitoring points were selected in the stream in Oudebosch catchment (Kogelberg Nature Reserve). All the biotopes: stones; vegetation; and gravel, sand and mud (GSM) present were sampled together, resulting in one sample per sampling point. The GIS has the location of the point in the sampling area and information related to the measurements taken.

Diatom collection was undertaken during the flow-sampling trips and at each flow-sampling point. The botanical investigation was carried out at Kogelberg Nature Reserve. The measurements, which included botanical description, are still to be added to the GIS.

4.1.13 Other Data

The following data will be collected during or after the exploration phase of the TMGA project:

- Hydrological records of rivers;
- Downhole logs, including geophysical logs, drill core description and borehole video; and
- Pump test data.

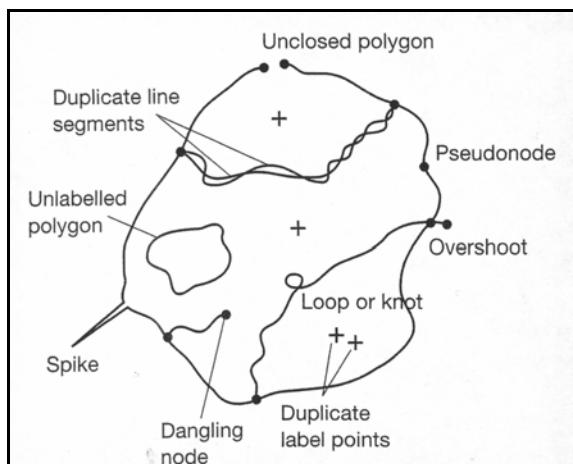
An inventory of acquired data were created and it is updated every time new data are received (Appendix D).

4.2 DATA PREPROCESSING

Data preprocessing, commonly known as data editing or cleaning, looks at editing errors in input data which may come from three main sources: errors in the source data; errors introduced during encoding; and errors derived during data transfer and conversion. Data preprocessing covers three topics; detection and correction of errors; re-projection, transformation and generalization; and edge matching and rubber sheeting (Heywood, Cornelius & Carver 2002).

4.2.1 Detection and Correction of Errors

It is important to detect and correct errors in data from the beginning stages of data input to minimize the amount of error at the later stages of data analysis. Several kinds of errors may occur during data encoding. Heywood, Cornelius & Carver (2002) gives an illustration of some of the vector errors (see Figure 4-2).



Source: Heywood, Cornelius & Carver (2002: 100)

Figure 4-2 Examples of spatial error in vector data

Buckley (s.d) and Martin (1996) classify the different types of errors as follows:

- Incompleteness of the spatial data, which includes missing points, lines or boundary segments.
- Duplication of the spatial data, which includes points, lines or polygons that have been digitized twice.
- Misplacement of the spatial data, which includes points, lines or polygons digitized in the wrong place. These types of errors are usually the result of careless digitizing or poor quality of the original source data.
- Distortion of the spatial data, e.g. cases where the base maps are not scale-correct over the whole image, because of aircraft movement or differential stretching of the base map, which occurs with paper documents.
- Missing labels or mislabeling of spatial data, this includes spatial features being assigned a wrong attribute or more than one feature being assigned the same attribute, e.g. a road labelled as a railway line.
- Artifacts of digitizing, during which a number of errors may be made, including some of the errors mentioned above. The common artifacts are undershoots, overshoots, wrongly placed nodes and sliver polygons.
- Noise, which is a kind of error that normally occurs with airborne imagery. Due to sensor errors or atmospheric conditions noise may be present in the image. This is noted by speckleness in the image or dark areas where it would not normally be dark. There are filtering processes that can be applied to minimize the effect of noise in the imagery (Jenson 1996). Depending on the type of noise and filtering process, data may be lost during the filtering process.

Because the data has been collected from different sources, the checking and correction of errors is crucial to bring the data into a standard data quality. The process also allows for updating the data catalogue in terms of what data is actually usable.

4.2.2 Re-projection, Transformation and Generalization

Once data has been encoded and edited, it may be necessary to process the data geometrically in order to provide a common framework of reference for all data sets (Bernhardsen 2002). Data for the project was received in different projects. Data received in different projects and different co-ordinated systems need to be re-projected and transformed into a common

projection and co-ordinate system before it can be combined or analysed or else the data will not plot accurately. The projection system used for the project is Universal Transverse Mercator, Zone 34(18 to 24) South. This system has a central meridian of 21E and the datum used is World Geodetic System 1984 (WGS 84).

Generalization is intended for when data derived from differently scaled maps are to be used together for analysis. Data derived from larger-scale mapping is generalized to be comparable with the data from smaller-scale maps. The simplest technique for generalization deletes points along a line at a fixed interval. The disadvantage of this technique is that the shape of features may not be preserved. Another simple technique is applied using attribute data. This method allows that certain features be given a group attribute instead of individual specific attributes.

In raster data the most common method of generalization is to amalgamate pixels with the same attribute value. This method may result in loss of data. Filtering algorithms are also used for generalization and the loss of data is better controlled. When the reason for generalization is to save storage space, it may be better to perform a data compaction technique as this will result in a volume reduction without loss of detail. The size of the data image also plays a role in display time, i.e. the larger the dataset the longer it may take to display. The project used the raster pyramiding technique to reduce display delays. The pyramiding process creates tiered raster objects and saves them as sub-objects of the original raster object (MicroImages 2005). The display processes extract the tier needed for the current viewing parameters, but the structure of the pyramid is not apparent to the user.

4.2.3 Edge Matching and Rubber-sheeting

Edge matching compares and adjusts features along the edges of the neighbouring map sheets to create a seamless map sheet (Haithcoat s.d.). The project study area extends over 15 1:50 000 toposheets. Data acquired from CDSM and the Council for Geoscience was received in individual 1:50 000 toposheets. The data had to be joined together to form a seamless map of the project area. Particular attention was given to the edges where the maps joined, to make sure that the lines and boundaries from the different sheets matched properly. Edge matching can be difficult as sometimes different people, using different mapping methods and labelling, produced the maps from which the data were acquired.

Rubber sheeting or warping involves stretching the map in various directions to fit with the control points. The process corrects internal distortions within individual map sheets that might have come from the source data. This error is normally common with data captured from aerial photography caused by the movement of the aircraft and camera lens. When using this process the user must have enough control points covering the map area otherwise unrealistic distortions in some areas may occur.

4.3 METADATA

The matter of neglecting to gather or obtain information about the data during data acquisition is noted in literature (Star & Estes 1990). The information to be obtained includes the georeferencing system and scale, accuracy, precision and currency of the data. This information about data is known as metadata. NISO (2004) defines metadata as structured information that describes, explains, provides information about location, and the use of a dataset. The information includes source of data, date of capture, projection information and description of the dataset, as well as what the layer was meant to be used for. From a data management perspective, according to ESRI (2002), metadata benefits an organisation in its investment in spatial data in the following ways:

- Provides an inventory of data assets.
- Helps determine and maintain the value of the data.
- Helps determine the reliability and currency of the data.
- Helps keep data accurate.
- Helps with project planning and budgeting because it provides a clear understanding of when or if data needs to be collected or updated.
- Supports decision-making.

Metadata informs the user about data type and purpose, e.g. information about the scale at which the data were captured warns the user that the data will not necessarily be relevant or able to provide information at a much *smaller* or much *larger* scale. This is especially important when the data is going to serve multi-disciplinary users and/or some users are not fully GIS literate. Furthermore, information on the method of data capture and the individual involved gives an indication of accuracy and possibly the quality of the data. This is very

important for maintaining data quality and assurance as well as supporting hand-over between different team members in the course of and closure of a project.

Official metadata standards organisations, like the South African Bureau of Standards (SABS), Federal Geographic Data Committee (FGDC) and the International Organisation for Standardization (ISO) TC 211, define metadata standards. The project adhered to the common metadata standards to produce metadata for the project (Appendix E). The project metadata is updated every time a change occurs in the data.

4.4 CONCLUSION

Data acquisition, encoding and editing are time-consuming processes in a GIS project but they are the basis and cornerstone of the type of product the GIS will provide. This stage allows the SDSS operator to get to know the data and in that way evaluate how the SDSS will appear and how the analytical queries can be achieved.

This chapter described the collection and preparation of the data for analysis and presentation. The following chapter will consider the design and implementation of the SDSS.

CHAPTER 5: TMGA SPATIAL DECISION SUPPORT SYSTEM

The requirements analysis informed the planning and development of the Table Mountain Group Aquifer Spatial Decision Support System (TMGA SDSS). The TMGA SDSS was built using a GIS, databases, and programming tools. The chapter discusses the design and development of the TMGA SDSS, beginning with the design of the user interface by means of an Atlas interface and the system dialogue window. The development of the spatial analysis tools is discussed in this chapter as well as the dissemination of the TMGA SDSS.

The development of the TMGA SDSS went through a number of iterations as the users were presented with the results and their comments were incorporated into the development of the SDSS.

5.1 GIS AND USER INTERFACE

The dialogue generation and management system of an SDSS could also be called a user interface. The main function of this system is to provide a platform for the user to interact with the analytical procedures and database management system.

The interface has to meet certain standards as discussed in the previous chapter. One of these is that it must be user-friendly and simple for the user to understand. There are various ways of setting up the user interface, depending on how the SDSS application has been designed and what it is intended to do.

The user interface for the TMGA SDSS has a two-fold design. The first part of the interface is the front end of the GIS, and is termed the Atlas. The second part of the interface links the user to the GIS data and the spatial analytical tools.

5.1.1 Atlas Interface

One of the challenges and motivations that supported the building of the TMGA SDSS was to make spatial data available to the project team in a structured manner. The Atlas allows for the data to be presented in a structured way, thereby making it easy for the user to find the data and view it. The Atlas acts as a user interface as the user is unable to see where the data are actually stored or what its format is. He/she therefore does not need to know how the data are structured in the actual GIS as the data have already been structured and prepared for viewing in a user-friendly way.

Each data layer input into the Atlas has to be carefully checked and prepared for viewing. Tables 5.1 and 5.2 give a check-list of elements to be checked on raster and vector data layers respectively.

Table 5-1 Raster data check-list

Action	Details
Object Name	An understandable name must be used
Object Description	A concise, informative description must be given
Map Projection	Set up correct projection parameters and resample to projection
Contrast	Set up best contrast stretch to enhance data visibility
Colour Table	Where a colour table is needed, set the most appropriate colour palette and check that the legend is set to read the colour table
Data Tip	Set appropriate data tip with suitable labels
Metadata	All correct metadata must be captured

Table 5-2 Vector data check-list

Action	Details
Object Name	An understandable name must be used
Object Description	A concise, informative description must be given
Check & Clean Elements	Remove dangling lines, undershoots; clean up sliver polygons; remove excess nodes; check all polygons are closed
Map Projection	Ensure a proper metric projection has been used. Geographic or latitude/longitude are not true projections. This allows distance spatial analysis and measurements to be performed on the data
Set up Data for Fast Display	Check the display speed of the data
Validate	To clean up topology and make sure standard attribute tables are built
Attributes	Make sure proper attribute tables are built and have all relevant information Use consistent naming, consistent spelling and capitalization Use string expressions/computed fields to clean up, simplify or add to tables Check attributes for styling Check attributes for datatips

Styling	Adhere to styling and cartographic standards where possible, e.g. rivers are normally blue lines
Scale Controls	Set up minimum and maximum scale the object should be viewed at
Metadata	All correct metadata must be captured

The structure adopted in the study is that of single layer or one-level structure layout. A one-level structure allows for different data sets to be overlaid. In cases where the database contains different types of data that may be grouped into different sections depending on viewing requirements of the user, a structure layout of more than one level may be developed. Based on the user requirements for the TMGA SDSS it was determined that a one-level structure would be an efficient and adequate beginning, given the generally low level of GIS competence amongst the specialist scientists and the data integration requirements.

Though the Atlas may be a single level structure, it is possible to subdivide the data into groups, based on the relations between the data layers. The data layers were grouped together into meaningful themes, e.g. all cadastral data layers were put under the theme Cadastral (Figure 5-1). The theme layers were then ordered according to the appropriate sequencing of different visual options, e.g. raster themes below vector themes. Then within each theme the layers were ordered according to cartographic conventions, in terms of symbols and colours used (Robinson et al. 1995), e.g. roads are red, overlain on rivers, which are blue.

The display of the themes in the Atlas has to be defined. The available horizontal and vertical linking options are for displaying the groups either next to or on top of each other, using options like centre-to-centre, left-to-right and geographic with regards to a specific group. The option used in the SDSS is the geographic attachment option. The geographic option is preferably used to attach georeferenced groups ‘geographically’. This forces the attached group to have the same projection, zoom, and orientation as the reference group. These measures ensure that the georeferenced data layers overlay properly.

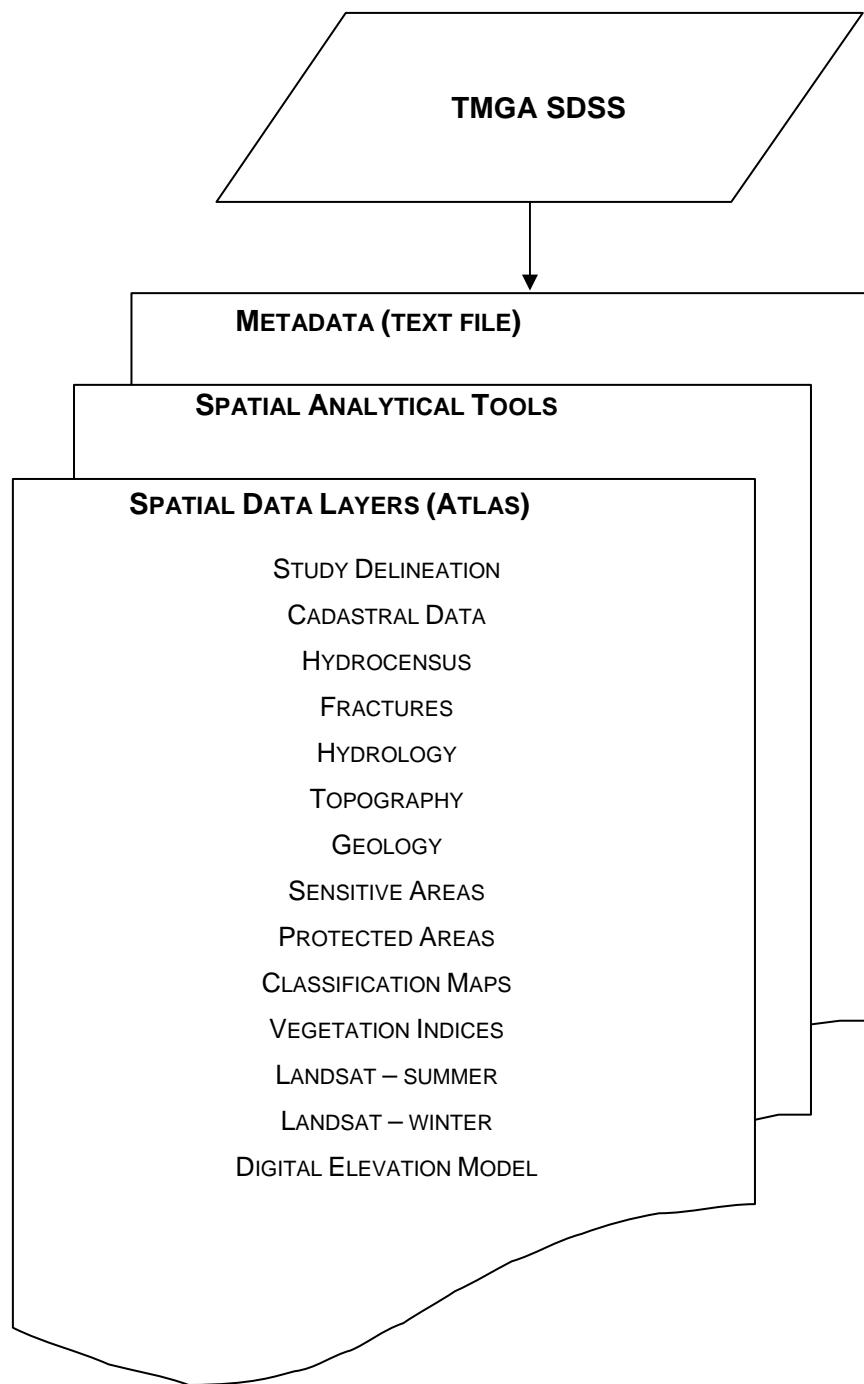


Figure 5-1 Table Mountain Group aquifer spatial decision support system (TMGA SDSS)

Other useful group settings for better presentation of data in an Atlas include the global and minimum scale options. The scale ranges are used to control the display scale of the data layers, as the user might want to see only certain features at a certain scale (Figure 5-2). For example, only national roads may be seen at a scale of 1:250 000, while at a scale of 1:50 000 the user can see roads at both a national and street level.

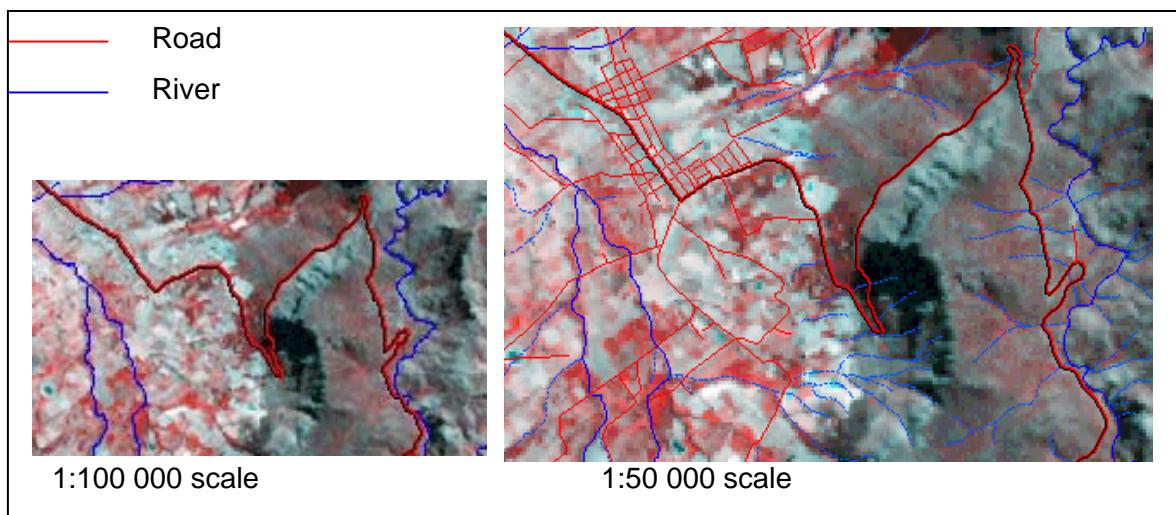


Figure 5-2 Feature scale display control

The scale settings assist to make sure that the data view window is not cluttered with information, especially at global scale, where too-detailed information is not needed. The scale display controls are also useful to ensure that data is not displayed at an improper scale. The Landsat imagery, for example, has been set to a maximum scale of 1:25 000. If the user zooms to a larger scale the image will disappear because at the larger scale the image will show up as pixels, therefore not useful to the user.

The Atlas was developed on TNTatlas®, which is a free software available from MicroImages for viewing hierarchical atlases prepared in TNTmips®. It has almost the same display and viewing functions as found on a GIS and therefore allows the user to interact with the data. The installation and use of TNTatlas® is described in detail in the tutorial ‘Using TNTatlas® for X Windows’ (MicroImages 2003).

The components of the Atlas are grouped into three windows:

- View window,
- Layer Manager, and
- HyperIndex Navigator.

The hyperindex navigator window is not implemented in the TMGA SDSS.

The view window (Figure 5-3) contains the graphical display area, the legend view, the menu bar and several icons for commanding the program. The grouping and sequence of data

layers within the legend view are equal to the structure of themes shown in Figure 5.1. The user may switch theme groups and data layers on and off (toggle in legend view), zoom in, zoom out and redraw as per user preference (relevant icons). Icons that are normally available on TNTAtlas, but that the user will not need have been removed to make the view window less cluttered.

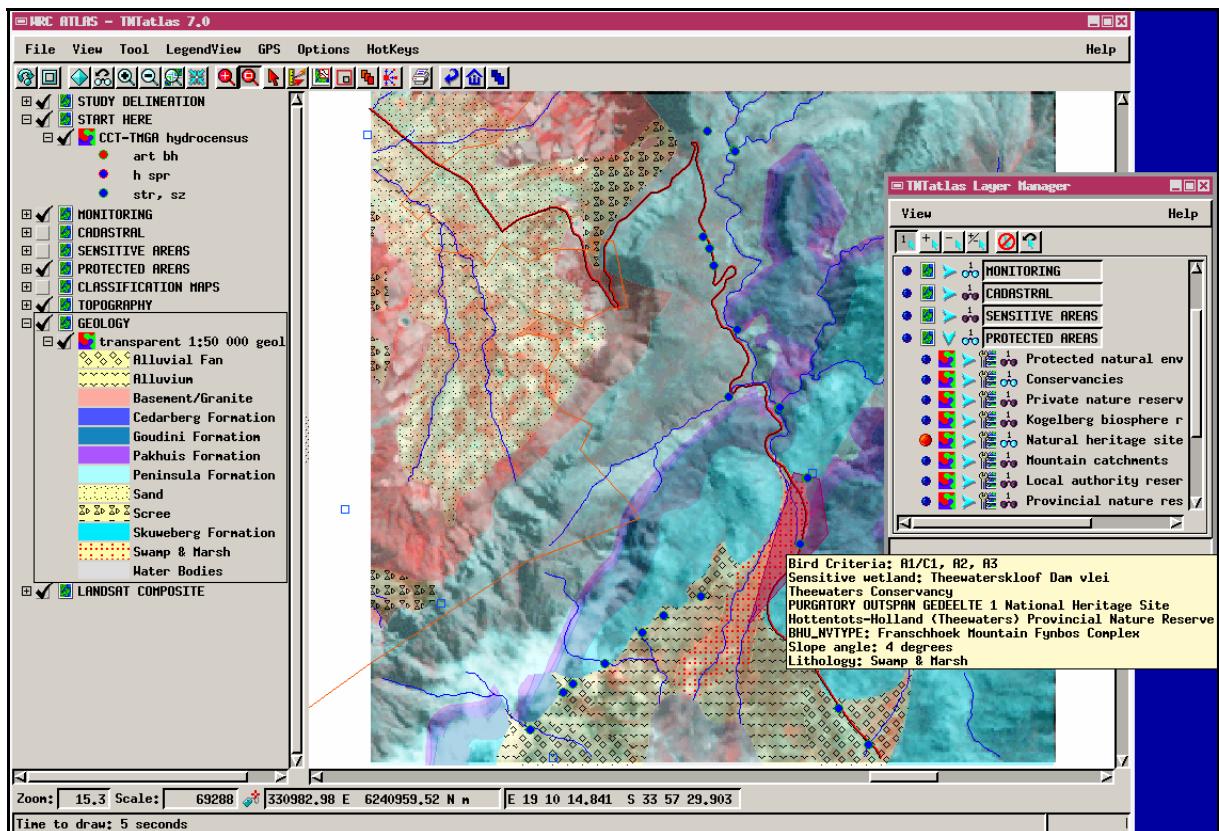


Figure 5-3 Digital Atlas window

The printing function allows the user to print the current contents of the graphical display area at the selected scale. When the user is unsure about how to operate the Atlas, a Help function is available.

Access to the attribute databases of the data layers is possible via the Layer Manager. The user can view the table contents, select specific elements from the list or query the database. A predefined “datatip” with relevant information is displayed. The datatip gives the user information about layers in the position of the cursor. The datatip has been set up in a way that the user may see information about hidden layers that are also in the cursor position.

Amongst other functions available to the user in the Atlas is the Geotoolbox (Figure 5-4). This tool enables the user to draw measurement elements, like the ruler or an area, based on

the data layers. The toolbox also allows the user to draw regions of interest.

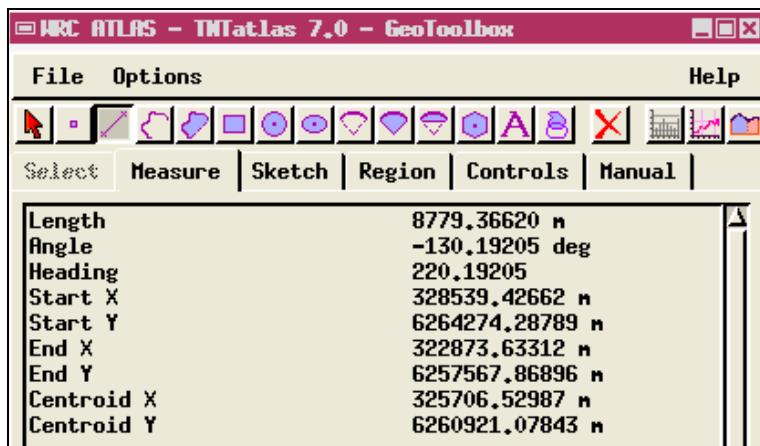


Figure 5-4 Geotoolbox window

The statistical result from the toolbox may be saved as a text file. The toolbox also has a profile view and can generate cross-section functions.

5.1.2 Dialogue Window

Once all the data were assembled in the Atlas, spatial analytical tools were developed. An icon representing the tools was attached on the menu bar of the Atlas window (Figure 5-3). The spatial analytical tools retrieve the spatial database from data layers in the Atlas. When the user selects the icon, an interactive dialogue window is opened for the user to start using the spatial analytical tools (Section 5.2).

The spatial analytical tools interface was designed using the Extensible Markup Language (XML). The main difference between XML and HTML is that HTML is about displaying information, while XML is about describing information (W3schools s.d). A markup language is a set of words and symbols for describing the identity of pieces of a document, e.g. ‘this is a menu list’. XML tags are not predefined; the user must define the tags.

The language therefore allows for the creation of push-and toggle buttons, tabs and list menus amongst other dialogue widgets. Each of these widgets has specific ways of responding and specific functions that they perform, e.g. a toggle button does not perform the same function as a push button. The use of pull-down menus and push buttons make the interface accessible and easy to use.

According to Fedra (1995) and Ascough et al. (2002), the interface must have visualization capabilities either in the form of graphical and/or tabular display. The dialogue window has a

results display panel, for displaying text results. These results may be saved in a text file, using the save button. The graphical results can be viewed in the Atlas viewing window.

Other added functions of the interface window include:

- The cancel button, which allows the user the flexibility to recover from unintended actions.
- The help button gives the user information about how the dialogue window and the analytical tools work.
- The save function which enables the user to save text results of the analytical procedures.

The dialogue window is designed to receive the user queries and to print or display results.

5.2 SPATIAL ANALYTICAL TOOLS

The spatial analytical tools were developed using the Spatial Manipulation Language (SML). SML is a programming language that allows one to write scripts that operate on the spatial data (Smith & Ghormley 2003). The SML language may be used to write standard queries, complex queries, macro-and tool scripts. To build the SDSS the project used a tool script as it provides a unique interactive graphic tool to select data in a view window and apply custom processing. The analytical procedures developed for the TMGA SDSS use both the spatial and the attribute databases.

Based on the user requirements, four main spatial analytical routines were developed (Figure 5-5), namely

- Borehole analysis
- Topographic analysis
- Sensitive area analysis
- Image classification.

These procedures are grouped together in the proximity analysis toolbox, as this was the major need of the project team. The selected procedures serve all disciplines in the team.

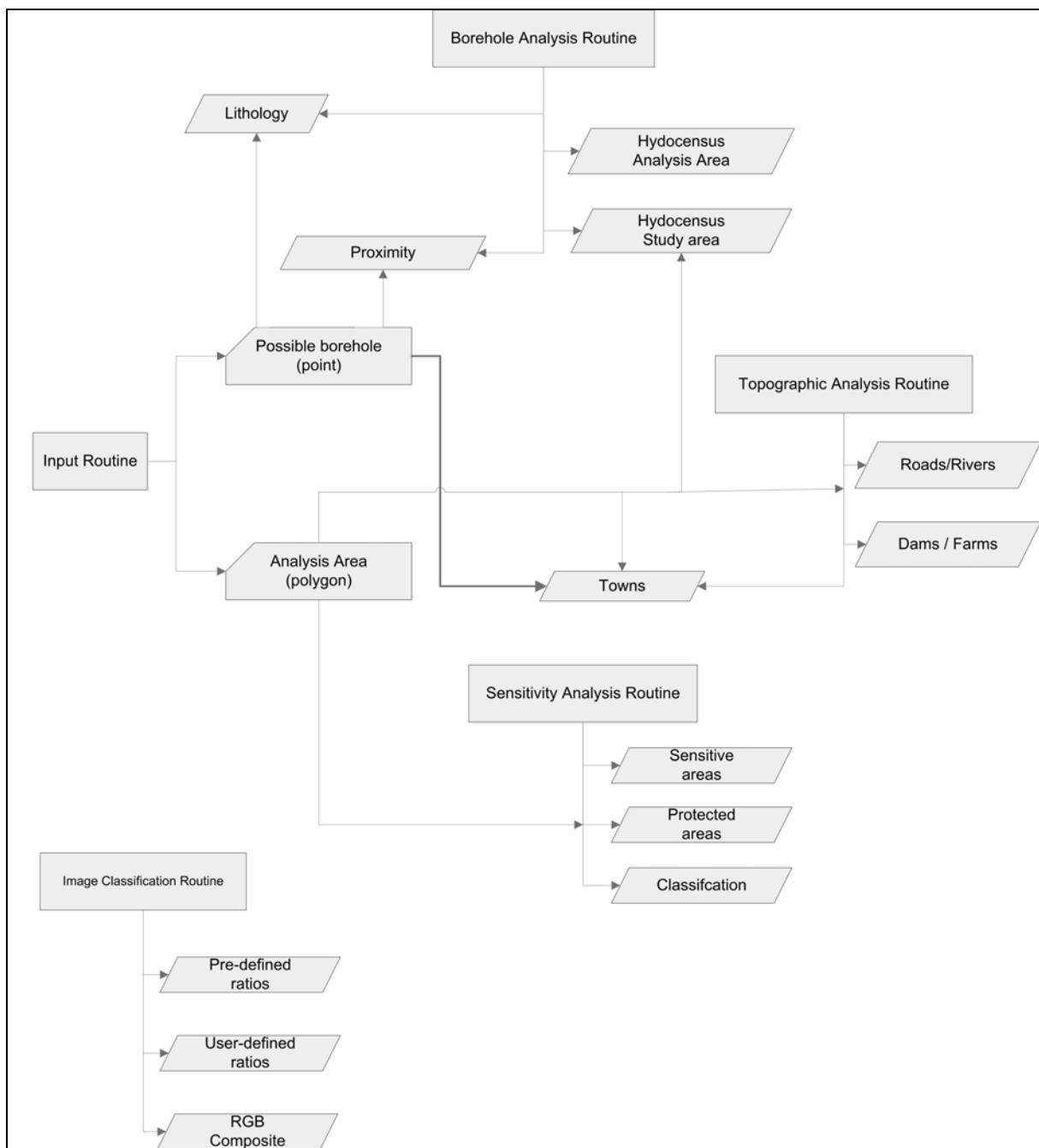


Figure 5-5 Spatial analytical routines

An input routine was developed as an over arching routine for other routines (Figure 5-5). These analytical procedures are designed to assist the user in making decisions about a potential borehole site.

5.2.1 Site Selection

This section of the spatial tool is mandatory, meaning that the user has to create a point and region of interest before continuing with the analysis (Figure 5-6). The point is to be situated

where the user might want a borehole to be drilled (hereafter called the possible borehole site). When the user creates the point on screen, the programme first checks if the active layer is a vector (Figure 5-7).

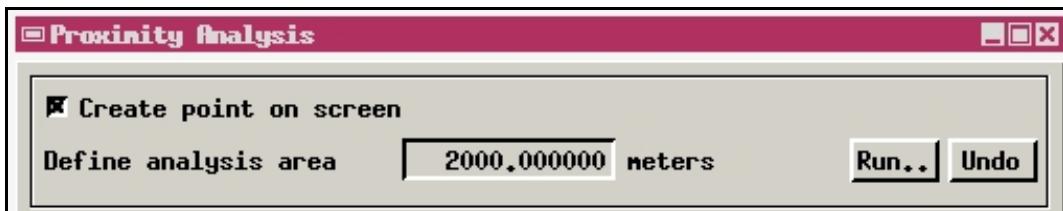


Figure 5-6 Top of dialogue window defining the area of interest

```
Numeric valid = true
if(Layout.activegroup.ActiveLayer.Type == "Vector"){
    thisvectorlayer=Layout.activegroup.ActiveLayer
    DispGetVectorFromLayer(INVECT, thisvectorlayer)}
else {PopupMessage("Active layer not a vector!")
    valid = false}
return valid
```

The tool returns an error if the active file is not a vector, whereas if the file is the vector it then checks if the vector file contains point data.

```
if(INVECT.$Info.NumPoints < 1) {
    PopupMessage("No points in active layer!")}
else mode$ = "point"
```

The active point file must contain point data to be queried by the user. The point data may be project hydrocensus data or the National Groundwater Database (NGDB). In the layout structure, a group called 'Start Here' has been created to allow the user to know which group and vector point file must be active. Once the programme has found a vector point file, the point will be created on the screen.

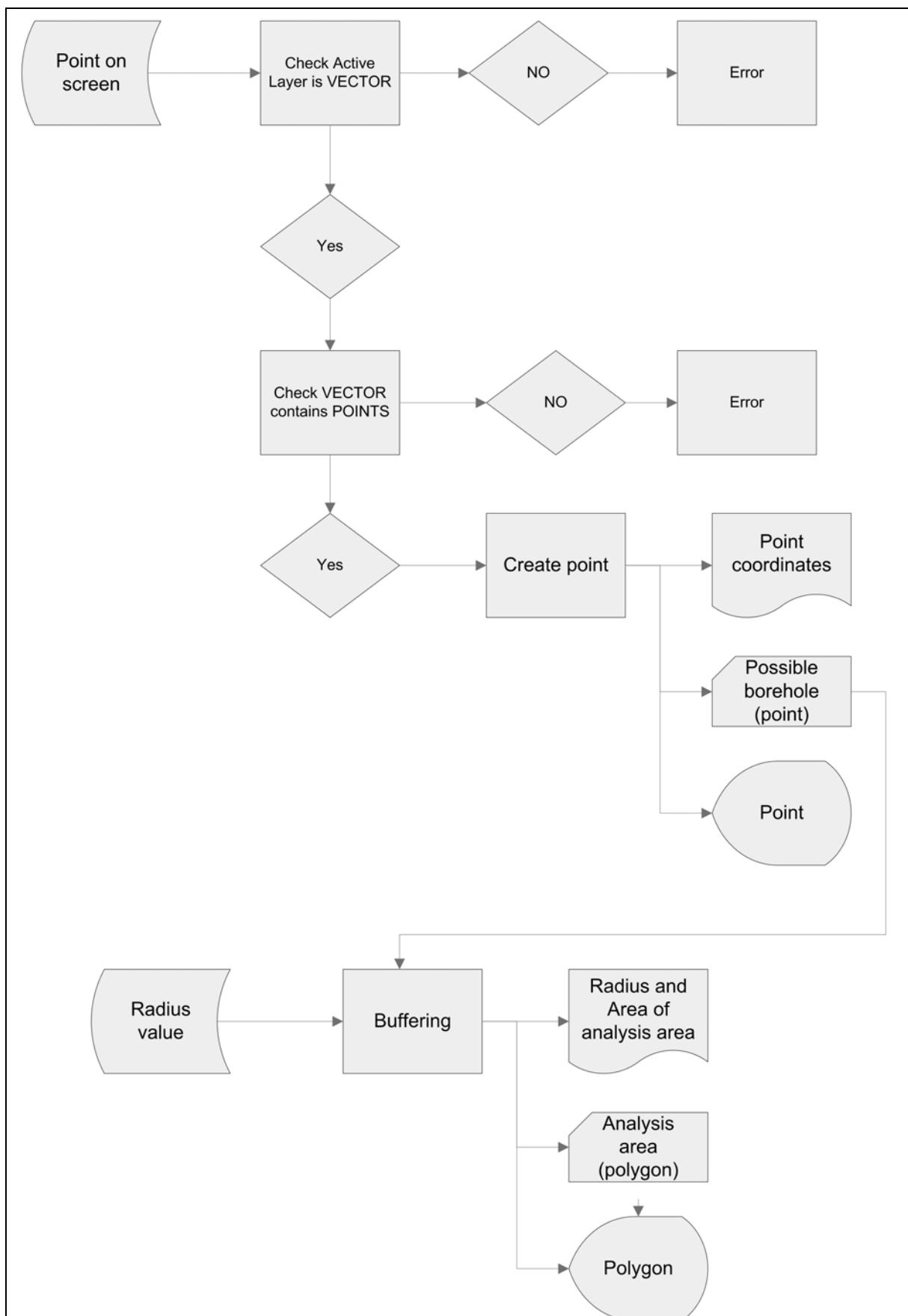


Figure 5-7 Input point routine for site selection

In GIS, when a new file or object is created, it must also be given georeferencing information. One of the ways of assigning the georeference information is by asking the object to obtain georeferencing information from a reference object. When the user creates the possible borehole site georeferencing information must be assigned. The code below forms part of the script that assigns the point georeferencing information.

```
ptlayer = TransPoint2D(ptlayer, ViewGetTransLayerToScreen(View, projlayer, 1));
ptlayer = TransPoint2D(ptlayer, ViewGetTransLayerToView(View, projlayer));
ptlayer=TransPoint2D(ptlayer, ViewGetTransMapToView(View, projlayer, projection, 1));
VectorAddPoint(PTVECT, ptlayer.x, ptlayer.y)
```

TransPoint2D is a function based on the POINT2D class that transforms the georeferencing of a point, from one layer to another. The point is first georeferenced to the screen, then to the view window and finally to an assigned object layer. The assigned object layer in this case is the active vector point file discussed above.

Because borehole siting is not only about a point in the ground, but rather about the area in which a borehole might be sited, the user must then specify the area of interest around the created point (Figure 5-6). The value to be entered must be in metres.

```
CreateTempVector(BUFFER, "VectorToolkit")
BUFFER=VectorToBufferZone(PTVECT, "point", buffdistance, unit$, " ", selpoint)
addvectresults(bufferlayer, Layout.activegroup, BUFFER)
createdtempBuffer$="Y"
```

When the user presses the Run button (Figure 5-6), the programme creates a temporary buffer vector file to store the analysis area results. The buffer vector file is then displayed on the screen. Another module of the script uses the last line of the above code to allow for the temporary buffer vector file be destroyed when the user presses the Undo button. Similarly when the spatial tools window is closed, the buffer vector file will be destroyed.

The system allows only one point to be used for analysis. If the user wants to edit the point, e.g. change its position, he/she must click at the new position of the point, then the first-created point will be deleted and a new one will be created. If the user wants to change the point position after the area of analysis has been defined, the user must first press the Undo button (Figure 5-6) to delete the area of analysis, then click where the new point is to be

created. The Undo button may also be used when the user wants to change the size of the analysis area.

The co-ordinates of the possible borehole site, the radius and area of the analysis area are displayed on the results bar (Figure 5-8). These results may be saved to a text file using the Save button.

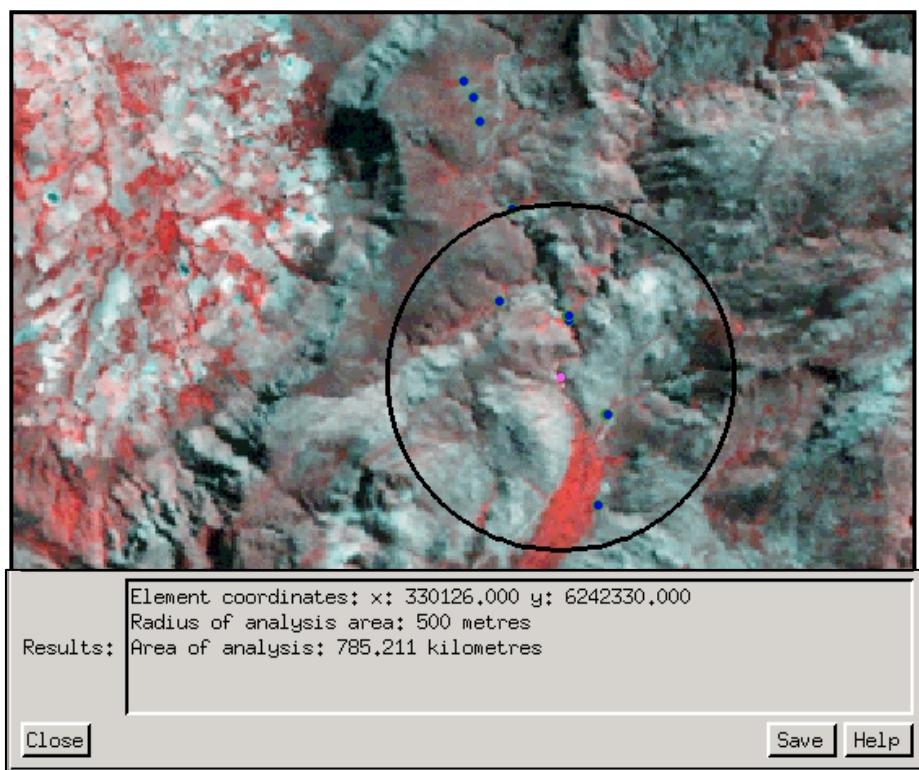


Figure 5-8 Results of possible borehole site and buffer area

The point creation and area specification then forms the basis of the analysis performed by three spatial tools built namely, borehole analysis, topographic analysis and sensitive area analysis.

5.2.2 Borehole Analysis

The spatial tool named Borehole Analysis (Figure 5-9) mainly deals with spatial analysis related to stratigraphic information and existing boreholes or hydrogeological point data. The queries are meant to find information about existing data and its relation to the possible borehole site. The data analysis gives the users an indication of what groundwater exploration and monitoring has been undertaken in the area of interest. For example, it gives the

information about where boreholes have already been drilled and in which lithology they were drilled. The analysis also gives the user information on other monitored water sources, like streams and rivers, to measure flow and water quality. Knowing whether there are any weather stations or rainfall collectors in the area is crucial for determining the rainfall or other climatic variables in the area of interest.

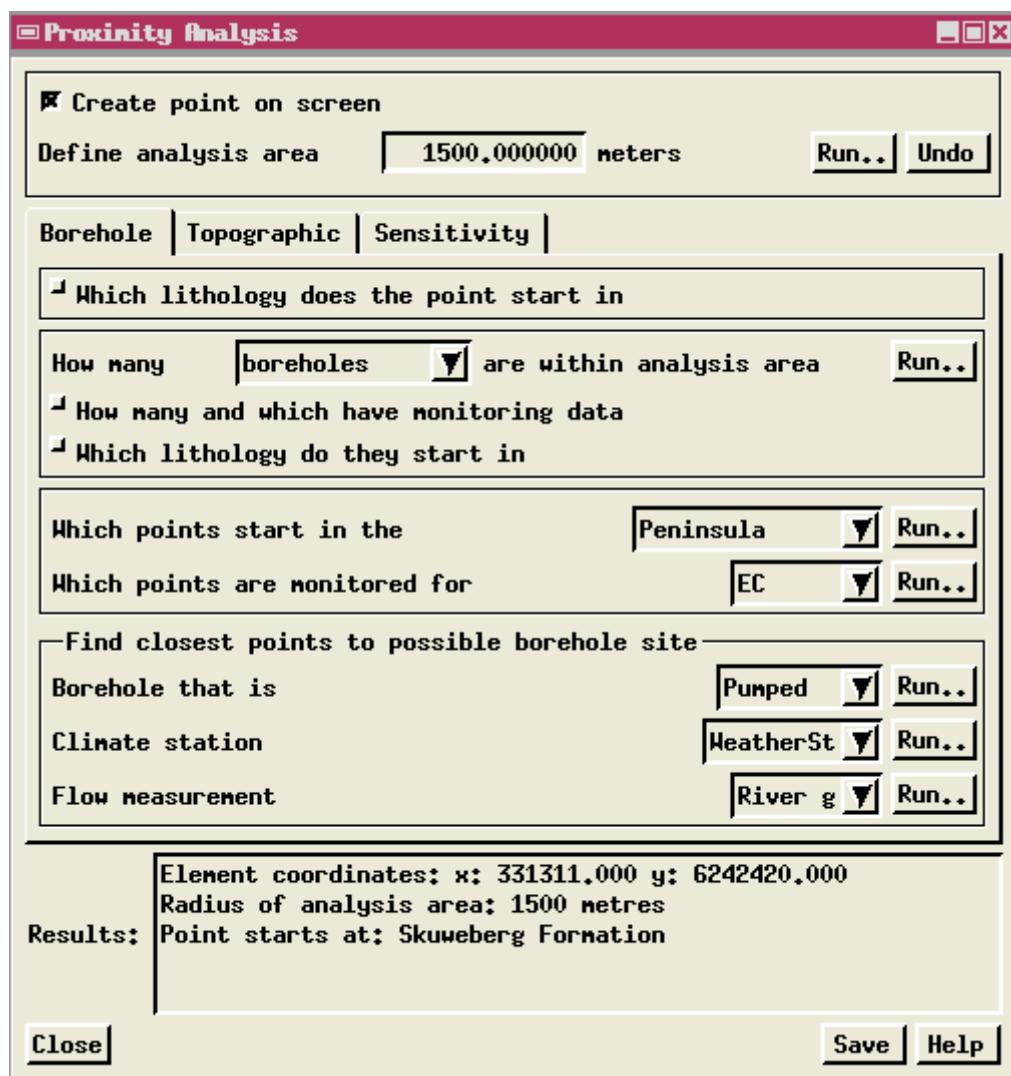


Figure 5-9 Dialogue window with the Borehole Analysis Tool

The tool requires that a vector point file be active on the layout. This option also allows the user the flexibility of choosing which point database to query. For example, the user may want to query the NGDB or a hydrocensus survey on a previous or the current project. Though only one point file may be queried at any given time, the user may select different point data files to be queried. The structure of the point files will have to be the same for programming purposes.

The first query looks at what geological formation the possible borehole site has been plotted at (Figure 5-10). The script below extracted from the “FindLithology()” procedure illustrates how the geology formation is determined by using the x and y co-ordinates of the possible borehole site.

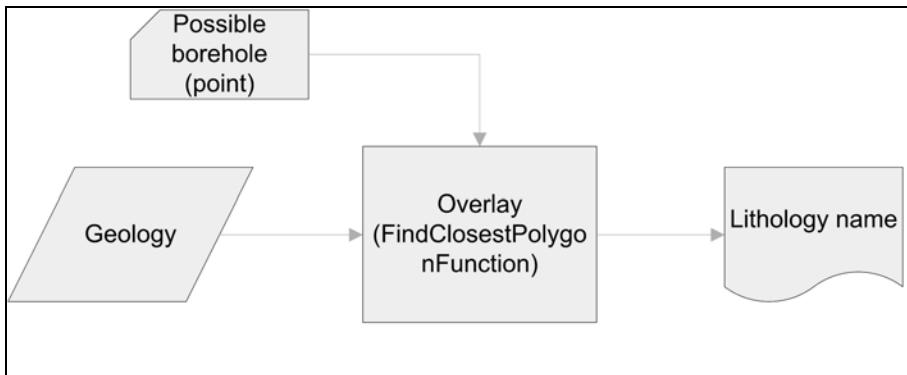


Figure 5-10 Borehole Analysis subroutine – lithology of the possible borehole point

```

PolyNum = FindClosestPoly (LITHO, selpointx, selpointy,
                           GetLastUsedGeorefObject(LITHO))
if (polyNum > 0){
    lithologylayer.Poly.HighlightSingle(polyNum)
    lithologylayer.NoFillWhenHighlight(polyNum)
    litho$ = LITHO.poly[polyNum].GEOLOGY.LITHOLOGY$
    string printlitho$ = sprintf ("%s %s", "Point starts at:",litho$)
    resulttext.AddItem(printlitho$) }
```

When the user selects the query about the lithology of the point, the FindLithology() procedure is called. The procedure highlights the selected lithology polygon boundary and feeds its formation name into the result bar. This information is crucial for borehole design and planning of drilling.

The second section of the tool looks at finding data and information within the specified area of interest (Figure 5-11). In this section the questions follow a specific sequence, i.e. the user first asks how many boreholes there are within the specified area of interest. The extraction from the “FindnumPoints()” procedure below illustrates the query.

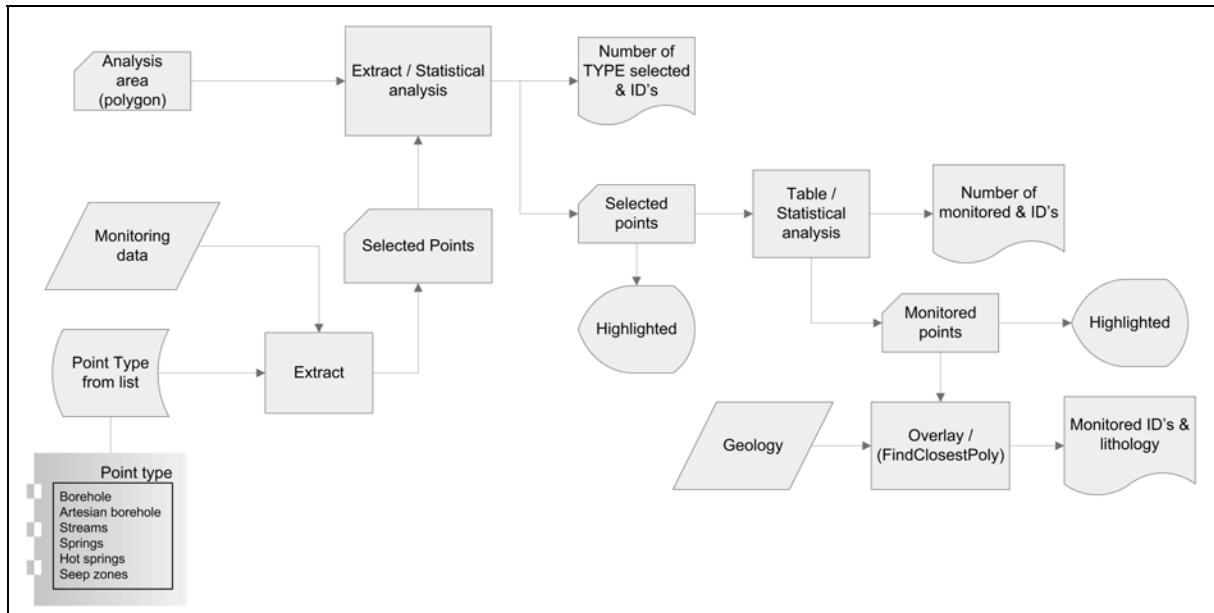


Figure 5-11 Borehole Analysis subroutine – monitoring points within area of analysis

```

if(pttype$ == "Borehole") then
{   TEMPPT = VectorExtract(BUFFER, INVECT, "CompInside", flag$,
                           TABLE.TYPE.ID == 1", "0", "0")
    numpoints = NumVectorPoints(TEMPPT)
    string printnumpoints$ = sprintf("%s %s", "Number of boreholes:", numpoints$)
    resulttext.AddItem(printnumpoints$)
    for i = 1 to numpoints
    {
        if(typepoint[i] > 0)
            thisvectorlayer.Point.HighlightMultiple(numpoints, typepoint, "Replace")} }
  
```

If the procedure finds any borehole points within the area of interest, they are highlighted on the view window and the total number of boreholes found is printed in the Results bar.

The second query of the section asks which of the boreholes thus identified have monitoring information (Figure 5-11). Using results from FindnumPoints() procedure, the following query looks for borehole points that have monitoring information. The code below is extracted from the “MonitoredPoints()” procedure.

```

monpoint = TableKeyFieldLookupList(TEMPPT.Point.TABLE, "MONITORED", 1, buffpoint)
monpointcount = TableGetRecordListElementList(TEMPPT.Point.TABLE, buffpoint,
                                              monpoint, monpointArray)
typepoint[i] = FindClosestPoint (INVEST, pointx[j], pointy[j], GetLastUsedGeorefObject
                                  (INVEST));
if (typepoint[i] > 0)
{
    thisvectorlayer.Point.HighlightMultiple(monpointcount, typepoint, "Replace")
    string printmonpointcount$ = sprintf("%os %os", "Number of monitored points:",
                                         monpointcount$)
    resulttext.AddItem(printmonpointcount$)
    bhid$ = TEMPPT.Point[monpointArray[i]].TABLE.SITE_ID$
    string printresults$ = sprintf("%os %os", " ", bhid$)
    resulttext.AddItem(printresults$) }

```

The script first searches the attribute table for the record field of the monitored points. Using the retrieved record list, it then looks for the elements linked to the record list. The x and y coordinates of the elements found are then written into an array which is used to highlight the retrieved monitored elements on-screen. The total number of elements found is printed on the Results bar. The script also finds and prints the borehole ID numbers of the monitored points.

The last query in the section asks in which stratigraphic unit the monitoring boreholes start (Figure 5-11). The extracted script below illustrates how the “LithoMonitoredPoints()” procedure searches and retrieves the lithology at each point.

```

for i = 1 to monpointcount
{
    monpointx = TEMPPT.point[monpointArray[i]].Internal.x
    monpointy = TEMPPT.point[monpointArray[i]].Internal.y
    polyNum = FindClosestPoly(LITHO, monpointx, monpointy,
                              GetLastUsedGeorefObject(LITHO));
    if (polyNum > 0)
    {
        lithoArray[i] = LITHO.poly[polyNum].Internal.ElemNum
        litho$ = LITHO.poly[lithoArray[i]].GEOLOGY.LITHOLOGY$ }
    bhid$ = TEMPPT.Point[monpointArray[i]].TABLE.SITE_ID$
    string printbhidlitho$ = sprintf("%os %os", bhid$, litho$)
    resulttext.AddItem(printbhidlitho$)
    fprintf(outfile, " ", bhid$, litho$) }

```

The LithoMonitoredPoints() procedure first writes the x and y co-ordinates of the monitored points into arrays, and then these arrays are used in the “FindClosestPoly()” function. The function looks for the closest polygon to each point on the array. The procedure then finds the attributes linked to the polygons found. The lithology of each point is printed on the Results bar with the point ID (Figure 5-12).

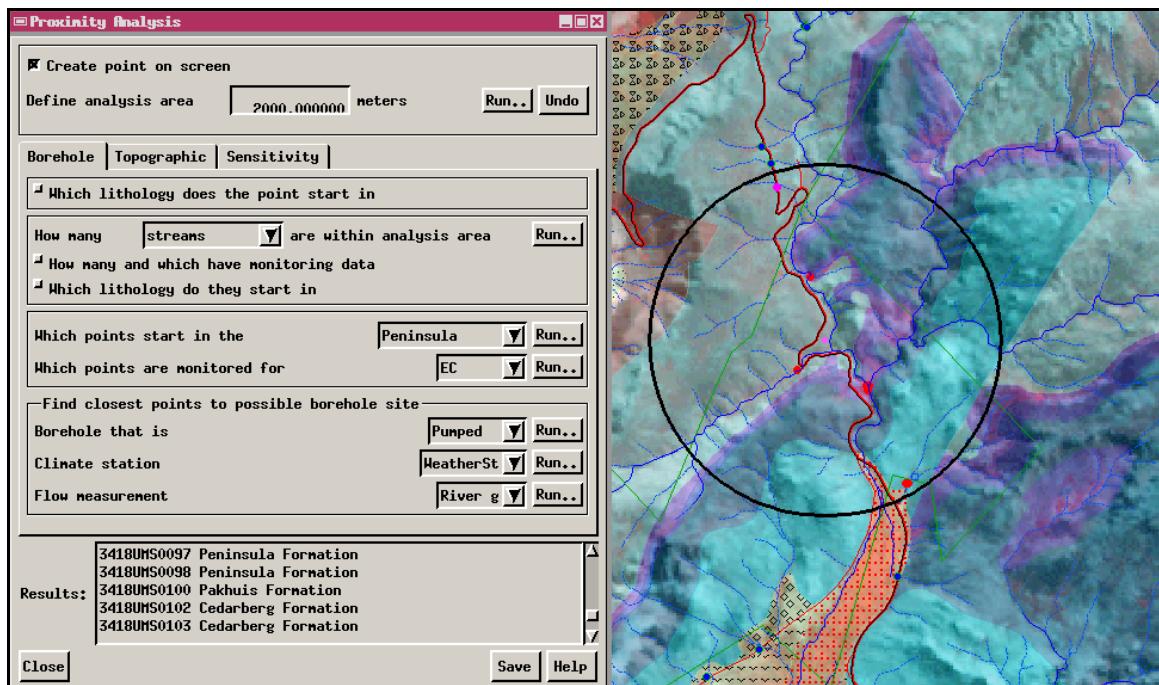


Figure 5-12 Results of the second section of the Borehole Analysis Tool showing point streams found and the lithology they start in

The above queries are written to search not only for existing boreholes, but also for artesian boreholes, springs, seep zones, hot springs and streams. Since each of these monitoring points has unique aspects, they need to be considered separately. The tool window gives users a drop-down menu to select the point data type they are interested in.

The third section of the Borehole Analysis tool scripts performs queries on the point file as a whole, not only within the defined area of interest (Figure 5-13). The first of these sections looks at the existing point data and stratigraphic information. The first query looks at which points are starting at a certain geological formation. The tool window gives the user a drop-down menu of the mapped lithology of the area. The following code is an extract of the “LithoPoints()” procedure.

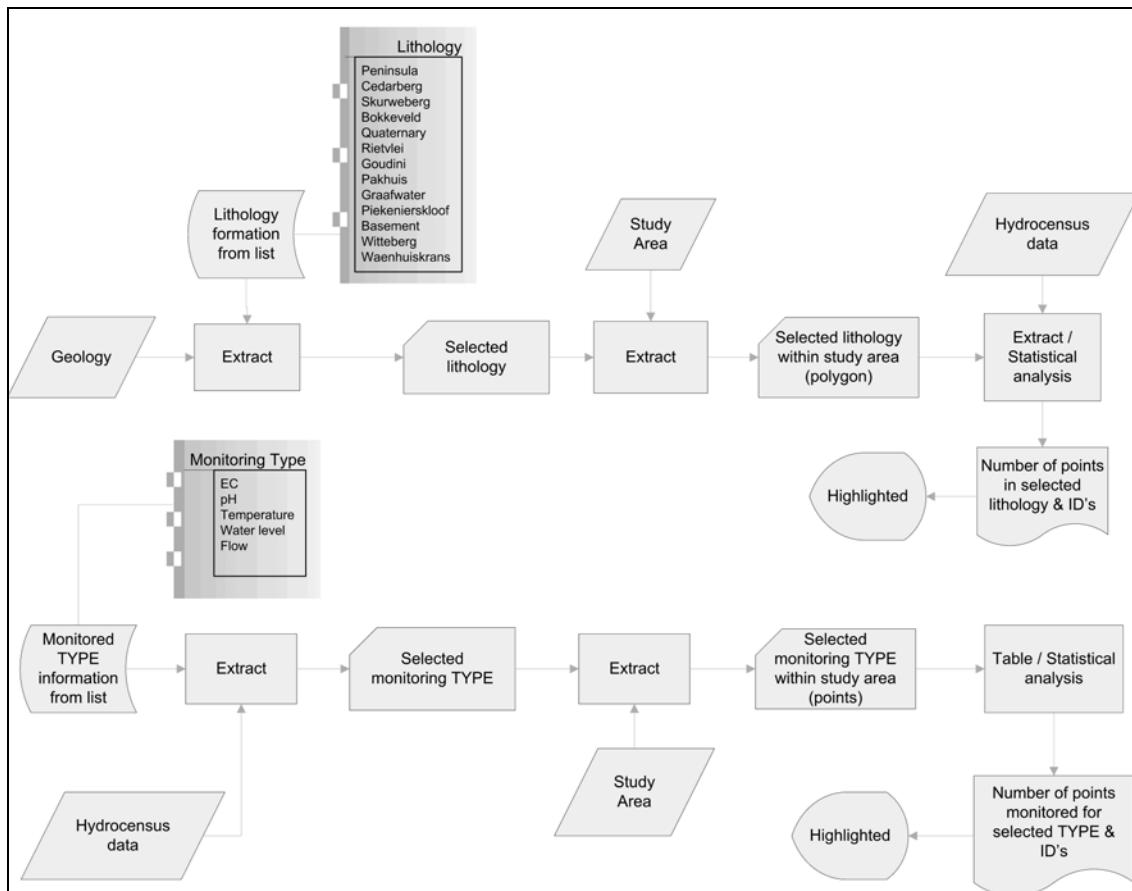


Figure 5-13 Borehole Analysis subroutine – stratigraphic information and monitoring points within study area

```

lithologytype$ = dlgwin.GetCtrlValueStr("litholist")
if (lithologytype$ == "Peninsula") then
{
    GEOVECT = VectorExtract(STUDYAREA, LITHO, "InsideClip", flag$, "0", "0",
                           "GEOLOGY.LITHO_ID==8")
    CreateTempVector(TEMPLITHOPT, "VectorToolkit")
    TEMPLITHOPT = VectorExtract(GEOVECT, INVECT, "CompInside", flag$)
    local numeric numOpepoints = NumVectorPoints(TEMPLITHOPT)
    local string numOpepoints$ = NumToStr(numOpepoints)
    local string printnumOpepoints$ = sprintf("%s %s", "Number of points starting in"
                                              Peninsula:", numOpepoints$)
    resulttext.AddItem(printnumOpepoints$)
    for i = 1 to numOpepoints
    {
        pointx[j] = TEMPLITHOPT.point[i].Internal.x
        pointy[j] = TEMPLITHOPT.point[i].Internal.y
        typepoint[i] = FindClosestPoint(INVECT, pointx[j], pointy[j],

```

```

        GetLastUsedGeorefObject(INVECT));
if(typepoint[i] > 0){
    thisvectorlayer.Point.HighlightMultiple(numOpepoints, typepoint, "Replace")}
local string Opebhid$ = TEMPLITHOPT.Point[i].TABLE.SITE_ID$
string printresults$ = sprintf("%s %s", " ", Opebhid$)
resulttext.AddItem(printresults$)}

```

The procedure first reads the option the user has selected from the drop-down menu. The results of the user selection are linked with the attribute table of the geology map to find the lithology formation label ID. Using the VectorExtract function, the selected lithology is extracted from the main geology map (Figure 5-13). The results of the extraction function are then used to extract points that are within the extracted polygon boundary. The points found within the polygon are highlighted on-screen for the user to view and a list of each point ID is printed on the Results bar. Information on these data can then be compared to further evaluate the geological conditions of the proposed borehole.

The second query of the section asks for points that have monitoring information (Figure 5-13). The user again gets a drop-down list of monitoring parameters to select from. The list comprises of electric conductivity, pH, temperature, water level and flow.

The last part of the Borehole Analysis tool scripts focuses on flow measurements and climate points within the greater study area and their relation to the possible borehole site (Figure 5-14). The following script extracted from the “ClimatePoint()” procedure, illustrates the structure of the code used to perform the queries.

```

climate$ = dlgwin.GetCtrlValueStr("climate")
if(climate$ == "Station") then
{    CLIMVECT = VectorExtract(STUDYAREA, STATION,"CompInside", flag$,
                            "TABLE.TYPE_ID ==1","0","0")
    climpointcount = NumVectorPoints(CLIMVECT)
    local string climpointcount$ = NumToStr(climpointcount)
    local string printclimpointcount$ = sprintf("%s %s", "Number of weather stations:
                                                ", climpointcount$)
    resulttext.AddItem(printclimpointcount$)}

```

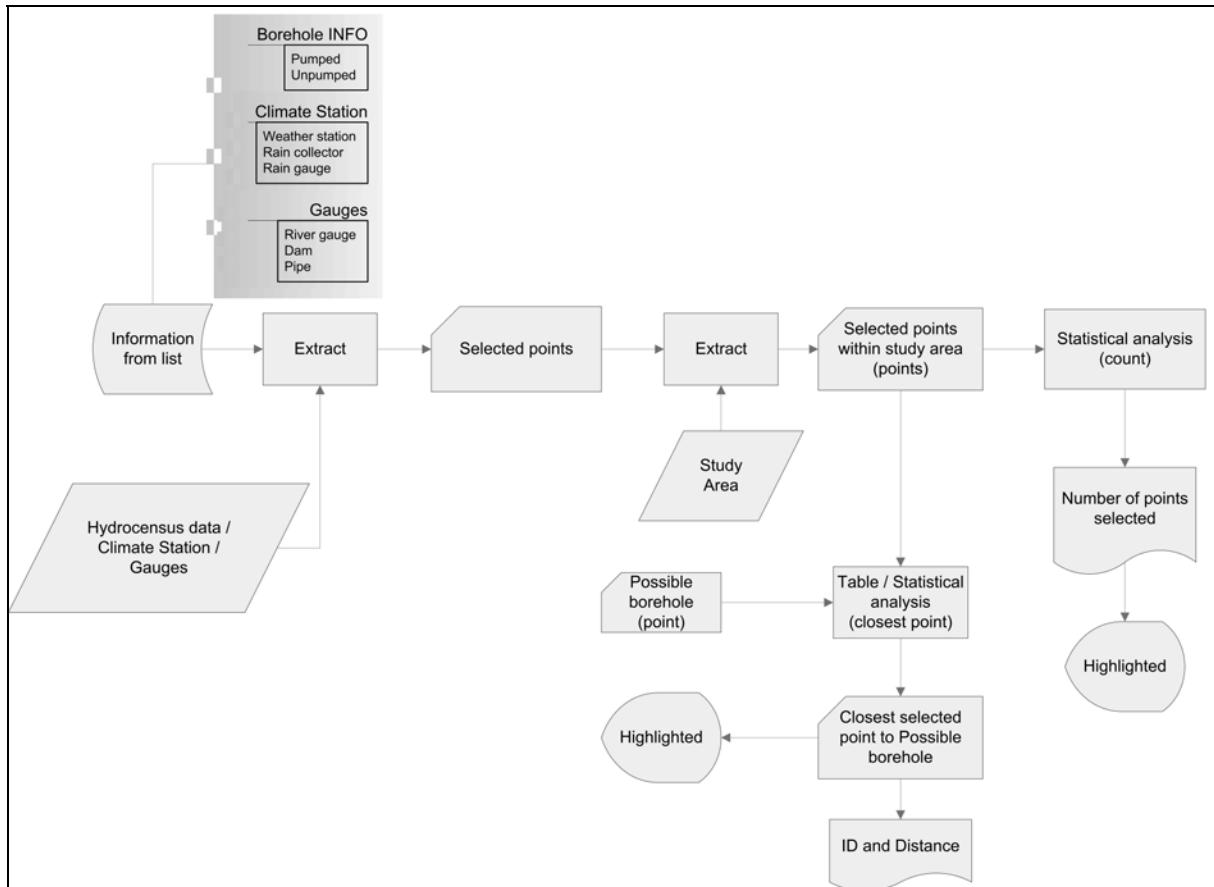


Figure 5-14 Borehole Analysis subroutine – climate stations and gauges within study area

The drop-down list allows the user to select the type of climate point of interest. The list comprises of weather stations, rainfall collectors and rain gauges. Once the number of existing climate station points have been found, the procedure then finds the closest point to the possible borehole site as this might be the one with the most relevant and closest information. The script below shows how the procedure calculates the distance between the points.

```

for i = 1 to climpointcount
{
    xcoord[i] = CLIMVECT.point[i].Internal.x
    ycoord[i] = CLIMVECT.point[i].Internal.y
    x1 = PTVECT.point[elementNum].Internal.x
    y1 = PTVECT.point[elementNum].Internal.y
    x2 = xcoord[i] ; y2 = ycoord[i] ;
    xdist = abs(x2-x1) ; ydist = abs(y2-y1)
    dist[i] = round(sqrt(sqr(xdist) + sqr(ydist)))
}
  
```

```

if(i == 1)
{
    minDistance = dist[i]
    indexMin = i
}
if(minDistance > dist[i] && dist[i] <> 0)
{
    minDistance = dist[i]
    indexMin = i } }

```

Once the closest climate station has been found, it is highlighted on-screen and its site ID and the distance to the possible borehole site are printed on the Results bar. The section also has a query that looks at flow measurement points. The list for flow measurement gauges comprises river gauges, pipe gauges and dam gauges.

Another query in this section asks for boreholes that are pumped or not pumped (Figure 5-14). Though the information of whether a borehole is pumped or not impacts on data interpretation of water level or chemistry data, this information is not always captured on the field, therefore some of the boreholes may have an unpumped status though they are being pumped.

The procedure for flow measurements points, “FlowPoint()”, and the procedure for pumped or unpumped borehole, “PumpPoint()”, follow the same structure as the climate stations procedure. First the relevant points are found, the total number of found points is returned on the Results bar and then the closest point to the possible borehole site is found. The results of the search are highlighted on-screen and printed on the Results bar.

The results of Borehole Analysis are presented both in graphical and text form. The user may also open the tables to see the results. The project tried to include a procedure to open the relevant tabular results automatically for the user, but due to programming language constraints this cannot be done as effectively as the project would have liked. During demonstrations, the users were shown how to open the tables after each result.

The Borehole Analysis tool allows hydrogeologists to spatially review existing point data in relation to the geology of the area. While reviewing the existing point data, users may undertake preliminary borehole siting.

5.2.3 Topographic Analysis

The tool “Topographic Analysis” (Figure 5-15) was developed to handle queries based on the proximity of the analysis area to cadastral data layers.

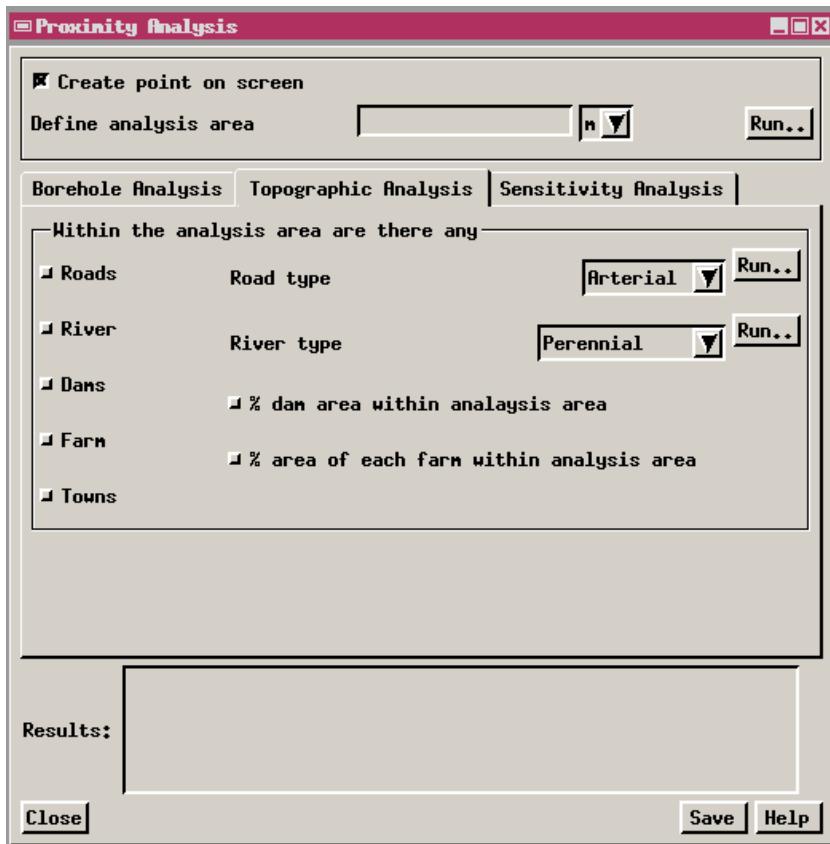


Figure 5-15 Topographic Analysis Tool window

The main purpose of the tool is to find whether there are any topographical and cadastral data within a certain distance from the possible borehole site. The tool uses the point defined at the main top section of the “Proximity Analysis” window (Figure 5-6) as well as the analysis area.

The data used in this tool comprise of 1:50 000 topographic, cadastral, infrastructure and hydrological spatial data. The data layers are roads, farm boundaries, towns, rivers and dams. The tool provides the user a drop-down list of the different types of roads mapped. The default option of the list is “Any”, this option giving the user all the roads available within the analysis area. The other options comprise national, arterial, main, secondary, hiking trails and other access roads. The roads classification is that used on the 1:50 000 maps of CDSM. Additional access roads, especially footpaths, were digitised by the project. The query below forms part of the “AccessRoad()” procedure.

```

roadtype$ = dlgwin.GetCtrlValueStr("roadtype")
if (roadtype$ == "Main") then
{   CADASVECT = VectorExtract(BUFFER, ROADS, "InsideClip", flag$, "0",
    "ROAD.FEAT_ID==3","0")
  numlines = NumVectorLines(CADASVECT)
  if (numlines > 0)
    resulttext.AddItem("YES there are Main roads")
  roadlayer = GroupQuickAddVectorVar(Layout.activegroup, CADASVECT)
  roadlayer.Line.Select.Mode = "ALL"
  for i = 1 to numlines
  {    numeric elemnum = CADASVECT.line[i].Line_ID.Current
    roadlayer.Line.HighlightSingle(elemnum) }
  View.ZoomToLayer(roadlayer,1)
}

```

The script first reads the user selection from the drop-down menu, and then matches the selection with the attribute table of roads (Figure 5-16).

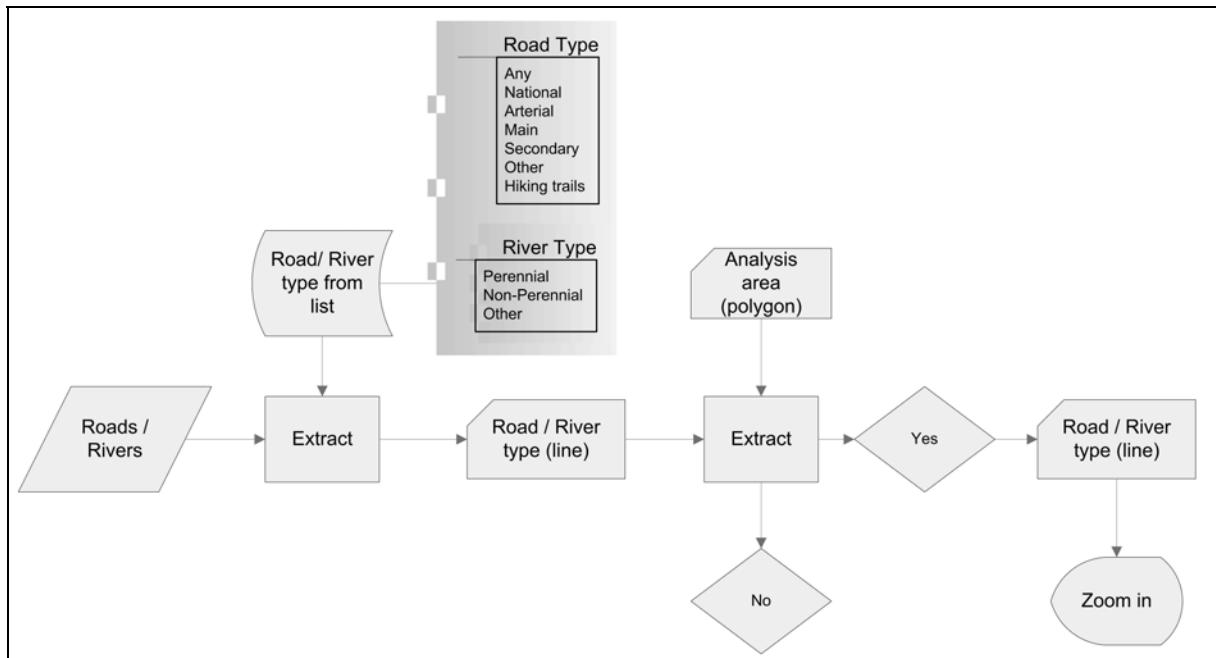


Figure 5-16 Topographic Analysis subroutine – roads and rivers within analysis area

A computed field that gives each road type a unique ID label is added on the attribute table to effect an easy search. The first result of the query is whether the road type selected exists

within the analysis area and then zooms into the particular road on the display window for the user to view (Figure 5-17).

It is important to know if there are any existing roads as well as the road type within the area of the possible borehole site, because there are cost and environmental considerations if additional access roads or tracks are needed. Hiking tracks and poorly maintained 4x4 tracks are not suitable for drilling rigs.

The tool also provides the user with a drop-down list of the different types of rivers within the area of interest. The list has three options, namely perennial, non-perennial and other river type. The “AccessRiver()” procedure follows the same coding methodology as the AccessRoad() procedure explained above.

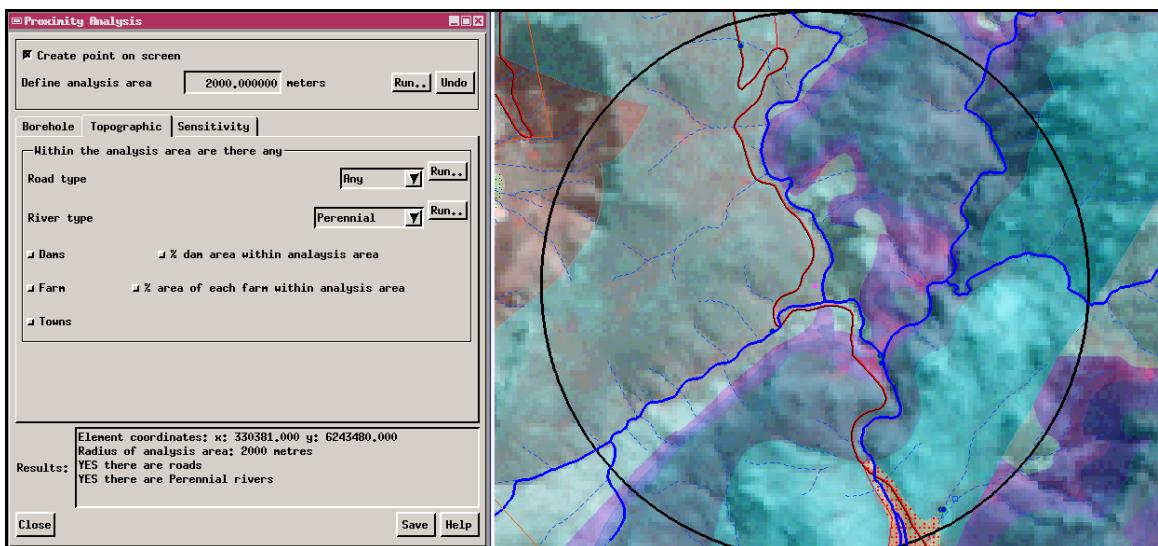


Figure 5-17 Topographic Analysis Tool results of roads and perennial rivers

The topographical analysis includes dam areas as well. Two procedures were written to perform the query on dams (Figure 5-18). The first procedure, “AccessDams()” looks at whether there are any dams within the analysis area. The code for this procedure is similar to the AccessRoads() procedure. The second procedure, “DamPerc()”, looks at how much of the analysis area is covered by dams. The code below forms part of the DamPerc() procedure.

```
for i = 1 to numdams
{
    damArea[i] = CADASVECT.poly[i].POLYSTATS.Area
    damareaSum += damArea[i]
}
numeric damareaPerc = round((damareaSum/drillsiteArea) * 100)
```

Because users are not interested in the area of individual dams, but in the area covered by dams in general, the script first looks at the number of polygons making up the dams found in the area. The area of each polygon is found and the sum is calculated. The percentage of the analysis area covered by a dam is then returned.

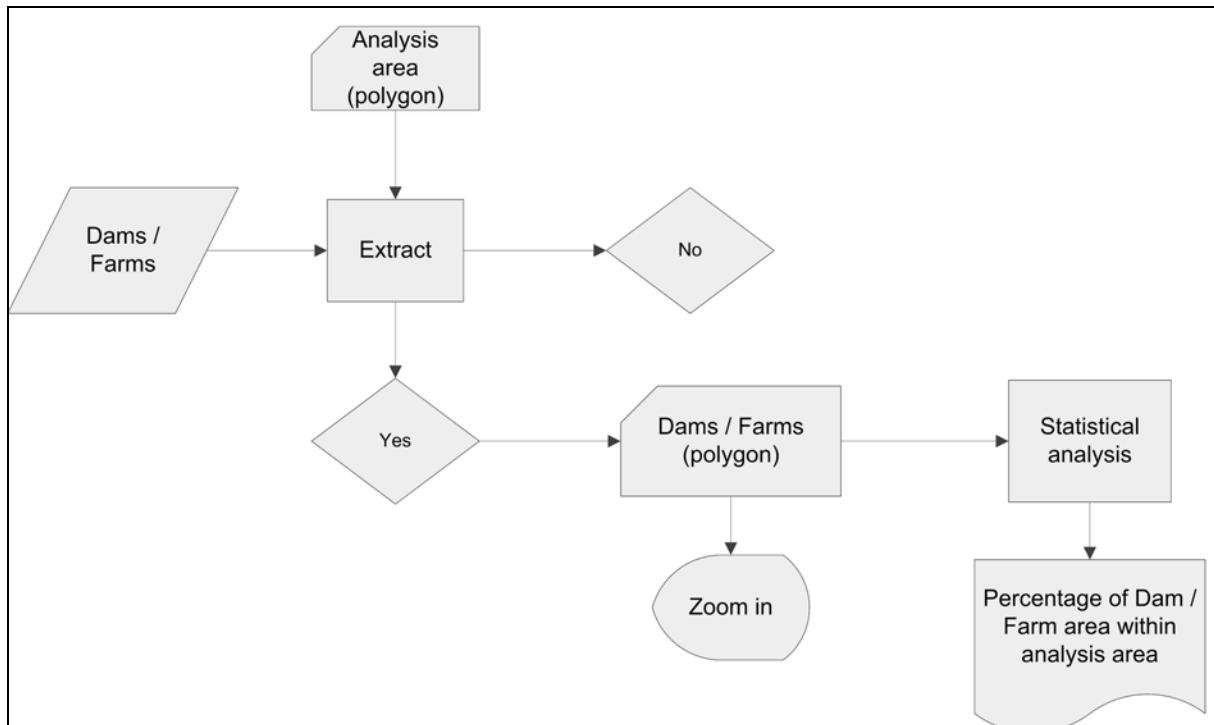


Figure 5-18 Topographic Analysis subroutine – dams and farms within analysis area

In most cases it is necessary to obtain access to the properties in which field-work is to be done. The need for farm boundaries within the area of the possible borehole site is thus essential. Two procedures for this analysis were written, namely “AccessFarms()” and “FarmsArea()”. The AccessFarms() procedure searches for farms within the analysis area and returns the total number of farms found and a list of farm numbers (Figure 5-18). FarmsArea() procedure calculates the percentage area of each farm within the area of analysis.

```

for i = 1 to numfarms
{
    farmArea = CADASVECT.poly[i].POLYSTATS.Area
    numeric farmareaPerc = round((farmArea/drillsiteArea) * 100)
    farmNumber$ = CADASVECT.poly[i].FARM.FARM_NO$
    string printfarmareaPerc$ = sprintf("%s %s %s", farmNumber$, farmareaPerc$, "%")
}
  
```

Unlike the script for the DamsPerc() procedure, which first added the individual dam areas together to calculate the percentage area, the above script for the FarmsArea() procedure calculates the percentage area for each farm. The procedure returns the farm number and the percentage area. The resulting information is very useful to the team when they speak to the land-owners, as the information accompanies the graphic maps.

The queries in the topographic analysis tool are useful to all specialists. During the wellfield phase, potential users of the water are evaluated. Therefore the team needs to know the closest towns to the wellfield site. The script for procedure “AccessTowns()” returns the number of towns found in the analysis area and their names (Figure 5-19).

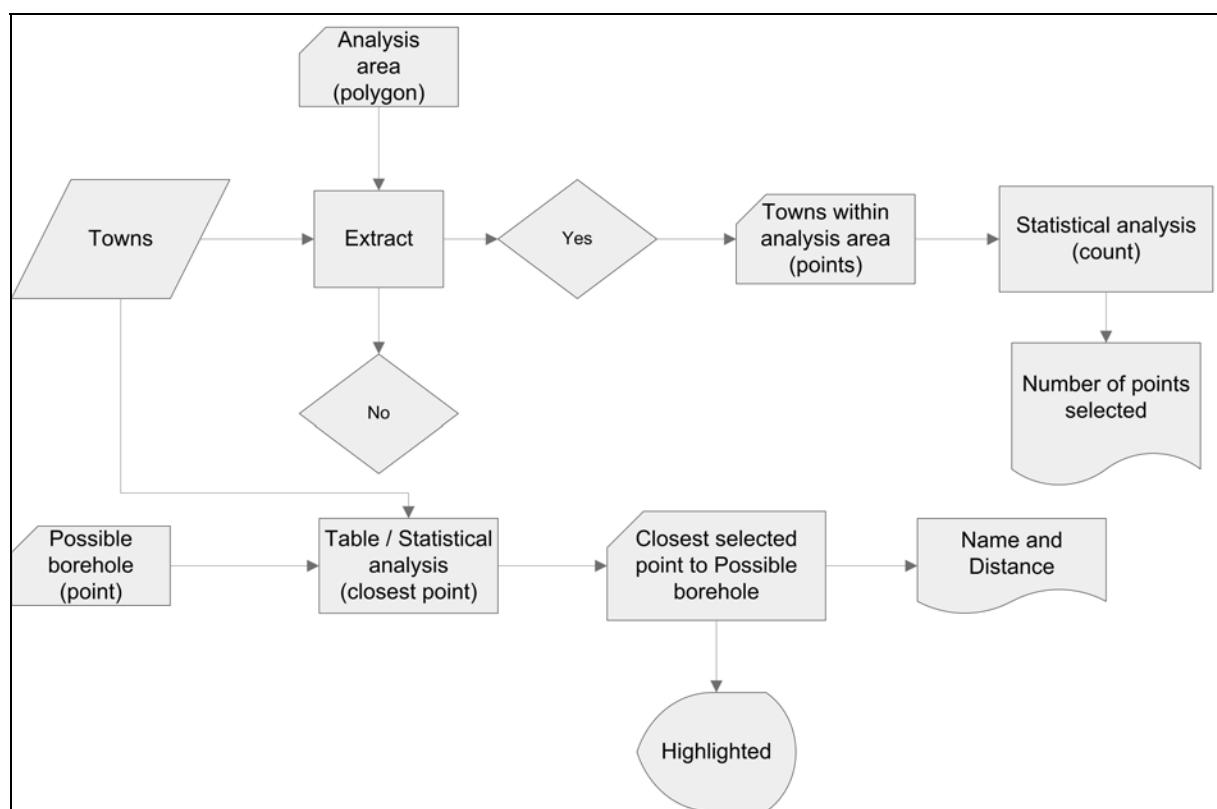


Figure 5-19 Topographic Analysis subroutine – towns within analysis and study area

The procedure also returns the name and distance of the closest town regardless of whether it is in the analysis area or not.

The topographic analysis tool is also important for engineers in terms of infrastructure analysis. Unfortunately, most of the data required by the engineers for proper terrain analysis to determine pipeline routes were not in the user requirements analysis. Some of the data

required is power lines, telephone lines and borehole yields. The latter could only be estimated at this stage, as the drilling has not yet started.

5.2.4 Sensitive Area Analysis

Before any land development can commence, the Department of Environmental Affairs and Development Planning (DEA&DP) requires an EIA study to be done (Ninham Shand 2006). Groundwater development is seen as land development.

The “Sensitive Area Analysis” tool (Figure 5-20) addresses queries with respect to sensitive areas, such as wetlands, statutorily protected areas and private nature reserves.

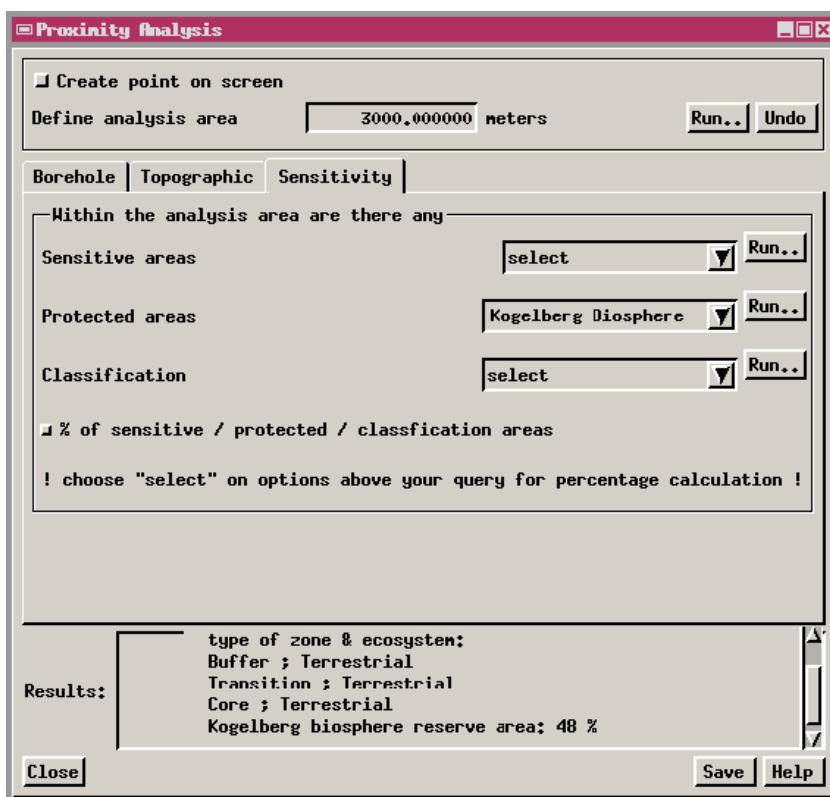


Figure 5-20 Sensitive Area Analysis Tool window

Three main procedures were written, namely “AccessSensitive()” which looks for data layers such as wetlands; the “AccessProtected()” procedure which looks for data layers such as national heritage sites; and the “AccessClassified()” procedure which looks at data layers such as broad habitat units. The tool script gives the user a drop-down menu for each category to select the particular data layer of interest (Figure 5-21).

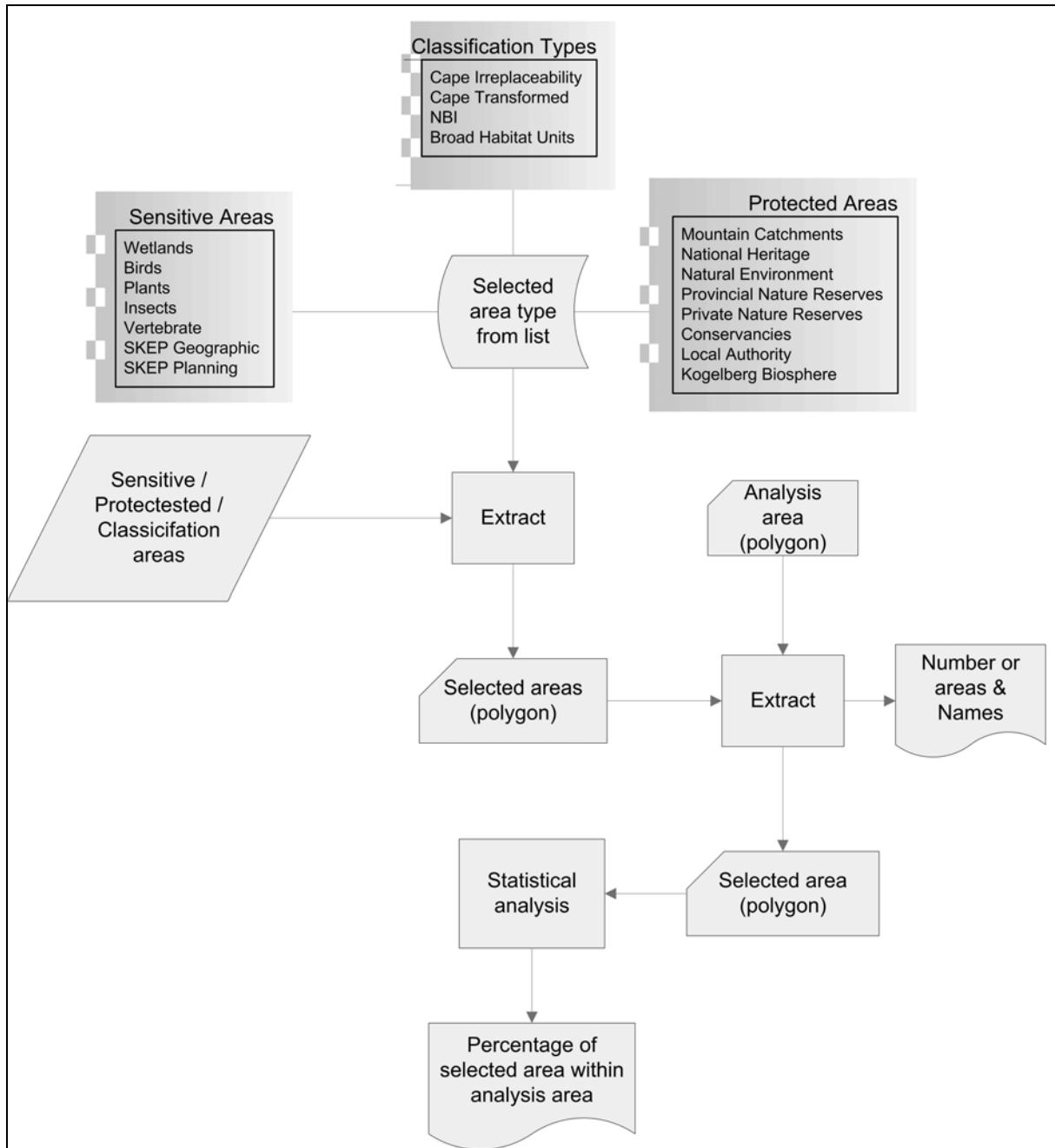


Figure 5-21 Sensitive Area Analysis routine

The first part of the procedure is to look at what the user has selected from the drop-down menu list. From the script below, taken from the AccessProtected() procedure, the user has selected to look for provincial nature reserves.

```

if(protectedtype$ == "Prov Reserves") then
{
    PROCTVECT = VectorExtract(BUFFER, PROVNAT, "InsideClip", flag$)
    numproc = NumVectorPolys(PROCTVECT)
    string printnumproc$ = sprintf("%s %s", "Number of Provincial nature reserves:", "
  
```

```

numproc$)
for i = 1 to numproc
{
    procname$ = PROCTVECT.poly[i].provincial_nature_.PNR_MAP$
    string printprocname$ = sprintf("%s %s", " ", procname$)}
}

```

The procedure looks for any provincial nature reserves within the area of analysis by using the VectorExtract function. The procedure returns the number of provincial nature reserves found and their names. The other two procedures follow the same method of searching and returning information.

The results are presented to the user in text format, written in the Results bar and by graphical display, using the display view window (Figure 5-22).

The second and last question allows the user to obtain the percentage of the selected layer, or elements of the selected layer, found in the area of the possible borehole site. The procedure “Percentage ()” calculates the percentage area of the analysis area covered by either data type.

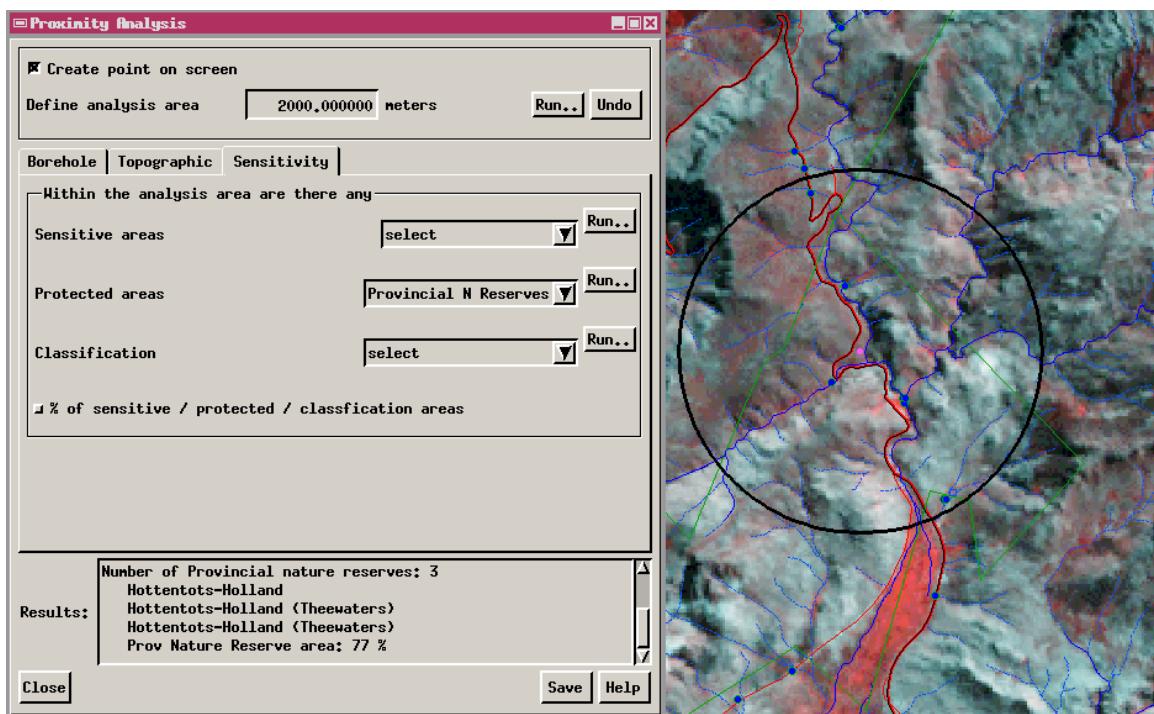


Figure 5-22 Results of Sensitive Area Analysis Tool query for provincial nature reserves

These data layers are part of the information that ecologists and environmentalists use to determine whether the possible borehole site is in a correct area. The sensitive area analysis tool enables users to query areas that may be no-go areas for borehole siting due to the environmental sensitivity of the area.

5.2.5 Image Classification

Digital imagery may be displayed as grey-tone images of single bands, or as three-band colour images. They can also be shown as various arithmetic combinations. The arithmetic combinations are useful when the user wants to single out certain features or for time-series analysis. The most useful and commonly used of arithmetic combination is the ratio of one band to another and is prepared by simply dividing the Digital Numbers (DN) of a pixel in one band by that of another band.

The “Image Classification” tool (Figure 5-23) queries different satellite image band ratios presently usable in hydrogeology projects. The number of band ratios is limited due to the number of bands available from the sensor. For this project Landsat 7 ETM is used. This sensor has six image bands that were found to be useful at this stage of the study.

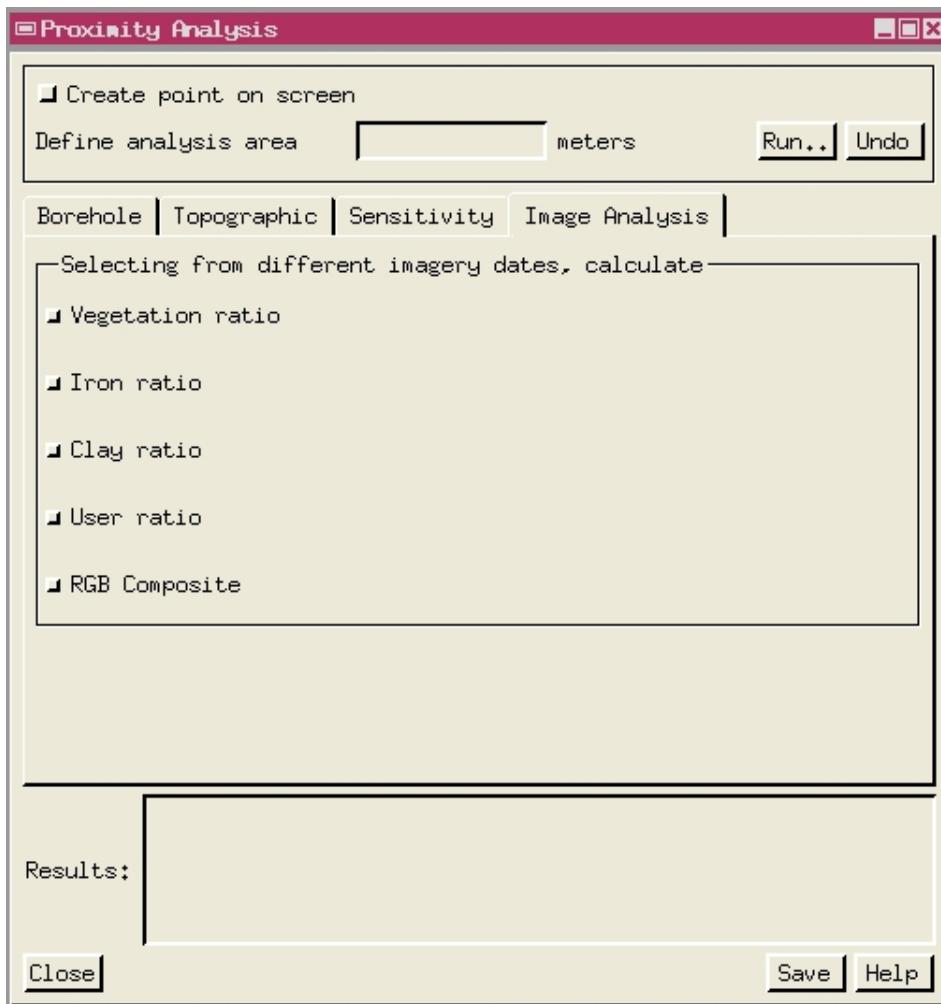


Figure 5-23 Image Classification Analysis Tool

The decision about which bands to use for ratios is based on the study of the spectral wavelength curves for the features of interest. The combination of an absorption and reflectance band is what is needed, with the reflectance band as a numerator and the absorption band as a denominator (Figure 5-24).

Because of the lack of detailed spectral resolution, the image bands are general and therefore can only give a broad idea of the mineralogy of rocks. Similarly, the image bands for vegetation analysis can be used to determine whether healthy vegetation occurs or not, but detailed information of the vegetation, like the exact type of vegetation, cannot be determined using only the spectral reflectance values of the image bands.

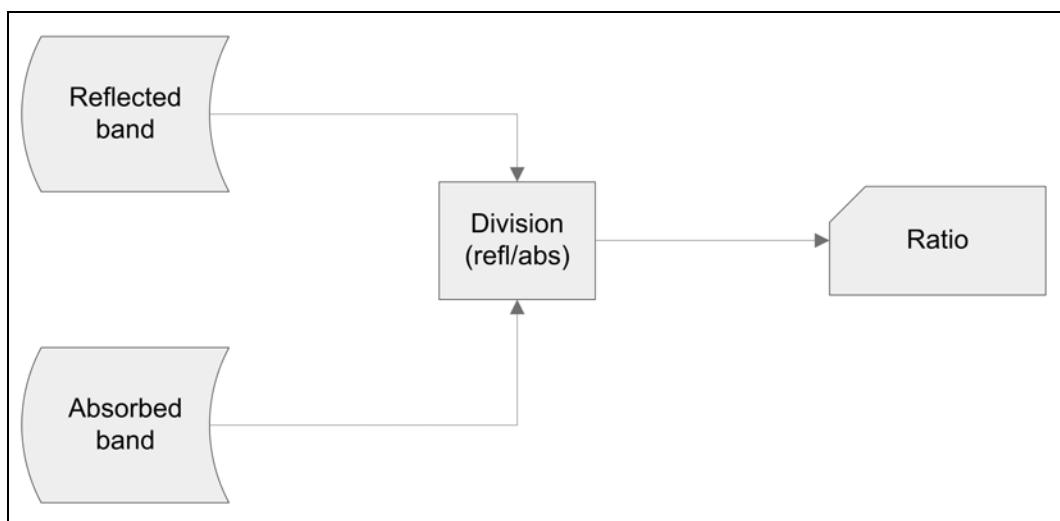


Figure 5-24 Image Classification subroutine – pre-defined and user defined ratios

Due to low spatial resolution, the pixel size of the imagery is 30 metres, the queries in this tool are performed for the study area and not just for the area of analysis. A scale-factor value of 10 is used and the image data type is set to 8-bit unsigned integer values to eliminate the decimal values which are a normal product of division.

The first query looks at vegetation occurrence in the study area. The query uses the red band and the near-infrared band. Chlorophyll absorbs the red band and reflects the near-infrared wavelength. The resulting image is a grey-tone image with bright areas highlighting high occurrence of healthy vegetation and dark areas highlighting lack of healthy vegetation.

The second query looks at highlighting iron-rich land surfaces. The red band is used as the numerator and blue band as the denominator. In the result bright grey-tones indicate high iron content and dark grey-tone areas indicate no iron content.

The third ratio aims to highlight clay-rich land surfaces. The bands used the mid-infrared (ETM band 5) and far-infrared band (ETM band 7). Like the other resulting images, the clay-rich zones are shown in bright grey-tone and areas of low or no clay content are dark grey-tones.

The fourth ration option gives the user the option to use any combination of two bands they would like besides the predefined ratios. The user has to take note that the image selected as numerator is the reflected image and the denominator the absorbed image band.

Though the satellite imagery is captured in greyscale, there are methods of displaying the imagery with colour, using the red, green and blue secondary colours to create a single colour image (Figure 5-25).

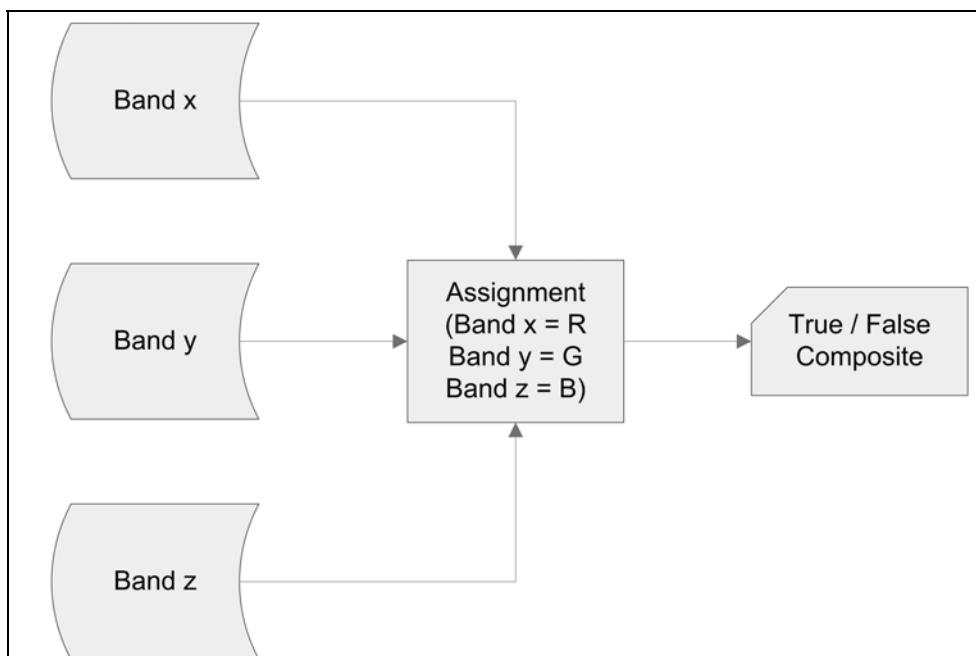


Figure 5-25 Image Classification subroutine – true and false colour composite

The last option of the analysis allows the user to create true and false colour composites of choice from the different seasonal imagery available. The true colour imagery is limited to only the first three bands of the visible spectrum of Landsat, whereas false colour composites may be created using any of the seven spectral bands.

5.3 DISSEMINATION

Data dissemination is crucial to this project. There are issues that have to be taken into consideration when disseminating the data. They are the following:

- Who are the recipients or users of the information? This is important as the level of detail or technicality depends on the users.
- What type of data or information is to be disseminated?
- What is the aim of disseminating the data or information?

The answers to the above questions determine how the data will be disseminated. Spatial data is usually presented as hardcopy maps accompanied by a report, but it may also be disseminated digitally on CD/DVD and/or via the World Wide Web or Internet.

The way this SDSS has been designed for usage requires it to be disseminated to the team in digital format. The TMGA SDSS is meant for a multidisciplinary group of scientists and, though their level of GIS knowledge may be limited, the aim was to provide opportunities for them to use GIS.

The dissemination of the TMGA SDSS took on a two-fold form, namely:

- *Provision of software and data on CD/DVD within the project teams.* The CD/DVD contains the GIS software that the SDSS is built upon. The software is a MicroImages product, TNTatlas. TNTatlas is available gratis to all users. The user will be required to install the TNTatlas software first. Fortunately the software does not require a lot of space on the hard drive. Once the software has been installed the user may retrieve the TMGA SDSS from the CD/DVD or copy the data to the hard drive before accessing the SDSS.
- *Publishing on the webpage of MicroImages Inc. (www.microimages.com)*. The SDSS was published on the MicroImages website for a limited time. In order to have the SDSS available for a longer period on the Internet a monthly fee is payable or a TNTserver will have to be acquired to be able to host the data. Users will need to install TNTclient on their machines after which they may be able to retrieve the SDSS. Unlike other Internet-published spatial data, the TMGA SDSS is available on the internet as interactive spatial data and not as maps.

5.4 CONCLUSION

The development of the TMGA SDSS was an interactive process with the project team to allow for clarification, comments and additions. The interactive process formed part of the evaluation process, which is discussed in the next chapter.

CHAPTER 6: TMGA SDSS EVALUATION

6.1 EVALUATION PROCESS

The evaluation of the TMGA SDSS was carried out in small groups of the project team members and with individuals. Though a full project team workshop would have been ideal, certain individuals and selected disciplines were not sufficiently motivated to finalize a date where all team members could be present. Some of the reasons were:

- No budget for team interactions within and between the projects;
- Lack of knowledge of GIS capabilities on the part of the users. For example, some of the team members still tend to use hard copy maps for pre-assessment and data processing, and other team members have inhouse GIS staff.
- Lack of curiosity about the potential advantages of using GIS in the different disciplines. This can be attributed both to shortage of time and imagination on the part of the users.

According to Chrisman (1997) the evaluation process involves comparing results to intended goals. Three simple criteria of assessment are accuracy, efficiency and effectiveness.

6.1.1 Accuracy of the Database

Knowing the quality of the data is important. The accuracy of the data is normally measured in terms of measurement frameworks put in place during data capture. Most of the data in the project database were acquired from external sources and the project had no say on the quality and accuracy standards of the data. In cases where accuracy is measured in terms of scale of capture, the project opted for the higher resolution data where necessary. The project looked at accuracy more in terms of whether the data layers overlay as expected after input in the GIS. Data were also checked against information gathered during field visits. Checks for projection and system errors on the data were undertaken during data overlay and by ascertaining whether the field-captured data plots were in the correct location.

The project team experts checked the accuracy of attribute data. Plotting the data according to certain attribute information and picking up expected patterns, or lack thereof, were used to check the attribute information. Before transformation and analysis of data were undertaken, the accuracy of the source data was taken into account to avoid producing inaccurate results by using irrelevant data during analysis.

6.1.2 Efficiency of the System

Efficiency is normally associated with costs in terms of allocation and use of resources like computer, financial and human resources. The project looked at its efficiency in terms of time costs that the system may save for the project team. Having a one-stop and structured data storage and retrieval station saves the users time that they would have used looking for the data. Data duplication is avoided as different disciplines in the team need the same data and they might have collected the data separately. Fieldwork time is minimised and more focused, as sites may be discarded during desktop work using the TMGA SDSS.

6.1.3 Effectiveness in Serving the Larger Purpose

The system designed by the project was meant to look at more than efficiency. The system involves the integration of diverse forms of geographic information and diversity in experts. The effectiveness evaluation of the tool did not only assess how effective the tool is for someone who is familiar with GIS technology, but also looked at how it may be used effectively by users who have no GIS experience.

6.2 PROJECT TEAM EVALUATION

The project team evaluated the TMGA SDSS according to user requirements. The evaluation looked at whether the documented requirements were met or not. Though most of the queries requested by the users were developed, due to complexity and time availability, some were not (Appendix B). Complexity could be attributed to the following:

- Unclear requests from the users.
- Lack of interdisciplinary knowledge.
- Lack of functions to do the processing in GIS.
- Challenges in programming spatial data.
- Lack of relevant scale data.

The process also looked at what needed to be revised and/or added. As some of the members of the project team had stated during the user requirements gathering phase, they first needed to see how the system worked to give them an idea of what GIS can do before they could give their input. This section, therefore reviews the original requirements, the refinements of those

requirements, and the changes or additions suggested. For easy reference, the comments and recommendations from the team are grouped in the different sections of the tool as follows:

- site selection and area of analysis;
- borehole analysis tool;
- topographic analysis tool;
- sensitive area analysis tool;
- image classification tool; and
- display of results.

6.2.1 Site Selection and Area of Analysis

The team suggested that a second option could be made available, where the user would select a point for analysis from an existing borehole site data file. This would be the case after field siting of possible borehole sites. The ‘select a point’ option was added on the analysis tool to accommodate this. After the point file is uploaded in the TMGA SDSS, the user may use this option to select a point from the file instead of creating a new one. This feature was later removed as the analysis of the field siting results required detailed analysis, extras that are not yet included on the SDSS.

The team preferred that there is an option to draw the area of interest around the point instead of using the buffering method. Though they agreed that the buffering method works well enough, a circle is not always the best option because of geological and hydrological patterns. The option of drawing an irregular polygon around a point would enable the team to define the area of interest based on factors related to physical processes. The team decided that the development of this option must be added to the list of further work required on the TMGA SDSS.

6.2.2 Borehole Analysis Tool

The way the queries were phrased and their sequence were revised during the evaluation exercise with the hydrogeologists. For example, grouping the queries relating to point data collection and monitoring, like weather stations and gauges. This discipline considered the borehole analysis tool to be very useful for planning and desktop siting decisions. They suggested that the tool might be expanded to allow further analysis of the data, e.g. the

plotting of selected monitoring information in graphs. In hindsight it was decided that it would be better to have an option to use a broader analysis area instead of just the study area as a whole for the borehole analysis queries looking at the monitoring data covering the full study area.

The ideal revision would be to combine the different point databases into one and run the analysis on this, but the process of combining the databases was found to be too challenging and complicated. This was due to the state of the databases, in terms of data format and capture. The databases do not follow the same data capture and storage formats and the nomenclature does not follow the same standard and consistency. The Department of Water Affairs has, however, recently distributed a report on “Standard Descriptors for Geosites” (DWAF 2004). The manual provides a guideline for field data capture. The team decided that a project database was required for the point time-series data. This database would be built on an external platform from the GIS and be linked to the GIS using a method like Open Database Connectivity (ODBC). However, this was beyond the scope of this project.

6.2.3 Topographic Analysis Tool

The team decided that the results of the topographic tool were adequate for now and further data analysis queries might be added as the project progresses. For example, the inclusion of power lines for the preliminary pipe route analysis. Additional requirements for this analysis were the total area of the analysis area covered by each farm and the total area covered by dams. These were added to the tool.

6.2.4 Sensitive Area Analysis Tool

The team suggested that it would be useful to have a query that displays areas that do not contain sensitive or protected species. This analysis query has been added to the list of further work to done on the TMGA SDSS. Another additional requirement was that, instead of the tool only showing which features are contained in the area of analysis, it must also indicate the amount of area covered by the features. For example, if a private reserve is within the study area, the tool must also indicate that ten per cent of the analysis area is covered by the private reserve. This function was added to the tool, but posed some technical challenges (see Section 6.3).

6.2.5 Image Classification

The team decided that the results of the image classification tool were adequate for the present as a detailed wetland mapping analysis was being done in a separate project, the results of which will be incorporated into the SDSS. Another suggestion was that the SDSS not automate the selection of bands to be used on the ratio combinations, but allow the users to select the bands, to accommodate this predefined ratios were created and a user defined option was created as well.

6.2.6 Display of Information and Results

In addition to printing the results in text format, the team suggested highlighting the query results and selected elements on-screen. Highlighting the elements of the results of the query in the display window was achieved satisfactorily when the elements are selected from the same object file, but when query results come from different object files the highlighting function presents some challenges (see Section 6.3). It was further suggested that detailed attribute information, more than that being printed on the Results bar, be made available. For example, detailed monitoring attribute information for each borehole ID printed on the Results bar. This could be achieved by opening the attribute tables of the relevant elements automatically. It was found that the table viewing function required for this is not yet compatible with the programming language (see Section 6.3).

6.3 TECHNICAL EVALUATION AND CHALLENGES

Besides the evaluation by the project team, technical evaluation of the TMGA SDSS was carried out to look at the programming and system development challenges that the project team was not able to do. The evaluation discusses the major challenges the project faced and for which alternative solutions had to be found.

6.3.1 Sensitive Area Analysis Tool

In the design of the Sensitive Analysis tool window, the user has just one button to press for calculating the percentage of the selected elements within the analysis area. It makes sense not to clutter the window with more than one button, but it requires that the user remembers to make sure that the first query is on “select” mode before calculating percentage of the second query results. For the third query results, on the first and second queries the menu list must also be on “select” mode. For example, if the user wants to calculate the percentage of a

feature on the “Protected areas” query, the “select” mode must be selected on the “Sensitive areas” query menu list. Likewise to calculate the percentage for a selection on the “Classification” query, both the “Sensitive areas” and “Protected areas” menu lists must be on “select” mode. To remind users, a text message has been added on the tool window.

6.3.2 Display of Information and Results

Results of any analysis are highlighted on the display window of the SDSS. If different analysis queries are carried out on the same file, the system deselects the previously highlighted elements. But if the analysis is done on different file layers, then the system may not deselect the previous highlighted elements. This is mainly seen with the highlighting of the formation unit that the possible borehole point starts in. The user has to use the deselect button on the “Layer Manager” window. This was shown to the users and is also included in the “Help” document.

The team’s suggestion that the tabular information, especially for monitoring point information, be opened automatically for highlighted elements, as it would be helpful to have the attribute information related to the selected elements, could not be incorporated as the software does not yet support the “view state” of the Tabular View on SML (Breitwisch 2006). A request has been submitted to the database developers of the GIS software to include this functionality, and the request is receiving priority status. To accommodate the need to view tabular information, users were shown how to open the tables on the SDSS. For reminder purposes, the “Help” document contains steps on how to open the file.

During the process of getting users to open the tabular information, it was noted that users may not know which group and or layer to open to view the relevant table. For the Topographic Analysis and tools it was decided that the names on the query window are easily related to the layers in the Layer Manager window. Confusion may occur though on the Borehole Analysis tool where a number of different layers and tables are used. A pop-up window was designed to tell the user which layer and table to open to view the results of each query.

In cases where the queries not only apply to the area of analysis but to the project study area at large, it was suggested that the display window zooms out to show all results and not only those within the area of analysis. For example, when a user wants to know if there are any weather stations in the study area, the analysis returns the total number of weather stations

found, their names and distance to the closest station from possible borehole site. Though the closest station is highlighted, if the station is outside the current display view, the user will not see the station. The project therefore aimed to get the display view to zoom out, to show both the possible borehole point and the selected element.

To enable the SDSS to refresh itself, a function was added to un-highlight all previously highlighted features on the display window and also to remove all temporary files created whilst a user was using the Proximity Analysis tool. These functions are implemented when the user presses the Close button. However, the system produces an error if the user closes the tool before any temporary files are created. When this error occurs the user has to close and then reopen the TMGA SDSS. The project is working towards solving this error as a similar error was occurring when no elements are highlighted, and this has been solved.

6.4 CONCLUSION

The evaluation process gave the team members the opportunity to understand how GIS worked and how it is used in the project by other team members. The opportunity was also taken by the system development team and project team members to understand the science and expected applications behind the queries requested by other project team members. As the evaluation process was the final step in the completion of the TMGA SDSS, the process was used to document other useful features might be included in the system which had not been previously foreseen. Some of the identified features were implemented during the finalization of the TMGA SDSS and others were noted as recommendations for further work on the project.

The next chapter looks at the conclusions of the project and also the recommendations made for further work.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

“... investment for one crucial objective-detailed assessment of water resources-potentially serves many others. The geological information applies equally to assessment of other physical resources. The same data and hardware serve a wide range of agricultural and environmental surveys”

Drury & Andrews (2002:8)

7.1 CONCLUSION

The aim of the study was to develop a spatial decision support system to be used in hydrogeological projects. The TMGA SDSS was meant to implement a decision support tool and then be used as an awareness-raising platform about GIS and its capabilities amongst the earth science community.

There is a need for GIS to be made more accessible to hydrogeologists, specialist scientists and resource managers. Earth scientists need the ability to know how to use spatial data and information so they may be able to know what spatial data and information is available in order to identify what they still require. This will enable them to:

- broaden their information sources, especially via data sharing amongst disciplines;
- use available programs and technologies more effectively; and
- supply spatial data and information requests needs more clearly.

The organising of the project team workshops were meant to further the awareness of spatial data use within a multi-disciplinary team. Unfortunately due to constraints discussed in the previous chapter, only small-group workshops were conducted. The small-group workshops were most useful when looking at the needs of the individuals or individual discipline requirements, but they were not very useful for incorporating tools to support knowledge transfer within the team and between disciplines. In certain cases an individual would ask for a certain analysis step to be changed or removed although he/she had not originally asked for the analysis. This happened because he/she did not fully understand what the step meant to another team member who, in most cases, represented a different discipline and was absent from the workshop. These issues might have been resolved easily if representatives of different disciplines and task teams were present at the same time.

However, on the premise that a picture is worth a thousand words, the SDSS is undeniably a powerful communication and teaching tool. The prototype tool that has been developed in this study is a commendable way forward. The reasons are:

- data quality and assurance is secured;
- limited GIS support is needed;
- quantitative and qualitative elements are addressed; and
- easy testing of scientific perception that can be expanded into 3D is facilitated.

The TMGA SDSS also includes the following creditable features:

- user input during conceptualisation, development and implementation stages;
- supports the cross-checking of conclusions and inferences;
- flexible query process;
- easy dissemination;
- readily updatable; and
- dissemination software platform is free.

In so doing it has raised awareness of the application benefits of GIS technologies. It has also promoted the mindset of questioning spatial data and the ability to identify data and information limitations.

Finally, there are the more intangible benefits that impact on relationships, understanding and communication between the disciplines. All users have equal and ready access to data acquired by the other disciplines at a scale that they need. This contributes to:

- intra-and inter-disciplinary exchange of views;
- understanding of how the data is or can be used;
- increased levels of confidence in decision-making; and
- a holistic approach to project design and implementation.

Spatial decision support systems are therefore an important part of bringing efficiency and effectiveness to groundwater projects. These tools are to add a positive value in evaluation of water resources in South Africa. The TMGA SDSS has shown that a system like this is

crucial in getting multi-disciplines communicating in the same language in terms of spatial data analysis and therefore assisting in solving water scarcity in the Western Cape.

7.2 RECOMMENDATIONS

Though most of the queries requested by the teams were developed, not all could be addressed in the prototype version of the TMGA SDSS. Future versions will hopefully include these additional data analysis tools (see Section 4.4).

The TMGA SDSS is primarily based on 2D data and information. It is possible to expand the SDSS to include the integration of 3D information, knowledge and output, e.g. topographical and geological cross-sections and aquifer storage modelling. The inclusion of 3D modelling would allow expert or specialist knowledge to be available to entry level users and would go some way to address the present gaps between different disciplines, for example those that have and those that do not have 3D and/or dynamic (as against steady-state) insight into earth and life science processes.

The presentation and analysis of temporal data could be improved to include graphic output. As monitoring data becomes available it would be useful to have time series data and information available to support decision-makers. Such a time series database linked to the TMGA SDSS would be a worthwhile addition.

Significant effort needs to be expended to facilitate South African scientists' interest in what they do not know about in areas outside their disciplines. A limited sense of enquiry or curiosity about new tools and ways of viewing and evaluating data more critically and objectively was a surprising finding of this study. It cannot only be attributed to limited time. It does seem to be related to organisational and/or individual psyches that support a view that if a particular organisation does not know about or has not yet initiated a study, then it cannot, by definition, be worth knowing about. Humility and curiosity are essential ingredients for innovation, and measures are solely needed to support their survival in the competitive South African environment.

REFERENCES

- Alexander WJR 1985. Hydrology of Low Latitude Southern Hemisphere Land Masses. *Hydrobiologia*, 125: 75-83.
- Ascough J C II, Rector H D, Hoag D L, McMaster G S, Van den Berg B C, Shaffer M J, Weltz MA & Ahjua L R 2002. Multicriteria Spatial Decision Support Systems: Overview, Applications, and Future Research Directions. [Online] In Rizzoli, A.E. and Jakeman, A.J., (eds.), *Integrated Assessment and Decision Support, Proceedings of the First Biennial Meeting of the International Environmental Modelling and Software Society*, Volume 2, pp 175-180. Available from www.iemss.org/iemss2002/proceedings [Accessed December 2005].
- Assero Limited (2003), *How to Write Better Requirements*. Issue 1.0. [Online] Available from www.assero.co.uk [Accessed March 2004].
- Becker A & Bugmann H 2001. *Global Change and Mountain Regions: The Mountain Research Initiative*. IGBP Report 49. IGBP Secretariat: Stockholm.
- Beniston M 2003. Climate Change in Mountain Regions: A review of possible impacts. *Climate Change* 59: 5-31.
- Bernardsen T 2002. *Geographic Information Systems: An Introduction*. 3rd ed. John Wiley & Sons: New York.
- Bidwell V 2003. Groundwater management tools. *Analytical procedure and case studies*. MAF Technical Paper No. 2003/06: New Zealand.
- Brown C, Colvin C, Hartnady CJH, Hay ER, Le Maitre D & Riemann K 2003. *Ecological and Environmental Impacts of Large Volume Groundwater Abstraction in the Table Mountain Group (TMG) Aquifer System: Summary Report for the Scoping Phase*. WRC Project K5/1327.
- Buckley DJ s.d. *The GIS Primer: An Introduction to Geographic Information Systems*. [Online]. Available from <http://www.innovativegis.com/basis/primer/primer.html> [Accessed August 2006].
- Breitwisch D 2006. E-mail from Dave Breitwisch, MicroImages Inc., 10 July.
- Cape Metropolitan Council 2001. Draft Water Services Development Plan. Internal report Cape Metropolitan Council: Cape Town.
- Carver S, Evans A, Kingston R & Turton I 1998. Geographic Information System on the World Wide Web: Improving Public Participation in Environmental Decision-making. [Online] Available from <http://geog.leeds.ac.uk/papers/98-4> [Accessed 17 February 2004].
- CeG - School of Civil Engineering and Geosciences, University of Newcastle on Tyne 2006. Earth Systems Observation. [Online] Available from <http://www.ceg.ncl.ac.uk/research/reseso.htm> [Accessed 12 August 2006].

- Chrisman N 1997. Exploring Geographic Information Systems. John Wiley and Sons Inc: Chichester, Sussex.
- City of Cape Town. CMC Administration 2002. *The Potential for Exploiting the Table Mountain Group Aquifer*. Compilers: Brown C, Hartnady CJH, Hay ER, Kleynhans SH & Luger MK. CMA Bulk Water Supply Study. Water Department, City of Cape Town: Cape Town.
- City of Cape Town. CMC Administration 2004a. *Inception report*. Compilers: Kleynhans SH & Shelley AJ. Table Mountain Group Aquifer Feasibility Study and Pilot Project: Inception Phase. Water Department, City of Cape Town: Cape Town.
- City of Cape Town. CMC Administration 2004b. *Hydrogeological Report*. Compilers: Hartnady CJH, Hay ER & Riemann K. Table Mountain Group Aquifer Feasibility Study and Pilot Project: Preliminary Phase. Water Department, City of Cape Town: Cape Town.
- City of Cape Town. CMC Administration 2004c. *Ecological and Environmental Report*. Compilers: Hay ER, Riemann K, Brown C, Colvin & Luger M. TMG Aquifer Alliance Report No. 1. Table Mountain Group Aquifer Feasibility study and Pilot Project: Preliminary Phase. Water Department, City of Cape Town: Cape Town.
- City of Cape Town. CMC Administration 2005. *Hydrocensus Survey and Review of November 2004*. Compilers: Hartnady CJH, Groenewald LG & Riemann K. TMG Aquifer Alliance Report No. 13 Table Mountain Group Aquifer Feasibility Study and Pilot Project: Preliminary Phase. Water Department, City of Cape Town: Cape Town.
- City of Cape Town. CMC Administration 2006. *Ecological and Hydro(geo)logical Monitoring Protocol*. Compilers: Riemann K, Hay ER & Brown C. Table Mountain Group Aquifer Feasibility Study and Pilot Project: Exploratory Phase. Water Department, City of Cape Town: Cape Town.
- Cloetingh SAPL, Ziegler PA & Cornu T 2004. *Environmental tectonics of the Northern Alpine foreland*. Geophysical Research Abstracts (European Geophysical Union), 6, 07554.
- Clarke KC 1999. *Getting Started with Geographic Information Systems*. 2nd ed. Prentice Hall: Upper Saddle River, New Jersey.
- Commission on Geosciences, Environment and Resources [CGER] 2001. Basic Research Opportunities in Earth Science. National Academics Press: Washington D.C.
- Committee on Hydrologic Science 2004. Groundwater Fluxes across Interfaces. Washington D.C.: National Academics Press. [Online] Available from <http://www.nap.edu/openbook/0309091136/html/R1.html> [Accessed November 2005].
- Cowling RM, Pressey RL, Rouget M & Lombard AT 2002. *A Conservation Plan for a Global Biodiversity Hotspot-the Cape Floristic Region, South Africa*. Biological Conservation 112(2003): 191-216. Available from www.sciencedirect.com [Accessed 01 September 2004].

- Batty M & Densham PJ 1996. *Decision Support, GIS, and Urban Planning*. University College London: Centre for Advanced Spatial Analysis. [Online] Available from http://www.geog.ucl.ac.uk/~pdensham/SDSS/st_paper.html [Accessed September 2005].
- Densham PJ 1990. *Spatial Decision Support System*. [Online] Canada: University of Western Ontario. Department of Geography. NCGIA Core Curriculum in GIScience, [Online] Available from <http://www.ncgia.ucsb.edu/giscc/units/u59/u59.html> [Accessed 17 February 2004].
- De Silva NF 2000. *Challenges in Designing Spatial Decision Support Systems for Evacuation Planning*. Natural Hazards research working paper #105. [Online] Available from www.colorado.edu/hazards/wp/wp105/wp105.html [Accessed September 2005].
- De Wit M & Stankiewicz J 2006. Changes in Surface Water Supply Across Africa with Predicted Climate Change. *Science* 311: 1917-1921.
- Du Plessis HJ 2001. Exploitation of Geospatial Information as Intellectual Property for Commercial Gain. Presented at the Congress of South African Surveyors, March, Cape Town.
- Drury SA & Andrews DME 2002. Remote Sensing and Locating New Water Resources. [Online] United Nations Regional Workshop on the Use of Space Technology for Disaster Management for Africa, Addis Ababa (1-4 July 2002) Session IXA, paper 1 available from <http://www.oosa.unvienna.ord/SAP/stdm/2002africa/presentations/index.html> [Accessed July 2003].
- Dutta D 2002. AVSWAT- A Spatial Decision support System for Land and Water Management in Bankura District of West Bengal. NRDMS Division, Department of Science and Technology. Map India 2002. [Online] Available from <http://www.gisdevelopment.net/application/nrm/water/watershed/watws0003pf.html> [Accessed August 2005].
- DWAF 2004. *Standard Descriptors for Geosites. Toolkit for water services: Number 2.1*. Department of Water Affairs and Forestry: Pretoria.
- ESRI 2002. *Metadata and GIS*. An ESRI White Paper. ESRI: Redlands, USA.
- Fedra K 1995. *Decision Support for Natural Resources Management: Models, GIS and expert Systems*. Reports and Papers. [Online] Available from <http://www.ess.co.at/docs/papers/dssi.html> [Accessed November 2005].
- Global Climate Observing System GCOS 2006. [Online] Available from <http://www.wmo.ch/web/gcos/gcoshome.html> [Accessed 12 August 2006].
- Global Ocean Observing System GOOS 2006. [Online] Available from <http://www.ioc-goos.org> [Accessed 12 August 2006].
- Global Terrestrial Observing System GTOS 2002. *Organization*. [Online] Available from <http://www.fao.org/gtos/org.html> [Accessed 12 august 2006].

GISWEB 2006. *Spatial Data Acquisition - Specific Theory. SDETheory.doc*. Department of Geomatics: The University of Melbourne. [Online] Available from www.sli.unimelb.edu.au/gisweb/SDE_Module/SDETheory.doc [Accessed 16 August 2006].

Goodchild MF & Kemp KK eds. 1990. *NCGIA Core Curriculum in GIS. National Center For Geographic Information and Analysis*. University of California: Santa Barbara [Online] Available from <http://www.geog.ubc.ca/courses/klink/gis.notes/ncgia/toc.html> [Accessed 16 February 2004].

Greese PG 1997. *Sheet 3319 Worcester: 1:250 000 Geological Series*. Council for Geoscience: Pretoria.

Haithcoat T s.d. *Vector GIS*. [Online] Presented by Tim Haithcoat, University of Missouri Columbia, with material from Holly Dickinson, State University of New York at Buffalo. Available from http://msdisweb.missouri.edu/presentations/intro_to_gis/pdf/Vector.pdf [Accessed August 2006].

Hall G B, Bowerman RL & Feick RD (s.d.). *GIS-based Decision Support Architecture and Application for Developing Countries*. [Online] Faculty of Environmental Studies, University of Waterloo, Ontario, Canada. Available from <http://www.fes.uwaterloo.ca/Tools/docs/saj.pdf> [Accessed 16 July 2005].

Hartnady CJH 2005. Compilers: Hartnady CJH, Groenewald LG & Riemann K. *Hydrocensus Survey and Review of November 2004. Appendix D: Global Context and Relevance of TMGA Monitoring*. TMG Aquifer Alliance Report No. 13 (Table Mountain Group Aquifer Feasibility Study and Pilot Project: Preliminary Phase).

Hartnady CJH & Hay ER 2000. *Reconnaissance Investigation into the Development and Utilisation of Table Mountain Group Artesian Groundwater, using the E10 Catchment as a Pilot Study Area*. Final Report to South African Department of Water Affairs and Forestry (DWAF): Citrusdal Artesian Groundwater Exploration (CAGE) Project, Umvoto Africa (Pty) Ltd.

Hartnady CJH & Hay ER 2001. *Tectonic remote-sensing for hydrogeological modeling In Table Mountain Group Aquifers, Western Cape Province, South Africa*. Geol. Soc. Amer. Ann. Meeting, Boston (Nov 1-10, 2001), Massachusetts USA (http://gsa.confex.com/gsa/2001AM/finalprogram/abstract_26768.htm).

Hartnady CJH & Hay ER 2002a. The use of structural geology and remote sensing in hydrogeological exploration of the Olifants and Doring River Catchments. In Pietersen, K. & Parsons, R. (eds). *A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy*. Water Research Commission Report TT158/01, 19-30.

Hartnady CJH & Hay ER 2002b. Fracture system and attribute studies in Table Mountain Group groundwater target generation. In Pietersen, K. & Parsons, R. (eds). *A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy*. Water Research Commission Report TT158/01, 89-94.

- Hartnady CJH & Hay ER 2002c. Boschkloof groundwater discovery. In Pietersen, K. & Parsons, R. (eds). *A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy*. Water Research Commission Report TT158/01, 168-177.
- Hartnady CJH & Hay ER 2002d. Groundwater prospecting on Verlorenvalley 334, between Ceres and Touws River, Western Cape, South Africa. In Pietersen, K. & Parsons, R. (eds). *A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy*. Water Research Commission Report TT158/01, 183-191.
- Hartnady CJH & Hay ER 2002e. Experimental Deep Drilling at Blikhuis, Olifants River valley, Western Cape: Motivation, Setting and Current Progress. In Pietersen, K. & Parsons, R. (eds). *A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy*. Water Research Commission Report TT158/01, 192-197.
- Hay ER & Hartnady CJH 2002. Towards “map-centric” simulation modelling of TMG recharge. In Pietersen, K. & Parsons, R. (eds). *A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy*. Water Research Commission Report TT158/01, 103-107.
- Hay ER, Hartnady CJH & Riemann K 2002. Integrated Water Resource Management in mountainous areas in South Africa; solutions from a case study in the Western Cape Province. Conference paper, presented at the Africa Mountains High Summit, United Nations – Nairobi, 6 to 10 May.
- Hay ER & Riemann K 2002. Water source development and management plan for the Greater Hermanus Area, Overstrand Municipality: Proposal for a comprehensive monitoring programme of surface and subsurface water flow and quality. Umvoto Report to Overstrand Municipality.
- Heywood I, Cornelius S & Carver S 2002. *An Introduction to Geographic Information Systems*. 2nd ed. Prentice Hall: Harlow, England.
- Hoffmann J, Zebker H, Galloway D & Amelung F 2001. Seasonal Subsidence and Rebound in Las Vegas Valley, Nevada, Observed by Synthetic Aperture Radar Interferometry. *Water Resour. Res.*, 37: 1551-1566.
- Hughes D 2005. *Acquire Your Requirements*. [Online] Available from <http://www.doughughes.net/index.cfm?event=viewEntry&entryId=79&print=pdf> [Accessed March 2005].
- Intergovernmental Group on Earth Observation GEO 2006. *About GEO*. [Online] Available from http://www.earthobservations.org/about/about_GEO.html [Accessed 12 August 2006].
- Integrated Global Observing Strategy IGOS 2004a. *IGOS overview*. [Online] Available from <http://ioc.unesco.org/igospartners/over.htm> [Accessed 12 August 2006].
- Integrated Global Observing Strategy IGOS 2004b. *Water Theme*. [Online] Available from <http://ioc.unesco.org/igospartners/water.htm> [Accessed 12 August 2006].

- Jenner JR 1996. *Introductory Digital Image Processing, A Remote Sensing Perspective*. 2nd ed. Prentice Hall: Upper Saddle River, New Jersey.
- Johnson P & Lachman B 2001. *Rapid Scan of Decision Support System Tools for Land-use Related Decision Making*. Prepared for Association for Biodiversity Information. [Online] Available from <http://www.natureserve.org/library/toolsum.pdf> [Accessed August 2006].
- Joubert CV 1970. The incidence of possible large reserves of deep-lying groundwater in the sandstones of the Table Mountain Series in the South and Southwest Province. In: *Water Year 1970 Convention – Water for the Future*: Department of Water Affairs: Pretoria p. CV1 – CV5.
- Jousma G & Roelofsen FJ 2004. *Worldwide Inventory on Groundwater Monitoring*. International Groundwater Resources Assessment Centre: Utrecht.
- Keenan PB 1997. *Using GIS as a DSS Generator*. [Online] Dublin: University College. Department of Management Information Systems. Faculty of Commerce. Available from http://mis.ucd.ie/members/pkeenan/gis_as_a_dss.html/document_view [Accessed August 2005].
- Keenan PB 2004. *Spatial Decision Support Systems: Extending the technology to a broader user*. [Online] Available from <http://mis.ucd.ie/Members/pkeenan/extendsdss.pdf> [Accessed November 2005].
- Lawford R, Nakamura K & others 2003. *A global water cycle theme for the IGOS Partnership*. [Online] Report of the Global Water Cycle Theme Team: (Version 1.05, November 2003). Available from http://ioc/unesco/org/igospartners/docs/theme_reports/IGOS2.DOC Accessed 12 August 2006].
- Malczewski J 1997. *Spatial Decision Support System*. [Online] Canada: University of Western Ontario. Department of Geography. NCGIA Core Curriculum in GIScience, Available from <http://www.ncgia.ucsb.edu/giscc/units/u127/u127.html> [Accessed 17 February 2004].
- Martin D 1996. *Geographic Information Systems – Socioeconomic Applications*. 2nd ed. Routledge: London.
- McBride R & Schostak JF 2005. *An Introduction to Qualitative Research*. Enquiry Learning Unit. [Online] Available from <http://www.enquirylearning.net/ELU/Issues/Research/Res1Cont.html> [Accessed 8 January 2006].
- Messerli B, Viveroli D & Weingartner R 2004. Mountains of the World: Vulnerable Water Towers for the 21st Century. *Ambio, Special Report* 13: 29-34.
- MicroImages 2003. *Using TNTatlas® for X Windows – Tutorial*. MicroImages Inc: Lincoln.
- MicroImages 2005. *Reference Manual, Rasters* (page 575 – 578). MicroImages Inc: Lincoln.

- Midgley DC, Pitman WC & Middleton BJ 1994. *A Surface Water Resource of South Africa 1990 Volume IV: Western Cape, Appendices*. WRC Report No. 298/4.1/94. Water Research Commission: Pretoria.
- Mlisa A & Hartnady CJH 2003. *Geo-informatics for Groundwater Exploration in the Western Cape Province, South Africa*. 21st International Cartographic Conference (Presentation) (Abstract of Papers, 10-16 August), Durban, South Africa, p. 33.
- Mouton J 2005. *How to succeed in your Master's & Doctoral Studies. A South African Guide and Resource Book*. 8th Impression, Van Schaik Publishers: Hatfield, Pretoria.
- New M 2002. Climate Change and Water Resources in the Southwestern Cape, South Africa. *South African Journal of Science* 98: 1-7.
- Ningham Shand 2004. TMG Aquifer Feasibility Study and Pilot Project: Exploratory Phase: Draft Scoping Report. Report Number 400396/3715. Ninham Shand: Cape Town.
- Ningham Shand 2006. TMG Aquifer Study and Pilot Project: Site Specific EMPs. Exploratory Drilling Phase. (Working draft for comment). Prepared by Ninham Shand in association with the City of Cape Town.
- NASA 1999. *Landsat Program Homepage*. [Online] Available from <http://geo.arc.nasa.gov/sge/landsat/tofc.html> [9 August 2006].
- NISO 2004. *Understanding Metadata*. [Online] USA: Bethesda: National Information Standards Organisation (NISO) Press.MD 20814. Available from <http://www.niso.org/standards/resources/UnderstandingMetadata.pdf> [Accessed December 2005].
- Reasoner M, Graumlich L, Messerli B & Bugmann H 2002. *Global Change and Mountains: The need for an integrated approach to address human security in the 21st century*. [Online] IHDP Update - Newsletter of the International Human Dimensions Programme on Global Environmental Change, Nr 1/2002. Available from http://www.ihdp.uni-bonn.de/html/publications/update/update02_01/IHDPUpdate02_01_graumlich.html [Accessed 12 August 2006].
- Quick AJR 1995. Issues Facing Water Resource Managers and Scientists in a Rapidly Growing Coastal City: Cape Town, South Africa. *South African Journal of Science* 91: 175-183.
- Robinson AH, Morrison PC, Kimerling AJ & Guptill SC 1995. *Elements of Cartography*. 6th ed. John Wiley & Sons, Inc: New York.
- Segrera S, Ponce-Hernandez R & Arcia J 2003. *Evolution of Decision Support System Architectures: Applications for Land Planning and Management in Cuba*. *Journal of Computer Science and Technology* 3: 40-46.
- Sekkouri IH & Ouazar D 2002. *An Intelligent Spatial Data Preparation System for Groundwater Modelling*. [Online] Hydraulic Analysis System Laboratory, Department of Civil Engineering, Ecole Mohammadia d'Ingenieurs, BP 765, Agdal, Rabat, Morocco. Available from www.fu-berlin.de/iamg2002/download/Sekkouri_llham.pdf [Accessed November 2005].

- Scott RL, Goodrich DC & Levick LR 2003. *A GIS-based Management Tool to Quantify Riparian vegetation Groundwater Use.* [Online] In proceedings First Interagency Conference on Research in the Watersheds, October 27-30, 2003 pp 222-227. U.S. Department of Agriculture, Agriculture Research Service. Available from www.Tucson.ars.ag.gov/icrw/proceedings/scott.pdf [Accessed August 2005].
- Sinske SA & Zietsman HL 2004. A spatial Decision Support System for Pipe-break Susceptibility Analysis of Municipal Water Distribution Systems. *Water SA* 30 (1): 71-79.
- Smith RB & Ghormley 2003. *Writing Scripts with SML in TNTmips®, TNTedit™, TNTview™.* MicroImages Inc: Lincoln.
- South Africa (Republic of) 2000. Act on Policy on the Pricing for and Copyright of Spatial Information Products and Services, No. 2 of 2002. Prepared by Sub-committee on Policy (Committee for spatial Information) [online]. Available from <http://www.nsif.org.za> [Accessed 12 September 2002].
- South Africa (Republic of) 2003. Act on Spatial Data Infrastructure, No. 54 of 2003. *Government Gazette* Volume 464, No. 25973.
- Sprague JR & Ralph H 1980. *A Framework for the Development of Decision Support Systems.* [Online] Available from <http://web.njit.edu/~bieber/CIS677F98/readings/sprague80.pdf> [Accessed December 2005].
- Star J & Estes J 1990. *Geographic Information Systems.* Prentice Hall Inc. New Jersey.
- Stevens D & Thompson D 1996. GIS as Social Practice: Considerations for a Developing Country. Paper presented GIS/LIS 96.
- Tapley BD, Bettadpur S, Watkins M & Reigber C 2004. *The Gravity Recovery and Climate Experiment: Mission Overview and Early Results.* *Geophys. Res. Lett.* 31 (9): L09607, doi:10.1029/2004GL019920.
- Theron JN, Gresse PG, Siegfield HP & Rogers J 1992. *The geology of the Cape Town Area - Explanation Sheet 3318 Scale 1:250 000.* Geol. Surv. S. Afri: Pretoria.
- Tyson C 1999. Data Input, Digitizing and Scanning. Lecture Notes, Geographic Information Systems Course, Department of Survey and GIS, University of Fort Hare.
- Umvoto 2005. Deep Artesian Groundwater for Oudtshoorn Municipality Supply (DAGEOS) Project: Target Generation and Borehole / Wellfield Siting using Structural Geology and Geophysical Methods. Phase D of DAGEOS Project: WRC Project K5/1254.
- UNESCO – MAB - UNESCO man and the Biosphere Programme 2006a. [Online] *Biosphere reserves: reconciling the conservation of biodiversity with economic development.* Available from <http://www.unesco.org/mab/BRs.shtml> [Accessed 12 August 2006].
- UNESCO – MAB 2006b. Biosphere Reserve Integrated Monitoring (BRIM): *Observing global biodiversity changes.* [Online] Available from <http://www.unesco.org/mab/BRs/BRIM.shtml> [Accessed 12 August 2006].

- UNESCO – MAB 2006c. *Biosphere Reserve Information: South Africa, Kogelberg*. [Online] Available from <http://www2.unesco.org/mab/br/brdir/directory/biores.asp?mode=all&code=SAF+01> [Accessed 12 August 2006].
- UNESCO-WHC - UNESCO World Heritage Centre 2006. *Cape Floral Region Protected Areas*. [Online] Available from <http://whc.unesco.org/en/list/1007> [Accessed 12 August 2006].
- Urban C 2003. *Midwest Spatial Decision Support: Partnership – About SDSS*. [Online] Available from http://www.epa.gov/waterspace/tools_casestudies_vero.html [Accessed November 2005].
- Veregin H 1998. *Data Quality Measurement and Assessment*. [Online] NCGIA Core Curriculum in Geographic Information Science, [Online] Available from <http://www.ncgia.ucsb.edu/giscc/units/u100/u100.html> [Accessed 20 March 2004].
- Wiesmann U, Gichuki FN, Kitembe BP & Liniger H 2000. Mitigating Conflicts Over Scarce Water Resources in the Highland-lowland System of Mount Kenya. *Mountain Research and Development* 20: 10-15.
- W3schools (s.d). *Introduction to XML*. [Online] Available from <http://www.w3schools.com> Copyright Refsnes Data.

APPENDIX A: DATA CATALOGUE

The following tables outline data that is possible useful for the CCT_TMG and WRC Ecosystem project

Dataset	Custodian	Existence	Scale	License required	Cost	Have	Need
1. GEOLOGY							
Geological Structure & Lithology: 3324 PE	CGS	Y	1:250 000	Y	R6990	CSIR	2
Geological Structure & Lithology: 3322 Oudtshoorn	CGS	Y	1:250 000	Y	R7150	N	2
Geological Structure & Lithology: 3320 Ladismith	CGS	Y	1:250 000	Y	R8380	N	1
Geological Structure & Lithology: 3420 Riversdale	CGS	Y	1:250 000	Y	R3880	N	2
Geological Structure & Lithology: 3319 Worcester	CGS	Y	1:250 000	Y	R7620	N	1
Geological Structure & Lithology: 3318 Cape Town	CGS	Y	1:250 000	Y	R4710	N	1
Geological Structure & Lithology: 3218 Clanwilliam	CGS	Y	1:250 000	Y	R6650	N	1
Geology (1997)	CGS	Y	1:1 000 000	Y	R10 000	N (only 1993, no license)	3
Structural geology - shows dips, folds faulting, offsets, fractures etc.	CGS	y	1:50 000	?	?	?	
Lithology	CGS	y	1:50 000	?	?	?	

Dataset	Custodian	Existence	Scale	License required	Cost	Have	Need
2. HYDROGEOLOGY							
Groundwater Regions of South Africa	WRC	Y	1:1 000 000	N	N/a	CSIR	1
Standard Hydrological features	DWAF	Y	1:500 000	N	N/a	N	1
Hydrogeological Map Series – Cape Town	DWAF	Y	1:500 000	N	N/a	CSIR	1
Hydrogeological Map Series – Oudtshoorn	DWAF	Y	1:500 000	N	N/a	CSIR	1
Hydrogeological Map Series – Port Elizabeth	DWAF	Y	1:500 000	N	N/a	CSIR	1
Hydrogeological Map Series – Calvinia	DWAF	In Production	1:500 000	N	N/a	N	1
Breede River Hydro-census data	Groundwater Consulting Services	y	?	?	?	n	1
Berg River Hydro-census data, Borehole data: point data, groundwater quality, levels, time series and possibly pumping rates	<i>Unawarded tender</i>	y	?	?	?	n	1
Hex River Hydro-census data	Roger Parsons & Assc	y	?	?	?	n	1
Springs including mountain springs: Flow rates and point data	DWAF	y	1:500 000	?	?	?	?

Dataset	Custodian	Existence	Scale	License required	Cost	Have	Need
3. HYDROLOGY/GEOHYDROLOGY							
Hydrological Features – rivers, estuaries, coastal lakes and vleis. Includes river flow data (different annual or hourly flow regimes; different baseflow contributions; flow duration curves and analyses; flood recession curves)	DWAF Geomatics, CSIR (estuaries), Southern Waters.	Y	1:50 000 – 1:500 000	Y	N/a	N	1
4. CLIMATIC DATASETS							
Precipitation and evaporation	CSIR	y	1:50 000?	N	?	?	
Snowmelt data	?	?	?	?	?	?	
5. DIGITAL TOPOGRAPHY/TERRAIN							
SLI Digital Topographic Features ¹	Surveyor General	Y	1:500 000	Y	R3 025 Western Cape (poss. more for CFK)	N	1
Orthophotos and 20m contours	?	y	1:10 000	?	?	N	
6. GENERAL LAND COVER							
ARC Land-types (+ pdf of land types descriptions)	ARC ISCW	Y	1:250 000?	Y	R817 per sheet = R4902	CSIR - only for 1:250K Oudtshoorn sheet	1

¹ Digital Topographic Features include Roads, Rivers, Dams, Pans, Railways, Railway Stations, Bridges, Power lines, some communications features, Schools, 20m contours

Dataset	Custodian	Existence	Scale	License required	Cost	Have	Need
National Landcover	CSIR	Y	1:250 000	N/a	N/a	CSIR	1
ENPAT 2001 ²	DEA&T	Y	~1:250 000	Y	R500 for Eastern Cape, Western Cape and Metro Areas	Only previous version	3
7. CAPE LAND USE COVER							
Broad Habitat Units	Western Cape Nature Conservation Board (WCNCB)	Y	1:50 000 – 1:250 000				
Irreplaceability Values	WCNCB	Y	1:50 000 – 1:250 000	Y	N/a	CSIR	1
Mammal Irreplaceability Values	WCNCB	Y	1:50 000 – 1:250 000	Y	N/a	CSIR	1
Priorities	WCNCB	Y	1:50 000 – 1:250 000	Y	N/a	CSIR	1
Priority Remnants	WCNCB	Y	1:50 000 – 1:250 000	Y	N/a	CSIR	1
Sensitive Lower Vertebrates	WCNCB	Y	1:50 000 – 1:250 000	Y	N/a	CSIR	1
Transformed Areas	WCNCB	Y	1:50 000 – 1:250 000	Y	N/a	CSIR	1
Untransformed Areas	WCNCB	Y	1:50 000 – 1:250 000	Y	N/a	CSIR	1
8. AQUATIC FEATURES							
Degradation of Rivers and Wetlands	Fresh Water Research Unit-	Y	?	?	?	N	?

² ENPAT = Environmental Potential Atlas

Dataset	Custodian	Existence	Scale	License required	Cost	Have	Need
	UCT						
Wetlands	DWAF	Y	?	N	N/a	CSIR	1
Jackie King's wetland data	?	Check with Cate?	?	?	?	N	
Eco-regional level 2 and 3	DWAF or Southern Waters	Check with Cate?	?	?	?	N	
9. INFRASTRUCTURE							
N1 & N2 Data	Southern Waters	Y	?	N	?	Southern Waters	
10. TOPOGRAPHIC AND CADASTRAL MAPS							
Scanned Maps	GIMS	Y	1:50 000	Y		Selected	
Scanned Maps	GIMS	Y	1:250 000	Y		Selected	
Urban and Rural Cadastre	Chief Directorate: Cadastral Surveys (Surveyor General: Cape Town)	City of Cape Town (CCT) project	1:50 000	?	~R500		
Provincial Nature Reserve Boundaries	WCNCB	CCT project	1:50 000 to 1:6 250	?	?		
Local Authority Nature Reserves	WCNCB	CCT project	1:50 000 to 1:6 250		?		
Mountain Catchment Areas	WCNCB	CCT project	1:50 000 to 1:6 250		?		
Biosphere Reserves Zonation (Kogelberg & West Coast)	WCNCB	CCT project	1:50 000 to 1:6 250	?	?		
National Heritage Sites	WCNCB	CCT project	?	?	?		

Dataset	Custodian	Existence	Scale	License required	Cost	Have	Need
Conservancies	WCNCB	CCT project	?	?	?		
Private Nature Reserves	WCNCB	CCT project	1:50 000 to 1:6 250		?		
11. BOTANICAL MAPS							
Kogelberg data (Boucher map)	WCNCB	Y	1:10 000	?	?	?	
1970's/1980's CNC vegetation map	WCNCB?	?	?	?	?	N	
Eugene Moll's satellite map	CSIR digital copy	Y	1:250 000	N	?	?	
NBI vegetation map	?	Y	1:500 000	N	None	y	
Riverine vegetation type	Southern waters, Cate?	?	?	?	?	?	
Occurrence of rare species	WCNCB?	WCNCB?	N/A	N	?	?	
12. FAUNA							
Fish, amphibians, invertebrates etc	WCNCB?	?	?	?	?	N	
FAO Fisheries GIS	FAO		?	?	?	N	3
13. REMOTE SENSING	?	?	?	?	?	?	?

Need column: 1 = Essential, 2 = Useful, 3 = Nice to have

Franschhoek Map Catalogue

Dataset	Custodian	Existence	Scale/Resolution	License required	Cost	Have
Digital Topographic Features	SLI	Y	1:50 000	Y	R451 for 4 1:50k sheets	Part of above
Landsat 7 ETM+ 175 – 083/084 (19991102)	CSIR	Y	30m Multi-spectral 15m Panchromatic	N	N/a	CSIR/ Southern Waters
DEM	CSIR	Y	20m	?	N/a	CSIR

Zachariashoek Map Catalogue supplied by David Le Maitre, CSIR. From Zachariashoek data document describing the main sources of existing data for the area.

Description	Scale (approx)	Date
Aerial photograph B& W	1:12 000	1967
Topo & boreholes x 3	1:20 000	
Geology transparency	1:20 000	
Catchments topo	1:10 000	
Catchments ortho-photo 3319CC 6&7	1:10 000	1978 photo
Catchments topo	1:10 000	1971
Catchments topo + treatment sheet	1:10 000	1971
Ortho-photo transparency with overlay	1:10 000	1978 photo
Ortho-photo paper	1:10 000	1978 photo
Ortho-photo transparency x2	1:10 000	1978 photo
Plant releve locations grid		
Vegetation map paper	1:10 000	
Spot heights	1:12 000	
Vegetation map transparency	1:10 000	
Topo transparency	1:10 000	1971

(The data outlined here be captured into GIS format through either digitising or scanning and geo-referencing if required)

Appendix B: Questionnaire and Interviews

The disciplines and experts interviewed are the following:

Table B.1 Experts interviewed

DISCPLINE	EXPERT	COMPANY
Environmental and Legal	Karen Shippey	Ninham Shand
Environmental and Legal	Penelope Jones	Ninham Shand
Hydrogeology	Chris Hartnady	Umvoto Africa
Hydrogeology	Chris Jackson	Umvoto Africa
Hydrogeology	John Weaver	CSIR
Hydrogeology	Kornelius Riemann	Umvoto Africa
Hydrogeology	Leon Grenewald	Umvoto Africa
Ecology	Cate Brown	Southern Waters
Ecology	Charlie Boucher	University of Stellenbosch
Ecology	David le Maitre	CSIR
Engineering	Stephan Kleynhans	Ninham Shand

Methodology / Agenda

1. Aim of project

Brief explanation of project aims, which is to develop a spatial decision support system.

2. GIS background

The second step of the interview was to find out how much knowledge the expert has on GIS. In most cases the experts were aware of the use of GIS but haven't used it personally. In other cases they said that GIS is something that they are just beginning to learn about. They have not yet been exposed to it a lot. Examples of GIS capabilities were given to assist the user in determining what the needs might be.

3. Spatial analysis requirements

The question posed to the expert was "what kind of questions would you like the GIS system to give you without having a GIS technician involved in order to assist you and make your decision process efficient?" The question was further explained using examples to make sure the expert understood.

SPATIAL ANALYTICAL REQUIREMENT ANALYSIS

The spatial analytical requirement analysis gave a range of answers, ranging from simply GIS analysis to complex processes. Below are examples of analytical processes the various disciplines require to assist them in decision making.

ENVIRONMENTAL

- Proximity of potential drill site to sensitive areas: select areas that are in or within a certain distance from highly sensitive areas e.g. areas identified by ecologist as highly sensitive
- Slope and terrain analysis: highlight areas of suitable slope terrain for drilling (could eliminate areas where it is impractical to drill)
- Where are the areas that are high hydrological priority within low environmental sensitivity i.e. these are much more favourable.
- Proximity of potential drill site to existing boreholes and springs (could highlight these areas as areas that would have a direct impact on use of water by farmers)
- Proximity of potential drill site to existing access roads and certain infrastructure (this will relate to cost involved in building additional access roads/tracks).
- Wellfield phase: proximity to dams and nearby towns (or other potential users).
- Proximity of potential drill site to monitoring holes / surface monitoring sites
- Proximity to various types of protected areas
- Density of areas containing threatened species within 500m, 1km, 2km of potential drill site
- Size of area of interest
- Slope and slope stability
- Average annual rainfall
- Groundwater recharge zones / aquifer protection zones?
- Proximity to hiking paths and recreational wilderness areas, i.e. those areas where a drill site or wellfield may be offensive to people enjoying the natural beauty
- Queries regarding hydrogeological potential vs. whether within a nature reserve or not
- Farm numbers and areas within the potential drill site

ECOLOGY

- Sensitive areas proximity to streams or fresh water
- Relationship between sensitive layers and other GIS layers e.g. do highly sensitive areas occur where lithology is Peninsula?
- Determine water path if borehole strikes water: will the water run to a river or stream, which might cause erosion and blockage.
- Proximity of potential drill site to road
- Proximity of drill site to stream / freshwater
- Relationship between streams, geology, structural geology: is the change in stream direction due to geomorphology or structural geology
- River base flow analysis
- Elevation / terrain analysis
- Vegetation Indices, TCI: map sensitive areas
- Amphibians, frogs: indicate presence of water and season

HYDROGEOLOGY

- Lineament (fractures, faults, fold axis) analysis
 - Proximity of existing borehole to nearest lineaments within a certain radius
 - Orientation of each lineament segment
 - Number and length of lineament
 - Lineament density
 - Number of lineament intersections
 - Distance from borehole to intersection point
 - Draw connecting lines from borehole to intersection node
 - Highlight packages of connected lineaments
 - Contour intersection points
- Orientation and thickness analysis of aquifers for cross section
- Borehole data analysis: Most of the interpretation is done on aquifer basis to determine if borehole is plot specific
 - Group boreholes with regard to geology and water quality

- Find data points that plot in a certain aquifer on surface, compare that with borehole log information in the NGDB.
- Find data points plotting in Peninsula and have waterlevel data, EC and other measurements.
- Identify depth of casing in boreholes drilled in certain lithology

ENGINEERING

- Pipeline route attributes
 - Terrain analysis

DATA DISPLAY AND VISUAL INTERPRETATION

- Data overlay
- Transparency on polygon styling
- Statistics & measurement
- Datatips / multiple datatips
- Labelling options using attributes
- True & false colour composites of Landsat TM imagery
- Landsat TM image ratios
- HELP option
- PRINT with scale option

Appendix C: Database Management Protocol

In a multidisciplinary team, working at different locations with different software, the aspect of data sharing becomes critical to integrated problem conceptualisation and solving. The challenge to data sharing is the following:

- Maintaining the data integrity
- Ensuring data quality and access to users of different level of skill, insight and security clearance
- Standardisation in quality, georeferencing and completeness
- Updating and quality control of additional data and meta data sets supplied to the data base
- Variation in presentation style between different disciplines
- Respecting copyright and protecting intellectual property rights

In order to address these challenges standards and protocols have to be set for data input and distribution. These are summarised as the database management protocol in which particular attention is paid to data security and integrity issues. The final database will be provided in the proposed version as GIS Atlas.

DATABASE CONTENT

The database consists of the spatial and transient datasets, the metadata for each dataset and the maps and images produced with these datasets. A brief description of the software capability and the database content is given below.

Software

The GIS database is developed with TNTmips from MicroImages Inc., an all-in-one GIS system. It is capable of handling spatial and non-spatial data. Spatial data can be stored in either vector or raster format (binary to 64 bit floating point). Attribute tables are available for both vector and raster data and can be linked via an in-build relational database. Non-spatial data are linked via ODBC to other SQL databases. The GIS layers are arranged for viewing and querying using the free software TNTatlas.

GIS database

The spatial datasets that have been or will be assembled consist of:

- Cadastral data (e.g. roads)
- Topography and digital elevation model data;
- Spatial hydrological data;
- Hydroclimatology data;
- Regional geology data;
- Structural geology data;
- Aerial photography;
- Satellite imagery;
- Spatial environmental data;
- Spatial data analysis.

Point and transient database

Point and transient data linked to the spatial data mentioned above include:

- Hydrological records for rivers;
- Climatic timeseries;
- Point source hydrocensus and monitoring data.
- Downhole logs, including geophysical logs, drill core description, borehole video *inter alia*;
- Point source ecological, specifically vegetation, data;
- Pump test data;
- Other project data as yet unspecified.

RESPONSIBILITIES

When assigning responsibilities three different groups have to be distinguished:

- Users
- Data collection organisations
- Operator of GIS database system

Users

It can be distinguished between primary and secondary users, depending on the purpose of use and the responsibility.

- The primary users of the database are the teams of the WRC Ecosystem Project and the TMGA Project. They would use the data for analysis and manipulation.
- The secondary users comprise of the WRC and finally the public.

Data collection organisations

Since a number of already existing data will be incorporated into the database, there are the tasks of data collation and data collection. For both tasks the responsibility lies within the team. However, there are different quality control implications that require distinguishing between both.

- Data collation means to acquire already existing data from other organisations, e.g. DWAF, CPU, NBI, SAWB. These data have normally to be accepted as they are, although a quality control is pertinent. This is part of the collation process and therefore the responsibility of the collating organisation.
- Additional field data might be collected during the monitoring phase of the project. Since this is direct data collection, the field team is responsible for delivering correct and accurate data. However, the whole team has to set quality standards and the operator has to give formats and other requirements.

Database Operator

Database operation includes the database design, database management and hosting of final versions. The GIS task team, comprising of UMVOTO GIS Division in cooperation with Lucille Schonegevel (CSIR), will be responsible for and conduct all three aspects.

- Database design is nearly completed. However, as new datasets and requirements from different users become relevant, the task will continue and further database incorporation might become necessary.
- Database management includes incorporating of data, quality control of all new datasets, aspects of database access and data sharing.
- The database is hosted at the UMVOTO server. The final version for viewing and querying will be provided on request.

Note that Umvoto GIS division is considered the custodian for the database. However, if other divisions from Umvoto want to use the data, the organisation is considered a primary user and the same conditions apply, as described in this document.

DATA ACCESS

The database is only accessible as final version. Draft versions and working versions, which are not cleaned and structured according to the requirements, will not be available for either viewing or sharing to others than the GIS operator. The way and extent of access depends upon the assigned responsibilities (see above) and the needs.

- Operator has full access at all time;
- Primary user has access to view final version and access to actual data for selected datasets on request;
- Secondary user will get access to view and query final version only.

Data Viewing

For data viewing there are two options available:

- Downloading TNTatlas software and database from ftp-server, or
- Requesting CD with TNTatlas software and the database from the system operator.
- Metadata for all datasets are accessible in TNTatlas

Data Sharing

Data sharing is only possible within the project teams. The published version of the database will be locked for access. The operator will identify the datasets, which are available for sharing, based on mainly three criteria,:

- Ownership
- Copyright
- Restrictions

The available datasets will be provided to the team on request, which has to be submitted according to the form given in Appendix B. Copyright and ownership has to be acknowledged and respected, when using the data, even if the data are not restricted for further distribution. Restricted datasets can only be provided, when the need for these data is specified.

The clause on the Data Sharing Form (see Appendix B) has to be signed for each request, independent of copyright or other restrictions.

Ownership

The organisation that collates and provides data for incorporation into the database has to specify the ownership of the dataset. This must reflect in both the metadata and the Data Sharing Form (see Appendix B). The following options exist:

- The data collection organisation holds the ownership;
- The data collection organisation sells the data and the ownership goes over to the primary user and eventually to the client (WRC or CCT);
- If analysis of data results in new datasets, the organisation producing the new datasets can claim the ownership, if the new product is intellectual property (however, the owner of the original data has to be acknowledged);

Note that ownership does not automatically imply any restrictions for changing or distribution of these datasets.

Copyright

A number of datasets has copyright for publishing, distribution or changing. The copyright holder is usually, but not always, identical with the owner. For example, these copyrights may specify that data purchased for use on a particular project cannot be used outside of that project; or can be used generally by the organization that has purchased that dataset but cannot be distributed outside of the organisation.

There are different levels of copyright:

- Use of data only within organisation and for specific project;
- Use of data only in project for which the data were collated;
- Use of data only in original form (i.e. no manipulating);
- Use and manipulating of data within organisation;
- Distribution and manipulation allowed, when sharing the profit with copyright holder;
- Distribution of data without restrictions permitted;
- Publishing of data without restrictions.

The existing copyright for each dataset has to be specified within the metadata and has to be respected and acknowledged in the data sharing process.

The decision about data sharing lies with the owner or copyright holder.

Restrictions

Some datasets may have other restrictions for publishing, which has to be addressed. Special sensitive data, like cave locations, coordinates of archaeological sites (e.g. rock paintings), coordinates for rare plant species, should be subject to security and should not be published or distributed freely.

Appendix C lists copyright and restrictions for all current datasets.

Data sharing formats

The possible formats for data sharing are listed in Table 1 below. The user is required to specify the format, when requesting the data (see Appendix B). The same data formats are to be used for data to be incorporated into the database (see below).

Table 1 Available Data Sharing Formats

Table Formats	DBase III / IV		
Vector Formats	Arc/Info “Coverage”	Arc/Info “Export” (E00)	ArcView “Shapefile”
Raster Formats	GEOTIFF / TIFF (incl. Georeference header-file)	Arc/Info BIL/BIP	ERDAS-IMG
Image Formats	GEOTIFF / TIFF (incl. Georeference header-file)	JPEG	
Projection	UTM	Geographic WGS84	Lat Long WGS84 (GPS data only)

DATA INCORPORATION

Depending upon the source of the datasets to be incorporated different requirements and responsibilities for the quality control will be specified.

Requirements

- All datasets to be incorporated have to be submitted with the complete metadata set attached, as outlined in Appendix A.
- Spatial data has to be submitted either in TNTmips (RVC) format or in one of the formats specified in Table 1.
- Point and transient data has to be submitted in table format (i.e. Excel or dBase). If the data are collected within the team, the required fields and field types (e.g. field names, field length) will be specified prior to data collection or collating.
- All datasets should have been checked for quality and accuracy.

For data collected, prepared or modified within the team the submitting organization and or person is required to submit the following together with the modified datasets (see Appendix B):

- Original datasets or field notes;
- Description of procedure of modifying or analysis;
- Explanation of attribute fields;
- Quality control statement;
- Statement of ownership and copyright.

Quality Control

Only data of certain quality and accuracy will be incorporated into the database. The quality control of collated and or collected datasets is the responsibility of the whole team. However, the final quality control will be undertaken by the operator.

Data that do not comply with the quality standards will be rejected or adjusted, if applicable and reasonable. The standards are as follows:

Completeness

The data collection organisation has to ensure that the submitted datasets are complete according to the requirements, specified under “requirements” above and the following points.

Correctness of point coordinates

The data collection organisation has to ensure that all point data have coordinates assigned. These coordinates have to reflect the correct position. This will be verified during the quality control with overlaying other datasets (e.g. cadastral).

Correct georeferencing

The data collection organisation has to ensure that the data are properly georeferenced and according to the projections specified in the format table (Table 1).

Cleaned data

The data collection organisation has to ensure that vector data are clean, i.e.

- All polygons are closed;
- Sliver and island polygons are removed;
- Attributes are assigned to each object (i.e. no object without attributes);
- Attributes are assigned to the correct object;
- In the attribute tables attachment constraints have to be applied, e.g. one record per element;
- Map sheets must be properly edge matched.

The decision about data incorporation on quality grounds remains with the GIS operator.

Form C.1.

Information Requirements for Metadata Form

For each file of datasets a metadata form has to be completed, which contains as minimum requirements the following information. An example is given below.

File name:	name of each file must be written in the metadata file the same way as the object or file, without extension.
Description:	what kind of data the file contains
Data collection details:	information on the source of data, who collected it, when and their contact details. With this information the method of collection have to be supplied. Capture and presentation scales have to be provided. Geographic extents and key place names of the area the data covers.
Copyright:	copyright holder, copyright conditions and distribution restrictions.
Data format:	vector, raster or table
Projection details:	All relevant information relevant to the projection must be written e.g. system, projection, zone, datum, ellipsoid/spheroid, central meridian, false easting and false northing.
Detailed notes:	Give detailed description of the dataset and its usage.
Revision history:	dates of when the data was revised and reasons for revision and the name of the person who did the revision.
Attribute fields:	all fields in the attribute tables must be listed and the contents be explained.
Contact details:	the contact details of the person whom queries on the data could be sent to.

Form C.2.
Form for Data Sharing

Data Sharing Form

Data Request

Required Datasets		Data Format	Scale	partly	complete
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Please specify Datasets as listed in Appendix C of Database Management Protocol

Please specify Data Format (e.g. vector as shp, E00, raster as TIFF, JPEG, table as DBF)

If not required for complete study area, please specify corner coordinates on separate sheet.

Organisation

Date:

I herewith declare on behalf of the above-mentioned organization that we will neither use the requested data for purposes other than required by the CCT TMG or the WRC TMG Ecosystems Project nor distribute them outside of this organization (unless otherwise specified in Appendix C of the Database Management Protocol)

Data Providing

Required Datasets provided

Except:

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Date:

Reason:

GIS Operator

Data Submission

Type of Data submitted

Type of Data submitted		Data Format	Scale	partly	complete
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Please specify Data Format (e.g. vector as shp, E00, raster as TIFF, JPEG, table as DBF)

If not covering the complete study area, please specify corner coordinates on separate sheet or metadata form.

Attached Documentation:

- Original Datasets / Field Notes
- Description of Modifying or Analysis
- Statement of Quality Control

- Metadata Form
- Explanation of Attributes
- Statement of Ownership + Copyright

Data Incorporation

Datasets incorporated

Rejected:

1	2	3	4	5	6	7	8	9	10
---	---	---	---	---	---	---	---	---	----

Date:

Reason:

GIS Operator

Table C.1.
List of Datasets, Copyright, Restriction, Sharing

Dataset	Ownership	Copyright	Restriction	Data Viewing	Data Sharing
Topographic Data					
20 metre Contours	CCT	CDSM	No	Yes	Yes ¹⁾
Road_line	CCT	CDSM	No	Yes	Yes ¹⁾
Railway_line	CCT	CDSM	No	Yes	Yes ¹⁾
River_line	CCT	CDSM	No	Yes	Yes ¹⁾
River_areas	CCT	CDSM	No	Yes	Yes ¹⁾
Inland_water_areas	CCT	CDSM	No	Yes	Yes ¹⁾
20 metre Digital Elevation Model	CCT	ComputaMap	Yes	Yes	Yes ^{1) 2)}
Aspect Model	Umvoto	Umvoto	Yes	Yes	No ³⁾
Slope Model	Umvoto	Umvoto	Yes	Yes	No ³⁾
Cadastral Data					
Farm boundaries	CCT	Land Affairs	No	Yes	Yes ¹⁾
Towns	Umvoto	No	No	Yes	Yes ¹⁾
Project Delineation					
CCT TMGA Study area	CCT	TMGAA	No	Yes	Yes ²⁾
Target Zones	CCT	TMGAA	No	Yes	Yes ²⁾
Target Site Areas	CCT	Umvoto	Yes	Yes	Yes ^{1) 2)}
Sensitive Map Units	CCT	Ecologist	Yes	Yes	Yes ^{1) 2)}
Geology Data					
1:50 000 Geology (TMG)	CCT	CGS	Yes	Yes	Yes ²⁾
Structural geology i.e. faults, folds	CCT	CGS	Yes	Yes	Yes ²⁾
Dip & strike	CCT	CGS	Yes	Yes	Yes ²⁾
Lineament Data					
1:100 000 Fractures	Umvoto	Umvoto	Yes	Yes	No ³⁾
1:40 000 Fractures	Umvoto	Umvoto	Yes	Yes	No ³⁾
1:10 000 Fractures	Umvoto	Umvoto	Yes	Yes	No ³⁾
Hydrological Data					
Quaternary Catchments	Public	WRC	No	Yes	Yes ¹⁾
Mean annual precipitation	CCT	CCWR	No	Yes	Yes ¹⁾
Hydrocensus CCT April 2003	Umvoto	Umvoto	Yes	Yes	Yes ^{1) 2)}
Hydrocensus CCT November 2004	Umvoto	Umvoto	Yes	Yes	Yes ^{1) 2)}
Hydrocensus Bergriver Feb 2003	DWAf	R Parsons	Yes	Yes	Yes ^{1) 2)}
Hydrocensus Franschhoek	DWAf	Umvoto	Umvoto	Yes	Yes ^{1) 2)}
NGDB Data	DWAf	DWAf	No	Yes	Yes ¹⁾
DWAf Monitoring points	DWAf	DWAf	Yes	Yes	Yes ^{1) 2)}
DWAf Monitoring streams	DWAf	DWAf	Yes	Yes	Yes ^{1) 2)}
DWAf Springs (1:500 000)	DWAf	DWAf	Yes	Yes	Yes ^{1) 2)}
WRC Riverine Data	?	WRC	Yes	Yes	Yes ¹⁾
CNC Riverine Data	?	CNC	Yes	Yes	Yes ¹⁾
Wetland Data	?	?	Yes	Yes	Yes ¹⁾
Waste Water Treatment Plants	DWAf	DWAf	Yes	Yes	Yes ¹⁾

Dataset	Ownership	Copyright	Restriction	Data Viewing	Data Sharing
River gauge	DWAF	DWAF	Yes	Yes	Yes ^{1) 2)}
Pipe gauge	DWAF	DWAF	Yes	Yes	Yes ^{1) 2)}
Dam gauge	DWAF	DWAF	Yes	Yes	Yes ^{1) 2)}
Rain gauge Theewaterskloof	DWAF	DWAF	Yes	Yes	Yes ^{1) 2)}
Weather station	SAWS	SAWS	Yes	Yes	Yes ^{1) 2)}
Satellite and Aerial Images					
1:10 000 aerial photographs	DWAF	DWAF	Yes	Yes	Yes ^{1) 2)}
1:10 000 orthophotographs	Umvoto	CDSM	No	Yes	Yes ^{1) 2)}
Landsat 7 ETM	CCT	No	No	Yes	Yes ²⁾
Normalised Difference Vegetation Index	Umvoto	Umvoto	Yes	Yes	No ³⁾
Tasseled Cap Index	Umvoto	Umvoto	Yes	Yes	No ³⁾
Ecological Data					
Provincial Nature Reserves	Public	No	No	Yes	Yes
Conservancies	Public	No	No	Yes	Yes
Local Authority protected area	Public	No	No	Yes	Yes
Mountain Catchment Areas	Public	No	No	Yes	Yes
National Heritage Sites	Public	No	No	Yes	Yes
Protected Natural Environment	Public	No	No	Yes	Yes
Kogelberg Biosphere Reserve Zones	Public	CNC	No	Yes	Yes ¹⁾
Private Nature Reserves	Public	No	No	Yes	Yes
Broad Habitat Units	CAPE	No	No	Yes	Yes
Irreplaceability_value	CAPE	No	No	Yes	Yes
Mammal_irreplaceability_value	CAPE	No	No	Yes	Yes
Cape_priorities	CAPE	No	No	Yes	Yes
Cape_untransformed_areas	CAPE	No	Yes	Yes	Yes ²⁾
Important_bird_areas	CAPE	CAPE	No	Yes	Yes ¹⁾
Sensitive_lower_vertebrates	CAPE	CAPE	No	Yes	Yes ¹⁾
Sensitive_wetlands	CAPE	No	No	Yes	Yes
Skep_planning_domain	CAPE	No	No	Yes	Yes
Skep_expert_insects	CAPE	No	No	Yes	Yes
Skep_expert_plant	CAPE	No	No	Yes	Yes
Skep_geographic_priorities	CAPE	No	No	Yes	Yes
NBI_vegetation	NBI	No	Yes	Yes	Yes ²⁾

1) Copyright has to be acknowledged, when using the data

2) The use of the data is restricted to the WRC Eco Project and or the CCT TMGA Project

3) Exemptions can be granted, when the need for using the data in this project only is specified

4) Sensitive data, not open for public (*no datasets in this category have been added at this stage*)

Appendix D: Details of Data Layers

DATA SETS	projection	clean	attribute	validate	optimise/ pyramid	contrast	colour map/styling	Display Scale		
								Min	Max	Metadata
Topographic Data										
Contour	x	x	x	x	x	x	x	5 000	800 000	x
Spot_height	x	x	x	x	x	x	x	5 000	800 000	x
Road	x	x	x	x	x	x	x	5 000	800 000	x
Track	x	x	x	x	x	x	x	5 000	800 000	x
Railway	x	x	x	x	x	x	x	5 000	800 000	x
River	x	x	x	x	x	x	x	5 000	800 000	x
River_areas	x	x	x	x	x	x	x	5 000	800 000	x
Inland_water_areas	x	x	x	x	x	x	x	5 000	800 000	x
Digital Elevation Model	x	x	x	x	x	x	x	5 000	950 000	x
Aspect Model	x	x	x	x	x	x	x	5 000	950 000	x
Slope Model	x	x	x	x	x	x	x	5 000	950 000	x
Cadastral Data										
Farm boundaries	x	x	x	x	x	x	x	5 000	200 000	x
Towns	x	x	x	x	x	x	x	x	x	x
Provincial Nature Reserves	x	x	x	x	x	x	x	5 000	950 000	x
Conservancies	x	x	x	x	x	x	x	5 000	950 000	x
Local Authority protected area	x	x	x	x	x	x	x	5 000	950 000	x
Mountain Catchment Areas	x	x	x	x	x	x	x	5 000	950 000	x
National Heritage Sites	x	x	x	x	x	x	x	5 000	950 000	x
Protected Natural Environment	x	x	x	x	x	x	x	5 000	950 000	x
Kogelberg Biosphere Reserve Zones	x	x	x	x	x	x	x	5 000	950 000	x
Private Nature Reserves	x	x	x	x	x	x	x	5 000	950 000	x
Appendix D3: Project Delineation										
CCT TMGA Study area	x	x	x	x	x	x	x	x	x	x
Target Zone	x	x	x	x	x	x	x	50 000	950 000	x
Target Site Area	x	x	x	x	x	x	x	10 000	250 000	x
Target Site Subarea	x	x	x	x	x	x	x	5 000 / 0	50 000	x

DATA SETS	projection	clean	attribute	validate	optimise/ pyramid	contrast	colour map/styling	Min	Max	Metadata
Waste water treatment plants										
River gauge	x	x	x	x	x	x	x	5 000	950 000	x
Pipe gauge	x	x	x	x	x	x	x	5 000	950 000	x
Dam gauge	x	x	x	x	x	x	x	5 000	950 000	x
Rain guage Theewaterskloof	x	x	x	x	x	x	x	5 000	950 000	x
Weather station	x	x	x	x	x	x	x	5 000	950 000	x
Satellite and Aerial Images										
aerial photographs	x	x	x	x	x	x	x	5 000	950 000	x
orthophotographs	x	x	x	x	x	x	x	5 000	950 000	x
Landsat 7 ETM (p175r083 and p175r084)	x	x	x	x	x	x	x	x	x	x
Normalised Difference Vegetation Index										
Tasseled Cap Index										
Ecological Data										
Sensitive Map Units	x	x	x	x	x	x	x	5 000	000	x
Broad Habitat Units	x	x	x	x	x	x	x	25 000	950 000	x
Cape_Irreplaceability_value	x	x	x	x	x	x	x	25 000	950 000	x
<i>Cape_Mammal_irreplaceability_value</i>										
<i>Cape_priorities</i>										
Cape_untransformed_areas	x	x	x	x	x	x	x	25 000	950 000	x
Important_bird_areas	x	x	x	x	x	x	x	25 000	950 000	x
Sensitive_lower_vertebrates	x	x	x	x	x	x	x	5 000	950 000	x
Sensitive_wetlands	x	x	x	x	x	x	x	5 000	950 000	x
Skep_planning_domain	x	x	x	x	x	x	x	25 000	950 000	x
Skep_expert_insects	x	x	x	x	x	x	x	25 000	950 000	x
Skep_expert_plant	x	x	x	x	x	x	x	25 000	950 000	x
Skep_geographic_priorities	x	x	x	x	x	x	x	25 000	950 000	x
NBI_vegetation	x	x	x	x	x	x	x	25 000	950 000	x

Appendix E: Metadata Template

TMGA SDSS GIS METADATA: DETAILED REPORT

FILE NAME:
Description:
Copyright Holder:
Data Copyright:
Data Origin:
Capture Source:
Scale Digitised at or cell size:
File date:
To be distributed:

PROJECTION

Coordinate System:
Projection Name:
Zone:
Central Scale:
Central Meridian:
False Easting (metres):
False Northing (metres):
Datum/Spheroid/Ellipsoid:

DETAILED NOTES

REVISION HISTORY

Date:
Revised By:
Reason:
Notes:

CONTACT DETAILS

Organisation:
Contact Person:
Address:
Telephone:
Facsimile:
E-mail:

Appendix F: SML Scripts

SML Scripts are available in the TMGA SDSS Atlas, under Options/Tools/Scripts