A GEOGRAPHIC INFORMATION SYSTEMS APPROACH TO THE IDENTIFICATION OF TABLE MOUNTAIN GROUP AQUIFER 'TYPE AREAS' OF ECOLOGICAL IMPORTANCE

MILDRED FORTUIN

A thesis submitted in fulfilment of the requirements for the degree of Magister Scientae in the Department of Earth Science, Faculty of Natural Sciences, University of the Western Cape.

Supervisor: Professor Yongxin Xu

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KEYWORDS

raster-based GIS

aquifer

recharge

exploitation potential

exploration potential

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ecological importance

vegetation

type areas

ABSTRACT

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M. FORTUIN

M Sc Thesis
Department of Earth Sciences
Faculty of Natural Sciences
University of the Western Cape

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The TMG Aquifer System is a regional fractured aquifer system with the potential to be a major source for future water supply in the Western and Eastern Cape. The future existence of South Africa's floral kingdom depends on both management and water allocation decisions. In order to facilitate decision-making in both these spheres, it is necessary to understand the relative ecological importance of various vegetation types.

Prior to embarking on such detailed research, it is important to determine key 'type areas'. This is a prerequisite because of the variability in aquifer and ecological parameters over the TMG outcrop and sub-outcrop area. This study devises a method for prioritising South African vegetation types on the basis of ecological importance, and presents the results of a ranking based on the collation of existing data. Suitable 'type areas' for detailed research into the impacts of large-scale groundwater abstraction from TMG Aquifer Systems based on the ecological setting and the regional hydrogeological characteristics are identified.

Extensive use has been made of the advances in GIS technology and spatial modelling techniques, as well as the availability of a large number of GIS datasets (recharge, vegetation, aquifer systems, groundwater abstraction, rainfall, digital terrain models, nature reserves, ecologically sensitive zones etc.). All existing and relevant information

was collected and collated into a GIS and associated database. This has made it possible to cost effectively develop a regional perspective of the variability of key parameters and therefore to optimise the selection of 'type areas' required to address this variability.

The model employed in the ecological importance phase of the study provides a useful means of establishing which parts of the TMG Aquifer System are likely to contain important ecosystems. The analysis has considered a number of key parameters – area of vegetation type, transformation, fragmentation and ecological processes/gradients. However, this approach is not as robust as that adopted in the CAPE terrestrial layer (Cowling *et al*., 1999), whose ultimate aim was the setting of conservation targets for biodiversity patterns and processes in the CFR, where rigorous testing of a comprehensive set of data layers was used to determine areas and degrees of irreplaceability (Cowling *et al*, 1999). However, as regards the present study, the CAPE approach has two major weaknesses: the northern Saldanha-Sandveld region received a low conservation priority rating despite several reports that confirms the rarity and uniqueness of this region (e.g. Boucher & Rode, 1997). More recent reports (Low, 2003; Low & Pond, 2003) confirm this situation. Secondly, the BHU's are regarded as being too coarse for planning at the 1:250 000 scale (CPU, pers.comm.). This dictated the need for a method which:

1. concentrates on data which are consistent across the CFR, and
2. highlighted those areas of ecological importance only.

The model therefore aims to "plug the gaps" and focus on the TMG Aquifer Systems as a special ecological component of the CFR.

All models employed in the determination of ecological importance and ranking for conservation priority have, almost by implication, a built in subjectivity. This subjectivity revolves around factors such as choice and rating of criteria and is invariably encumbered by weaknesses caused by lack of data or, even worse, lack of consistency in data across a particular study area. The model employed in this study has used data that, by and large, are consistent throughout the CFR. Given the accuracy and detail of the new vegetation map of South Africa (Mucina & Rutherford, in prep.), the model has provided a useful means of determining zones of ecological importance in the study area, but at a strategic, regional level.

The model serves to highlight general areas of ecological importance, but does not, on its own, indicate those areas in which groundwater and related systems might occur. To this end exploitation and exploration potential maps of the study area were generated to assess the groundwater development potential of the TMG Aquifer Systems. These maps were then 'geospatially' intersected to produce a map showing a qualitative rating for the development of large-scale abstraction schemes.

The exploitation potential map considered the resource and recharge to show the potential of an area to sustain large-scale abstraction. The mean annual effective recharge was estimated from rainfall using raster-based grid analysis. The methodology is based on the Maxey-Eakin empirical method but has been adjusted to consider other critical factors such as lithology and slope. The results show that high recharge coincides with TMG outcrop areas in mountainous regions but that the accessibility to these regions may be problematic where the slope is in excess of 15%. The resulting recharge was checked and verified using the Harvest Potential map developed by DWAF. The recharge estimation takes the Mean Annual Precipitation (MAP), percentage Coefficient of Variance (CV) of MAP, %-Terrain Slope and Lithological-Recharge Factor raster-datasets for the study area into account, whereas the Harvest Potential map classification is broader.

Boreholes sited in groundwater units with higher rates of rainfall recharge should be able to sustain higher abstraction rates. However, it may not always be possible to find suitable drilling targets to site production boreholes capable of delivering the required yields. It is therefore essential that the potential for locating, siting and obtaining a successful borehole be considered. The exploration potential map assesses the accessibility and drilling success of a borehole according to a reclassification of Vegter's Borehole Prospects map.

The 'geospatial' intersection of the exploitation and exploration potential maps produced the groundwater development potential map. This map was reclassified to qualitatively rank the potential of an area to sustain large-scale abstraction. Results show that only 14% of the study area rates very high and 34% high for groundwater development potential. These areas supply the greater mean effective recharge per annum for the area. The areas that rate low to moderate, although constituting the greater surface area, only add a minimal amount to the mean annual recharge.

The groundwater development potential map and the ecological importance map were then 'geospatially' intersected to produce a map showing the coincidence of the two, depicted using a matrix. The coincidence map was then related back to the Quaternary catchments, qualitatively rating each catchment within the study area.

It should be noted that the maps generated during the process of determining 'type areas' for large-scale groundwater abstraction give a broad panoramic view rather than site-specific detail.

The mean annual effective recharge (R_e) for the entire study area is estimated at 3 777 x 10^6 m^3 (an average recharge rate of 6.4% of MAP). This is expected to decline to 2 794 x 10^6 m^3 during droughts (**Table 2**). The R_e was determined for each of the 314 Quaternary Drainage Regions in the study area.

Table 2: Summary of Effective Annual Recharge from Rainfall for Study Area.

Description	Value
Mean Recharge (x 10^6 m^3/yr)	3 770
Recharge Factor (%)	6.4%
Upper recharge limit (x 10^6 m^3/yr)	4 746
Lower recharge limit (x 10^6 m^3/yr)	2 794

Table 3: Summary of Mean Effective Annual Recharge from Rainfall for the various categories of development potential.

Description	1	2	3	4
	Low	**Moderate**	**Hig**	**Very High**
Mean Recharge (x 10^6 m^3/yr)	192	579	1119	1880
Recharge Factor (% of MAP)	3.2%	3.9%	5.5%	11.4%
Upper recharge limit (x 10^6 m^3/yr)	280	835	1573	2430
Lower recharge limit (x 10^6 m^3/yr)	137	422	855	1600

Given the ecological complexity of the CFR, areas of highest ecological importance (>60%) were identified and classified into subregions.

Finally, eight 'type areas' were identified for further research based on the possibility of future development of the groundwater in the area for towns that are in close proximity. In choosing 'type areas' the accessibility and recharge potential of the area was also considered as well as groundwater quality. The eight 'type areas' are as follows (**Figure 1**):

- Northern Sandveld
- Piketberg
- Ceres – Prince Alfred Hamlet
- Franschhoek
- George
- Knysna – Plettenberg Bay
- Humansdorp
- Port Elizabeth

The hydrogeological characteristics of the 'type areas' is summarised in **Table 4**.

Table 4: Summary of the hydrogeological characteristics of the 'type areas'.

TYPE AREA	QUATERNARY CATCHMENT(S)	(km^2)	RECHARGE ($X10^6 m^3/yr$)	RATE (%)	YIELD (l/s) [S	AVERAGE OLE DE [S	AVERAGE EC (mS/m) [ST	COMMENT
Northern Sandveld	G30C, G30E, G30F	1496	21	4.6	5 [7.98]	76.6 [48.74]	60.6 [70.26]	EC for G30C & G30F. Region severely impacted.
Piketberg	G10K	1186	23	5.1	1.4 [1.34]	102 [25.2]	254.5 [377.9]	
Ceres-Prince Alfred Hamlet	H40C	273.5	42	18	4.5 [5.68]	150	12.27 [7.4]	
Franschhoek	G10A	173.1	69	21	32 [3.93]	48 [47]	15 [12]	
George	K30C	190.4	17	9.4	0.7 [0.5]	110 [30]	252.5 [75.7]	
Knysna-Plettenberg Bay	K50B, K60F, K60G	611.9	56	10	1.75 [2.12]	88 [33.8]	22.5 [21.4]	
Humansdorp	K90F	250.3	17	8.4	1.23 [1.27]	425	151 [221]	
Port Elizabeth	M20A	361.5	24	8.4	4 [1.04]	107 [53.02]	167 [126]	

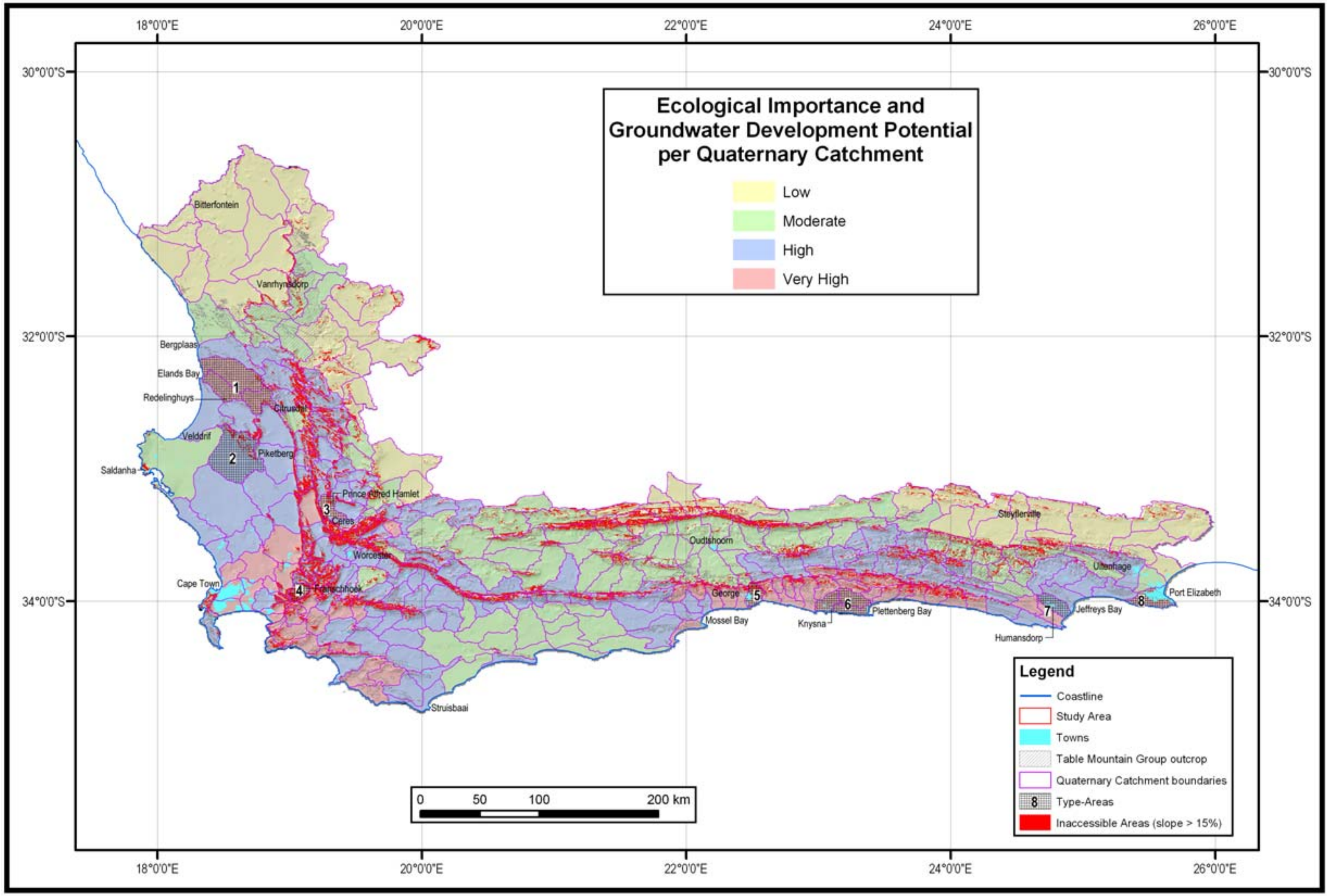

Figure 1: Map showing the qualitative rating of Ecological Importance and Groundwater Development Potential for each Quaternary Catchment (i.e. [pink box] indicates high ecological importance and high groundwater development potential).

DECLARATION

I declare that *A Geographic Information Systems Approach to the Identification of Table Mountain Group Aquifer 'Type Areas' of Ecological Importance* is my own work, that it has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full Name: Mildred Fortuin **Date**: 15th May 2004

Signed: ----------------------------

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GLOSSARY

Aquifer	Strata or a group of interconnected strata comprising of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to boreholes or springs.
Aquifer system	A heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.
Biome	Broad natural region, e.g. savanna, fynbos.
Ecosystem	Any system in which there is an interdependence upon and interaction between living organisms and their immediate physical, chemical and biological environments.
Endemic	Species having a restricted distribution.
Exploitation potential	Potential of an area to sustain large-scale abstraction.
Exploration potential	Probability of drilling high yielding production boreholes with a high success rate.
Groundwater	Water below the ground surface, generally within the saturated zone below the water table, but includes water found in the capillary fringe and partially saturated vadose zone. The water occurs within joints, fissures, fractures, cleavage planes and faults as well as pore spaces in sedimentary rocks and unconsolidated sediments.
Integrated management	A management approach which serves to co-ordinate management of the environment as a whole, rather than individual components.

Phreatophytic vegetation (terrestrial vegetation)	Capable of obtaining groundwater from the zone of saturation either directly or through the overlying capillary fringe.
Recharge	Process of the addition of water to the groundwater system by natural or artificial processes.
Regional scale	Scale equitable to surface water catchment areas and would typically be measured in thousands to hundred of thousands of km^2.
Vadose zone	That part of the geological stratum above the saturated zone in which voids contain both air and water.

ACRONYMS

BHU	Broad Habitat Unit
C.A.P.E.	Cape Action for People and the Environment
CCWR	Computing Centre for Water Research
CFB	Cape Fold Belt
CFR	Cape Floristic Region
CIL	C.A.P.E. irreplaceability layer
CPU	Conservation Planning Unit (WCNCB)
CV	Coefficient of Variance
DEADP	Department of Environmental Affairs and Planning
DEM	Digital Elevation Model
DWAF	Department of Water Affairs and Forestry
EIA	Environmental Impact Assessment
GIS	Geographic Information Systems
L_f	Lithological Factor
MAP	Mean Annual Precipitation (mm)
NGDB	National Groundwater Database
R_e	Mean Annual Effective Recharge
R_f	Recharge Rate
Riv_f	150m Buffered River Recharge Factor
S.K.E.P.	Succulent Karoo Ecosystem Plan

S.T.E.P.	Subtropical Thicket Ecosystem Plan
S_f	Slope Factor
TMG	Table Mountain Group
VU/VT	Vegetation unit/Vegetation type
WCNCB	Western Cape Nature Conservation Board
WRC	Water Research Commission

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CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND TO THE PROJECT

A major challenge in the exploitation of South Africa's groundwater resources is that the natural harmony of water and vegetation in the Cape mountain ecosystem is maintained. The future existence of both South Africa's groundwater resources and ecosystems is dependent on their direct management. In the past very little consideration has been given to the preservation of this natural harmony but it has been reviewed under the revised National Water Act (Act No 36 of 1998).

Research work carried out to date indicates that there may be billions of cubic metres of groundwater stored in the Table Mountain Group (TMG) Aquifer Systems. The TMG Aquifer System occurs within the Western and Eastern Cape provinces, extending from just north of Nieuwoudtville to Cape Agulhas and then eastwards to Algoa Bay, a linear outcrop distance of over 900 km (**Figure 1**). Recharge estimates to these aquifer systems vary from 10 to 50 % of mean annual precipitation (MAP). The winter rainfall area of the Intermontane Domain of the TMG Aquifer Systems offers a unique opportunity to maximise/optimise groundwater yield from this aquifer (Rosewarne, 2001). This area is characterised by reliable precipitation often in excess of 1000 mm/a, which is mainly concentrated during the period June to September.

1.2. HYPOTHESES

To unlock the true potential of the TMG Aquifer, quantitative studies need to be initiated, especially in terms of the new National Water Act, to ensure that the nature and extent of potentially negative environmental impacts are quantified. Prior to embarking on such detailed research, it is important to determine key 'type areas'. This is required because of the variability in key aquifer and ecological parameters over the TMG outcrop and sub-outcrop area.

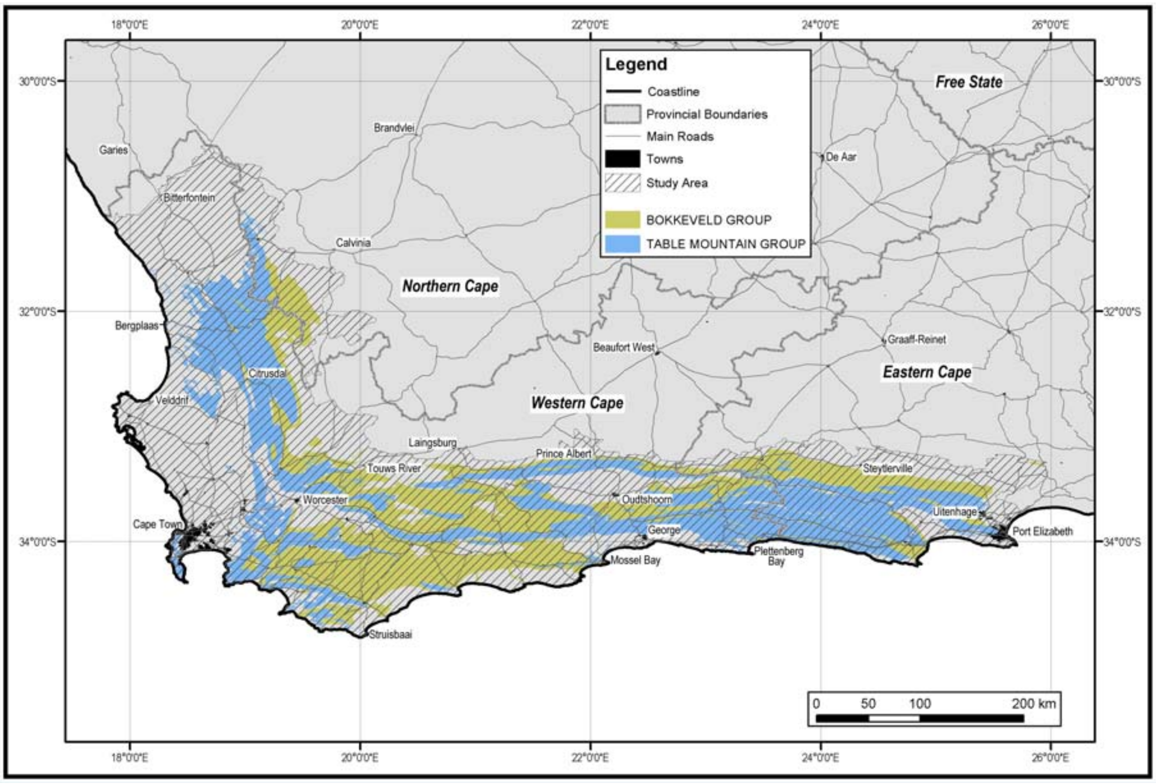


Figure 1: Locality of the study area showing the Table Mountain Group and Bokkeveld Group outcrops.

1.3. PRIMARY OBJECTIVE

The main objective of the present research is to characteristically identify 'type areas' for further detailed research. Since little information is available the project has had to make use of the advances in GIS technology and spatial modelling techniques, as well as the availability of a large number GIS datasets (recharge, vegetation, aquifer systems, groundwater abstraction, rainfall, digital terrain models, nature reserves, ecologically sensitive zones etc.) and review existing decision making tools to develop a model that was consistent across the study area. . This has made it possible to cost effectively develop a regional perspective of the variability of key issues and therefore to optimise the selection of 'type areas' required to address this variability based on the information available. The GIS database developed for this study will also provide valuable information for input into more detailed local research projects. This thesis documents the methodology employed to determine various parameters used in identifying the 'type areas' as well as the results of these applications.

1.4. SECONDARY OBJECTIVES

The research project aims to identify suitable 'type areas' for detailed research into the impacts of large-scale groundwater abstraction from TMG Aquifer Systems on the ecology, where the regional characteristics and variations in the TMG Aquifer Systems, climate and ecology are taken into account. The secondary objectives of the research project are to:

- Collect and collate all existing and relevant information into a Geographic Information System (GIS) and associated database.
- Identify 'gaps' in the information system and, if possible, fill-in and capture such information.
- Evaluate GIS datasets to ascertain key parameters required to characterize the geographical variability of the TMG Aquifer Systems and associated ecosystems.
- Apply GIS-based spatial modelling techniques to identify 'type areas' where research should be conducted in order to cover the variable conditions encountered in the TMG Aquifer System and floral-fauna habitats, as well as current and future areas where large-scale groundwater developments are or will be taking place.
- Describe the main characteristics used to define each type-area, which will serve as key research needs for detailed study within a specific area.

The project aims to particularly target the 'TMG Aquifer System' project managers at the Water Research Commission and the Department of Water Affairs and Forestry in order to coordinate and plan research programmes. The products of this study will also benefit the prospective researchers themselves in identifying suitable areas for detailed investigations as well as other organizations such as the Department of Environmental Affairs and Planning (DEADP) or educational institutions that are either directly or indirectly involved in TMG Aquifer System research programmes.

1.5. RESEARCH FRAMEWORK

In an attempt to meet the primary and specific objectives set out in the previous sections the following relevant information was sourced from various institutions:

- Geology.
- Surface water hydrology (Rivers, dams, estuaries, vleis etc).
- Vegetation types, ecologically important areas.
- Existing or future Nature Reserves (categorised).
- Mean Annual Rainfall.
- Borehole and springs ('hot' and 'cold' water) database.
- Hydrochemistry.
- Regional Classification of Aquifer Systems.
- Aquifer recharge.
- Groundwater Harvest Potential (or exploitation potential).
- Existing and future large-scale groundwater abstraction.
- Groundwater available for abstraction in terms of the General Authorization of the New Water Act.
- Quaternary catchment based hydrological information as well as catchments sensitive to large-scale groundwater development.

This data was then collated into a comprehensive GIS spatial database for evaluation. Based on the data output from various modelling techniques employed a number of significant research 'type areas' are identified and prioritised, as well as a description of the important distinguishing characteristics of each 'type area'. The accompanying GIS coverages serve as a decision-making tool whereby the Water Research Commission (WRC), Department of Water Affairs and Forestry (DWAF), Department of Environmental Affairs and Planning (DEADP) or any other interested organization can plan and coordinate the research programme(s) into the 'Environmental Impacts of Large-Scale Groundwater Abstraction in TMG Aquifer Systems', where:

1. 'type areas' for future research have been identified and prioritised according the regional variability of all the relevant parameters, e.g. TMG Aquifer Systems, present groundwater abstraction, sensitive ecosystems, and
2. specific research needs, key issues or concerns within each zone are detailed.

1.6. OUTLINE OF THESIS

The thesis comprises eight chapters of which Chapter One and Two provides a general introduction to the project. Chapter One outlines the background and motivation for undertaking the project as well as the aims and objectives of this thesis. Chapter Two describes the study area, its physical location, vegetation, climate as well as the general physiographic setting thereof.

Chapter Three provides a detailed synopsis of previous studies and research undertaken, and its relevance to this study.

Chapter Four provides an overview of the regional hydrogeology of the region including the general geology, hydrogeological and hydrogeomorhical domains, and existing groundwater usage in the Table Mountain Group.

Two aspects of relevance to the study area were addressed in Chapters Five and Six, namely, the regional geohydrological classification and the identification of areas of ecological importance, respectively. The thesis outlines the determination of the model employed and the criteria and subjective importance ratings used to rate the general state of the environment. Similarly, various existing datasets were used to determine and verify the exploitation and exploration potential of the study area, which was ultimately 'geospatially' intersected to determine the groundwater development potential.

Once the ecologically important zones were defined, the layer was intersected with the groundwater development potential layer to indicate the coincidence of the two parameters to identify 'type areas' (Chapter Seven). This map of coincidence was then related back to quaternary catchments so that the final data could reflect DWAF's catchment approach, for example WR90 data. Various appendices of the raw data used in the model and for verification have been included. The final map shows 'type areas' at a catchment level that have a high ecological importance and a high groundwater development potential.

Chapter Eight provides conclusions to the study and recommendations for further research.

CHAPTER TWO

2. PHYSIOGRAPHY

2.1. LOCALITY

The study area, occurring within the Western and Eastern Cape Provinces of South Africa, covers an area extending from 100km north of Bergplaas on the west coast to Cape Town and along the southeast coast to Port Elizabeth, a linear outcrop distance of approximately 900km (**Figure 2**). Into the interior the study area encompasses areas west of Calvinia to Laingsburg, Prince Albert and just north of Steytlerville. The study area covers nine 1/250 000 scale topographic/geologic map sheets listed in **Table 1**.

Table 1: 1/250000 Geological Maps covering the study area.

Map Name	Map Number
Loeriesfontein	3018
Calvinia	3118
Clanwilliam	3218
Cape Town	3318
Worcester	3319
Ladismith	3320
Oudtshoorn	3322
Port Elizabeth	3324
Riversdale	3420

The study area, as determined by the distribution of the TMG Aquifer System and quaternary catchments encompassing and abutting the TMG Aquifer System (**Figure 2**), encompasses over 116 000 km^2, including the Cape Floristic Region (CFR) of some 90 000 km^2 (Goldblatt & Manning, 2000). The study area falls within 314 Quaternary drainage regions or quaternary catchments (**Figure 2**).

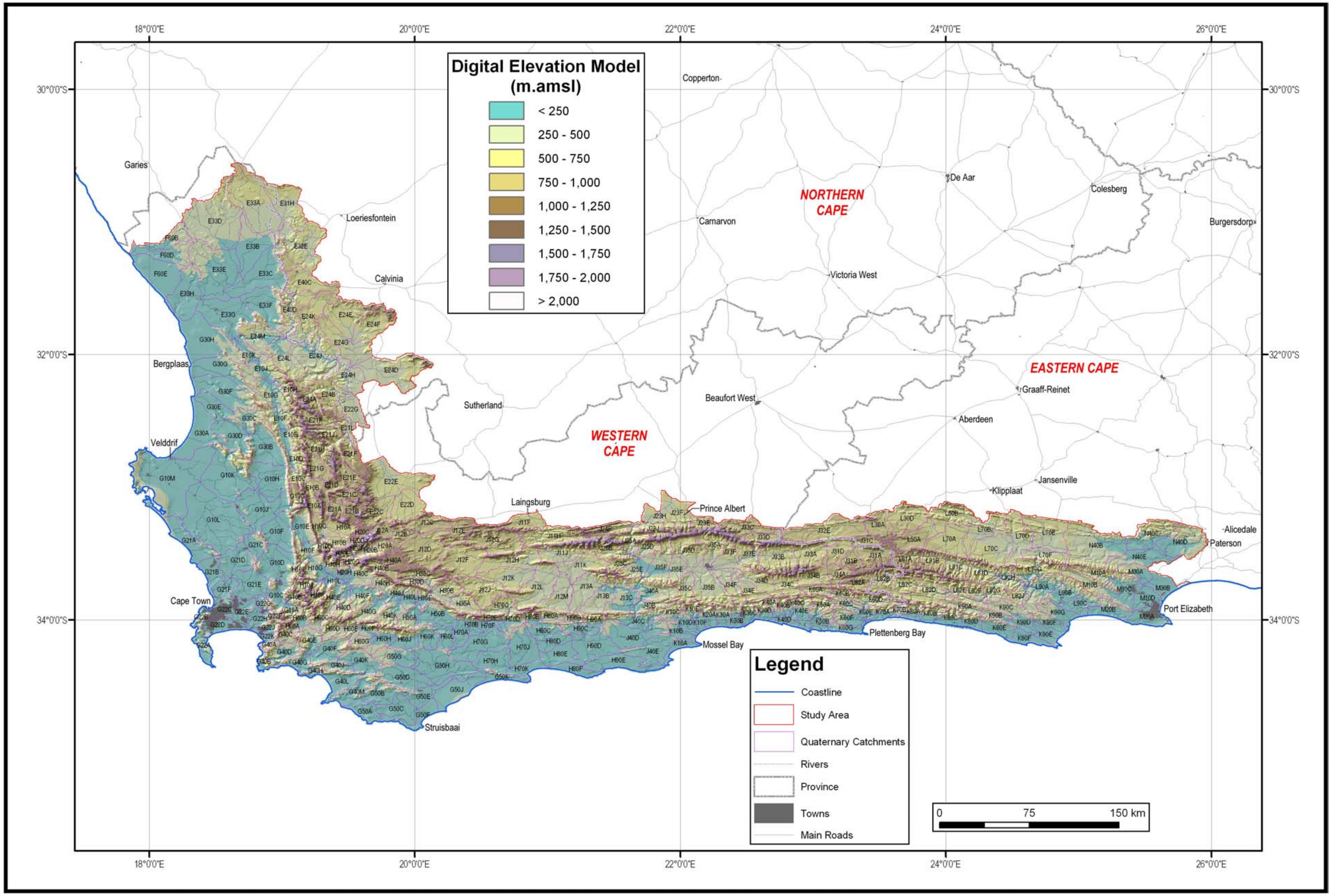


Figure 2: Physiographic setting of the study area.

2.2. TOPOGRAPHIC CHARACTERISTICS

The physiographic setting of the study area is extremely varied. In the mountainous areas elevations greater than 1500 m.amsl (**Figure 2**) occur while at Eland's Bay, the Cape Peninsula and along the Southern and Eastern Cape coast, wave-cut platforms occur at sea level. The topography of the area is dominated by very prominent mountain ranges, such as the Cedarberg and Hex River Mountains, separated by narrow cultivated intermontane valleys such as the Citrusdal and Koo Valleys. The syntaxis of the Cape Fold Belt (CFB), with its very high mountains, forms prominent water divides between major river systems.

2.3. CLIMATE

The climate is predominantly Mediterranean, but relief largely influences temperatures and precipitation. The region experiences a maximum rainfall during the winter months of May to August. Mean temperatures range between 6^0C and 36^0C, but during winters the high mountains are usually capped with snow. Similarly, the rainfall varies from less than 250mm in the north and northeast to values in excess of 1500mm in the mountainous areas (**Figure 3**) and, in places, greater than 2500mm.

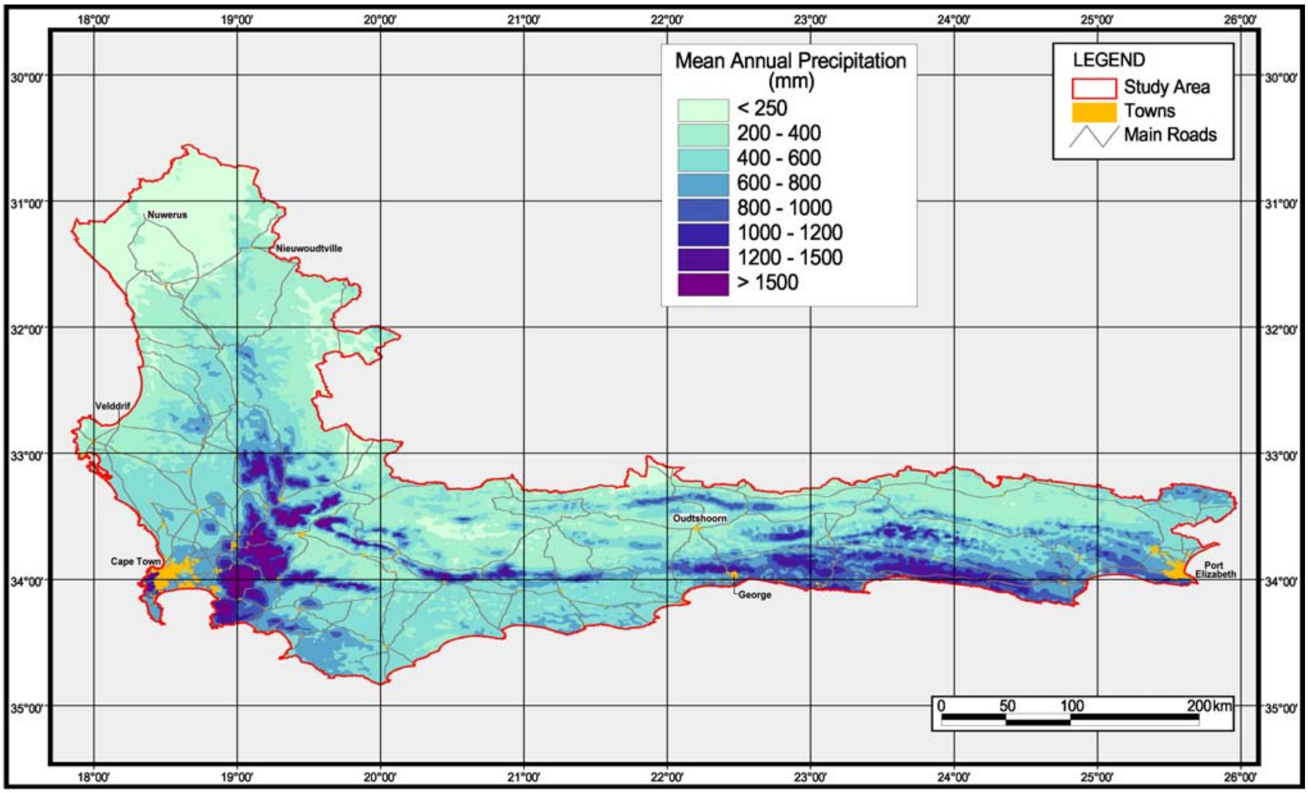


Figure 3: Mean Annual Precipitation (mm/yr) interpolated from the CCWR 1'X1' grid data (Schultze, 1998).

2.4. VEGETATION

The CFR is recognised as a floral kingdom in its own right (Goldblatt, 1978; Takhatajan, 1986; Cowling & Holmes, 1992) and botanically it is one of the richest regions in the world (Goldblatt & Manning, 2000) with 69% of its species being endemic (i.e. found nowhere else). This remarkable floral kingdom is dominated by members of:

- Asteraceae (daisies);
- Fabaceae (peas);
- Iridaceae (irids);
- Ericaceae (ericas); and
- Mesembryanthemaceae (mesems or vygies).

Five of South Africa's seven biomes – Fynbos, Forests, Thicket, Succulent Karoo and Nama Karoo and some 22 broad vegetation types are represented in the study area (**Figure 4**, **Appendix I**) (Low & Rebelo, 1996).

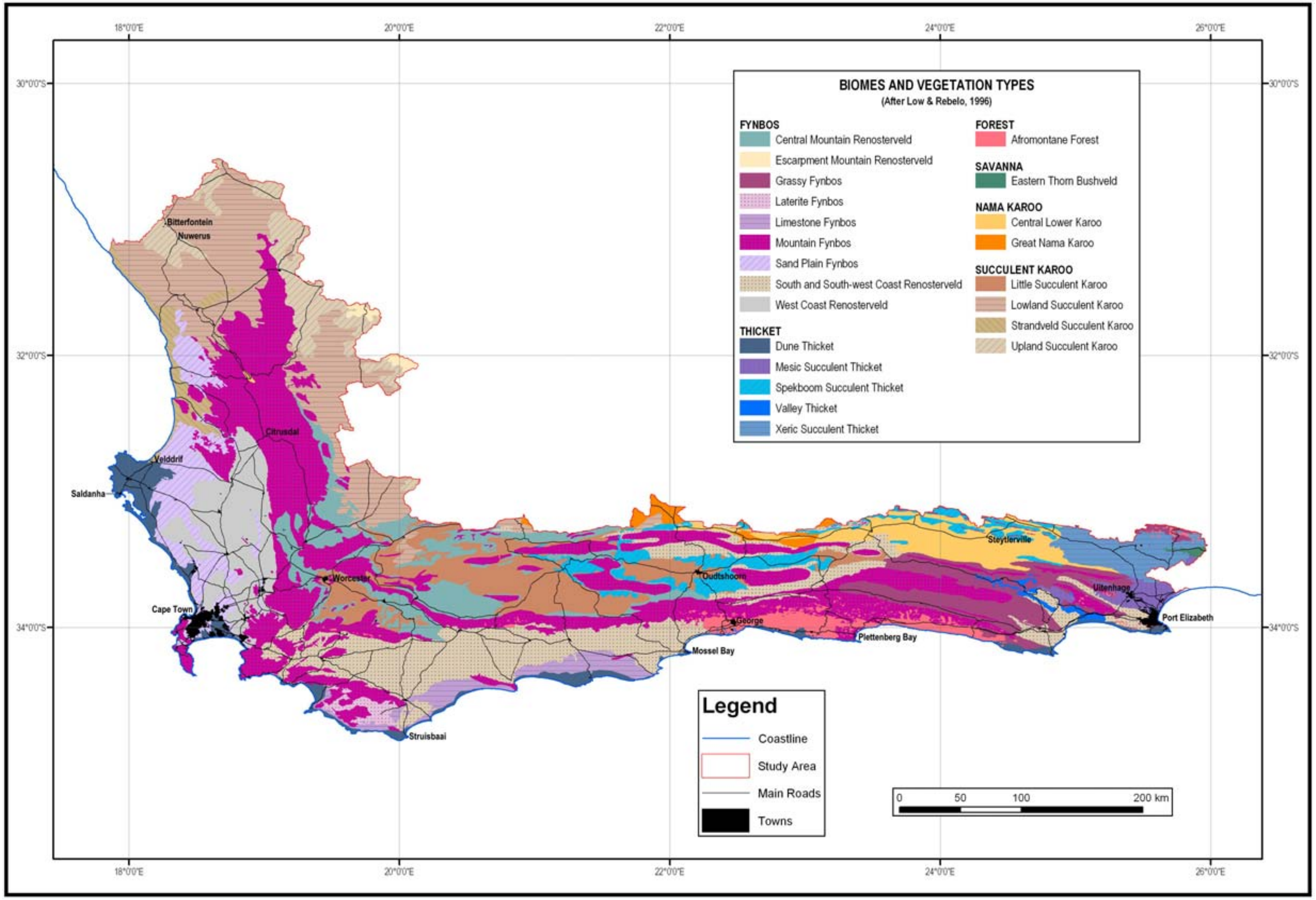
The number of vegetation types (VT's) is substantially increased when one uses the more detailed information of Mucina & Rutherford (in prep.). In this case, 164 VT's are found in the study area (**Appendix I**), but not all occur on soils derived from the TMG. These VT's can be divided into seven major categories, with only the first, vegetation on TMG outcrops, being of direct relevance to this study. Thirty-eight of these are fynbos types, with only one of these being Karoo (**Appendix II**). Of the remaining 125 units, 35 are located on sandstone, granite, shale, silcrete or unconsolidated Quaternary deposits and represent a variety of vegetation types (**Appendix II**).

The occurrence of vegetation types is closely correlated with geology in the CFR (Cowling & Holmes, 1992). Coupled with rainfall and other climatic variables these account for most of the vegetation variation and distribution within the region. The TMG Aquifer System by definition is overlain by sediments of the TMG and largely dominated by sandstones, quartzites, conglomerates, and, to a lesser degree, finer textured mudstones and siltstones (Theron, 1983; Theron *et al*., 1992)). Broadly speaking, this siliceous material produces soils that influence the vegetation in two ways: firstly soils are acidic (Schloms *et al*., 1983), deriving their acidity from the nature of the parent material and from leaching (Schloms *et al*., 1983) and secondly they are infertile or oligotrophic, with low agricultural potential (Schloms *et al*., 1983; Cowling *et al*., 1992). Both these factors have contributed to the evolution of a flora, which is heath-like in character and is both species rich as well as possessing extremely high levels of endemism (Cowling & Holmes, 1992; Cowling *et al*., 1992).

In general the vegetation of these soils is fynbos, although forest can develop in moist, sheltered ravines (Cowling & Holmes, 1992). At the other end of the rainfall spectrum, Karoo vegetation becomes dominant (Cowling & Holmes, 1992).

Outside the soils described above, is a suite of substrates regarded as being moderately high in nutrients and generally finer textured. These abut the TMG and include phyllite, schist, greywacke and shale of the Malmesbury and Bokkeveld Groups (Theron, 1983), whilst Cape Granite (Theron, 1983) also forms a more fertile and finer textured soil. The vegetation of these soils tends to be dominated by renosterveld (**Appendix II**) but can give way to fynbos at higher rainfall (Rebelo, 1996).

Along the coast another suite of soil types occurs, largely the result of coastal processes and broadly divided into two categories: calcareous sands and limestones, and non-calcareous (neutral to acidic) sands. These support a number of coastal vegetation types such as Strandveld and Sand Fynbos (**Appendix II**) (Mucina & Rutherford, in prep.).


BIOMES AND VEGETATION TYPES
(After Low & Rebelo, 1996)
FYNBOS
Central Mountain Renosterveld
Escarpment Mountain Renosterveld
Grassy Fynbos
Laterite Fynbos
Limestone Fynbos
Mountain Fynbos
Sand Plain Fynbos
South and South-west Coast Renosterveld
West Coast Renosterveld
THICKET
Dune Thicket
Mesic Succulent Thicket
Spekboom Succulent Thicket
Valley Thicket
Xeric Succulent Thicket
FOREST
Afromontane Forest
SAVANNA
Eastern Thorn Bushveld
NAMA KAROO
Central Lower Karoo
Great Nama Karoo
SUCCULENT KAROO
Little Succulent Karoo
Lowland Succulent Karoo
Strandveld Succulent Karoo
Upland Succulent Karoo
Legend
Coastline
Study Area
Main Roads
Towns
0
50
100
200 km
Bitterfontein
Nuwerus
Citrusdal
Velddrif
Saldanha
Worcester
Cape Town
Struisbaai
Mossel Bay
George
Oudtshoorn
Plettenberg Bay
Steytlerville
Uitenhage
Port Elizabeth

CHAPTER THREE

3. LITERATURE REVIEW

3.1. INTRODUCTION

In order to develop the methodology, it was important in the first instance to conduct a literature survey to assess the current thinking and developments regarding vegetation-groundwater interactions. It was also necessary to find out what GIS based work has been carried out to date.

The TMG Aquifer System is a regional fractured aquifer system with the potential to be a major source for future water supply in the Western and Eastern Cape. In 1999, the Coordinating Committee for Geohydrological Research, an advisory body for the Water Research Commission (WRC), recommended that attention be given to investigating the TMG Aquifer System for water supply purposes. A workshop was subsequently held in Cape Town with key role players. It was agreed that the preparation of a synthesis of current hydrogeological knowledge and understanding of the TMG Aquifer was a prerequisite to forming a logical and coherent research programme for this aquifer system. The overall goal for future research programmes was identified, ***"To develop and further enhance, within the Department of Water Affairs and Forestry and the broader scientific community, the capabilities to manage TMG Aquifers in a sustainable manner focussing on issues such as system dynamics, community water supply needs and water volumes required to sustain sensitive ecosystems"***.

A further workshop was held in Gordon's Bay on 3 April 2001 to discuss issues arising and to agree on ranking of research fields. In January 2002, WRC Report TT158/01 was published entitled, "A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy." One of the key areas identified requiring research was the ecological and environmental impact of large-scale groundwater development in the TMG Aquifer Systems.

3.2. GROUNDWATER DEPENDENT ECOSYSTEMS

The identification of groundwater dependent ecosystems is an important component of both groundwater and surface water management plans. Vegetation plays a key role in the interaction between groundwater and surface water systems owing to the direct and indirect influence of recharge and the dependence of vegetation communities on groundwater (Le Maitre *et al*, 1999). Even so, only a limited number of studies have been undertaken. Most of these studies have concentrated on the interaction between plants and soil or surface water in the disciplines of soil science and surface water hydrology. Due to the growing interest in the interaction between groundwater and vegetation, the Department of Water Affairs reviewed the water law declaring that surface and groundwater systems are in fact indivisible (DWAF, 1998).

In Western Australia publications prior to 1985 were not aimed at the dependency and potential vulnerability of selected ecosystems on groundwater, although many publications clearly recognised the relationship (Alpin, 1976; Arnold and Wallis, 1986; Bestow, 1976). Subsequently two studies concentrating on a basis for the identification and classification of groundwater dependent ecosystems were undertaken in Western Australia (Semeniuk, 1994; Commander, 2000). Semeniuk (1994) and Commander (2000) identified the use of GIS as the most effective means of combining, synthesising, comparing and correlating various databases in an attempt to identify groundwater dependent ecosystems.

The effects of the artificial lowering of the water table on plants and vegetation communities can be divided into two inter-related groups (Le Maitre *et al*, 1999), namely:

- riparian vegetation dependent on groundwater flowing into or out of the river system (influent or effluent); and
- wetlands.

The availability of groundwater may influence the type of plant growth as well as the species assemblage. Plants that use groundwater are called phreatophytes and are sensitive to changes in the hydrogeological regime (Le Maitre *et al*, 1999). This change may be in the form of a decline in the water table at a faster rate than root growth or an alteration in the annual fluctuations of the water table. Groundwater abstraction by man or the regulation of effluent rivers may result in these changes (Le Maitre *et al*, 1999).

According to Le Maitre *et al* (2002) the criteria used in the prioritisation of groundwater dependent ecosystems need to take into account both the benefits of protection and the opportunities that are lost if the groundwater is not abstracted. Hatton and Evans (1998) suggest that both the uniqueness and the expected vulnerability to change be considered.

Measurement and modelling of recharge on the Atlantis and Zululand coastal aquifers have highlighted the impact of vegetation cover on recharge, and abstraction from shallow groundwater (Kelbe *et al*, 1995). However, little direct information is available on vegetation- groundwater interactions on fractured aquifers that occur across approximately 90% of the surface area of South Africa (Vegter, 1995). There is no published documentation of groundwater dependency by ecosystems in the TMG Aquifer Systems. At present there are WRC funded projects underway to assess examples of aquatic and terrestrial ecosystem dependency in the TMG Aquifer Systems.

3.3. BIODIVERSITY SURROGATE

To determine ecological importance in the absence of detailed datasets one requires a surrogate for habitat difference and complexity, under the assumption that habitats reflect the sum of the environmental variation within a given area (i.e. geology, soils, climate, flora, vegetation, etc.), in this case across the spectrum of the study area, by and large that of the Cape Floristic Region (CFR). The CFR is some 90 000 km^2 (Goldblatt & Manning, 2000) with the main body of this flora covering a north-south distance of some 420 km between the northern Bokkeveld Mountains and Cape Agulhas, and a west-east distance of some 870 km between the Saldanha Peninsula and Grahamstown. Such a large area requires an appropriate scale of habitat for determination of ecological importance.

Vegetation type is often used as a surrogate for such habitat diversity; as such vegetation units tend to represent, again at a fairly broad scale, the diversity at a landscape level. For South Africa, three vegetation maps are available, together with a series of "broad habitat units" for the CFR, as discussed below.

Acocks' work, first published in 1953, is considered to be too coarse, with some 70 veld (= vegetation) types for the whole of South Africa. His approach, too, is unsatisfactory for the purpose of this study, as his veld types were largely based upon "a unit of vegetation whose range of variation is small enough to permit the whole of it to have the same farming potentialities" (Acocks, 1988, 2nd edition, page 1).

In Low & Rebelo's (1996) later map, vegetation types more accurately reflect the situation on the ground and were developed with the following in mind: "Each vegetation type had to be a coherent array of (*plant*) communities which shared common species (or abundance of species), possessed a similar vegetation structure (vertical profile), and shared the same set of ecological processes". Although this provided a good basis for habitat surrogacy, the scale used was again too broad (1:250 000 for the Fynbos and Forest Biomes (= natural regions), Eastern Cape, and Grassland, Savanna and Karoo Biomes at 1:1000 000) (68 vegetation types).

Subsequently Cowling and Heijnis (2001) developed a set of Broad Habitat Units (BHU's) for the CFR, based partly upon Low & Rebelo's (1996) work. The importance of this study was to identify what should be conserved, in order to fulfil certain conservation targets in the C.A.P.E. programme. However, the BHU's were derived from an intersection of homogeneous areas of geology, climate and topography, and then in turn intersected with the boundaries of the vegetation types of Low & Rebelo (1996) (Cowling & Heijnis, 2001). The main disadvantage of this approach is that vegetation units were not accurately mapped, i.e. from aerial photographs and ground-truthing in the field.

However, there is now much support for the new vegetation map of South Africa (Mucina & Rutherford, in prep.), where vegetation has been mapped at a consistent scale of 1:250 000 (there are over **350** vegetation types in this map) and depicting vegetation using a wide variety of techniques including plant community plot data, aerial photography and ground–truthing.

Thus for the current study, vegetation types from the new vegetation map of South Africa (Mucina & Rutherford, in prep.) have been adopted in the analysis as the most accurate surrogate for habitat diversity.

3.4. GROUNDWATER DEVELOPMENT POTENTIAL AND GIS

Groundwater is an important source of water and a powerful tool for creating a better life for many people. About 15 million South Africans rely on groundwater to some extent, especially in the drier western parts of the country. In 1994 the Reconstruction and Development Programme was introduced and one of this bodies objectives is to *ensure all households have a clean, safe water supply of at least 25 litres per capita per day within 200 metres walking distance, and an adequate, safe sanitation facility per site* (DWAF, 1994).

Regarding the GIS methodologies employed to determine the groundwater development potential , two main research fields were identified, namely:

- Integrating GIS with groundwater models (Batelaan *et al*, 1993; Deckers, 1993; De Lange and Van De Meij, 1993)
- Exploitation and exploration potential (Woodford, 1999; Baron *et al*., 1995; Seymour and Seward, 1997; Vegter, 1995)

The use of GIS is beneficial in that the methods employed allows the integration of various sources, parameters can be varied across spatial boundaries and datasets can be updated and incorporated into the models. The following table is a summary of useful references perused.

Table 2: Summary of literature survey.

RESEARCH TITLE	GENERAL COMMENTS	REFERENCE
Groundwater exploitation potential using GIS	Main elements considered in such a map are: recharge storage transmissivity, quality and cost. Data is also included.	Baron, Seward and Smart, 1995
Development and application of a groundwater model integrated in the GIS GRASS	A regional groundwater flow model has been integrated at different levels in the GIS, GRASS. The model simulates quantitative recharge, discharge and groundwater elevation maps.	Batelaan, De Smedt, Otero Valle and Huybrechts, 1993
Re-assessment of sustainable abstraction from groundwater basins of different size in semi-arid and arid areas	The sustainable abstraction from aquifers in semi-arid areas depends on recharge from rainfall and the size of the groundwater reservoir.	Boehmer, 1997

RESEARCH TITLE	GENERAL COMMENTS	REFERENCE
EGIS, a geohydrological information system	The system contains two subsets: (1) a range of general purpose packages for data presentation and processing, integrated with a database; (2) extends subset 1 with a set of advanced geohydrological applications which cover either processing and interpretation of data or focus on specific analysis.	Deckers, 1993
A national groundwater model combined with a GIS for water management in the Netherlands	A national analytic element technique groundwater model was coupled to the national geohydrological database which are both integrated with GIS.	De Lange and Van De Meij, 1993
Development of a three-dimensional hydrgeological framework model for the Death Valley region, southern Nevada and California, USA	Geoscientific Information System (GSIS) techniques were used for the synthesis of geological, hydrogeological and climate information gathered together from many sources including satellite imagery, published maps and cross sections.	Faunt, D'Agnese and Turner, 1993
Models, GIS and expert systems: integrated water resource models	The integration of water resource management models, geographic information systems, expert systems and interactive graphics are combined as tools for the management of groundwater resources.	Fedra, 1993
Application of GIS in decision support systems for groundwater management	Linked 2D groundwater model to GIS. GIS is raster based so that a minimum resolution has to be decided on when created. Therefore , if for a given area analysis needs to be done on different scales, the raster images have to have huge dimensions or information might be lost.	Fürst, Girstmair and Nachtnabel, 1993
High resolution satellite imagery and GIS as a dynamic tool in groundwater exploration in a semi-arid area	Satellite data integrated with field data and geophysics in GIS are used to facilitate the identification of target areas in groundwater exploration.	Gustafsson
The importance of GIS in regional geohydrological studies	A methodology is presented for the execution of regional geohydrological studies, with GIS enhancing the processing of data and the visualization thereof.	Hoogendoorn, Van Der Linden and Te Stroet, 1993
Environmental modelling and GIS: dealing with spatial continutity	Linking GIS to spatially distributed, physically-based environmental models.	Kemp, 1993
Application of a GIS for simulating hydrological responses in developing regions	Data capturing, processing and manipulation as well as ARC/INFO GIS processing.	Kienzle, 1993
Preparing inpt data for a national scale groundwater vulnerablility map of Southern Africa	The DRASTIC methodology was applied: Depth to groundwater, recharge due to rainfall, aquifer media, soil media, topography, impact of the vadose zone and hydraulic conductivity. GRID was used to rate and weight the factors influencing groundwater.	Lynch, Reynders and Schultze, 1994
Integration of three-dimensional groundwater modelling techniques with multi-dimensional GIS	GIS was used for the multi-dimensional analysis of spatial and temporal quantification of variables. Merged data displays were then created.	Schenk, Kirk and Poeter, 1993

3.5. CONCLUSION

The methodology employed builds on previous work conducted on quantifying aquifers in South Africa (Baron et al., 1995; Vegter, 1995; Seymour and Seward, 1997). It also introduces the ecological parameter. Unfortunately, very little is understood regarding groundwater dependent ecosystems. It is only recently that the WRC has undertaken studies regarding groundwater dependent ecosystems. This thesis concentrates on identifying areas of high groundwater development potential as well as high ecological importance using a GIS platform to capture, process and visualise the data.

CHAPTER FOUR

4. REGIONAL HYDROGEOLOGY

4.1. GENERAL GEOLOGY

The regional geology of the study area is presented in **Figure 5**. The study area comprises various structural terrains, such as the Saldania Mobile Belt, the Cape Basin, the Karoo Basin and the most recently deposited Cenozoic deposits. These terrains are discussed briefly below.

4.1.1 Saldania Mobile Belt

The Saldania Belt is comprised of a number of basement inliers, which are exposed along the coastline of southern Africa. The main exposures are the Malmesbury Group in the Cape Town area, the Kango Group in the Oudtshoorn area, and the Kaaimans Group in the George area and the Gamtoos Group in the Port Elizabeth area, with various associated intrusives.

The Precambrian age Malmesbury Group is mainly exposed on the coastal plain extending from Veldrif to Atlantis and up to the foothills of the eastern bounding mountains. These are the oldest rocks in the area, with an approximate maximum age of 830 to 980 Ma. The rocks are steeply folded along NW striking axes (Visser, 1989). The Malmesbury metasediments form part of the Saldania Subprovince, and have been subdivided into three tectono-stratigraphic domains i.e. the Tygerberg, Swartland and Boland terranes (**Table 3**). These are separated by two major north-northwesterly striking fault systems, the Franschhoek-Saldanha (Colenso Fault) and Wellington-Piketberg Faults (Visser, 1989).

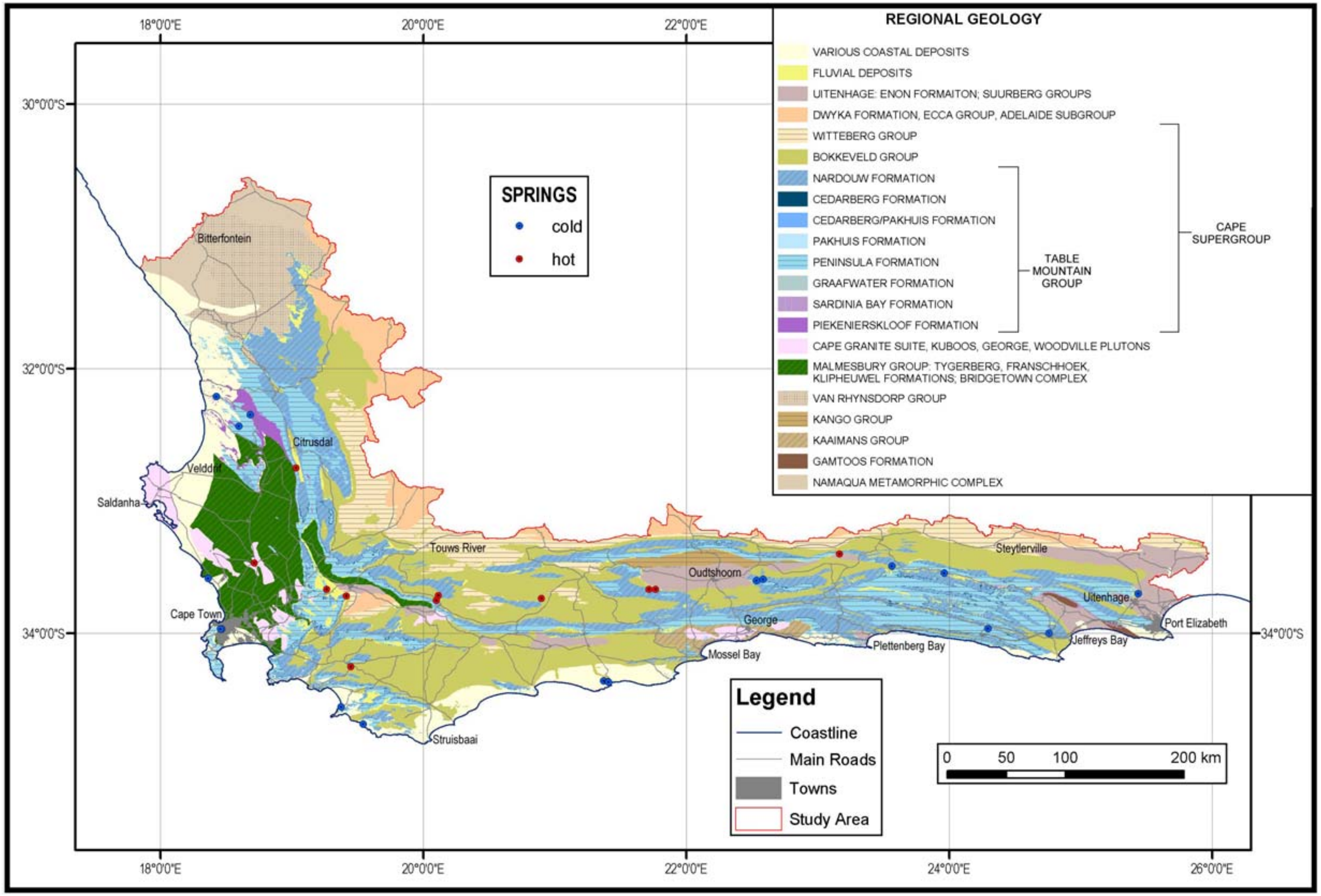

REGIONAL GEOLOGY
VARIOUS COASTAL DEPOSITS
FLUVIAL DEPOSITS
UITENHAGE: ENON FORMAITON; SUURBERG GROUPS
DWYKA FORMATION, ECCA GROUP, ADELAIDE SUBGROUP
WITTEBERG GROUP
BOKKEVELD GROUP
NARDOUW FORMATION
CEDARBERG FORMATION
CEDARBERG/PAKHUIS FORMATION
PAKHUIS FORMATION
PENINSULA FORMATION
GRAAFWATER FORMATION
SARDINIA BAY FORMATION
PIEKENIERSKLOOF FORMATION
TABLE MOUNTAIN GROUP
CAPE SUPERGROUP
CAPE GRANITE SUITE, KUBOOS, GEORGE, WOODVILLE PLUTONS
MALMESBURY GROUP: TYGERBERG, FRANSCHHOEK, KLIPHEUWEL FORMATIONS; BRIDGETOWN COMPLEX
VAN RHYNSDORP GROUP
KANGO GROUP
KAAIMANS GROUP
GAMTOOS FORMATION
NAMAQUA METAMORPHIC COMPLEX
SPRINGS
cold
hot
Legend
Coastline
Main Roads
Towns
Study Area
0 50 100 200 km
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
30°0'0"S
32°0'0"S
34°0'0"S
Bitterfontein
Citrusdal
Velddrif
Saldanha
Touws River
Cape Town
Oudtshoorn
George
Mossel Bay
Plettenberg Bay
Steytlerville
Uitenhage
Port Elizabeth
Jeffreys Bay
Struisbaai

Table 3: Lithostratigraphy of the Malmesbury Group.

Terrane	Formation	Lithology
Tygerberg	Tygerberg	Greywacke, phyllite and quartzitic sandstone; interbedded lava and tuff
Swartland	Franschhoek	Grey, feldspathic conglomerate, grit and sandstone with minor shale
	Moorreesburg	Greywacke and phyllite with beds and lenses of quartz schist, limestone and grit, quartz-sericite schist with occasional limestone lenses
	Bridgetown	Schist and fine-grained greywacke with beds and lenses of quartz schist and limestone
	Klipplaat	Quartz schist with phyllite beds with minor limestone and chlorite-schist lenses
	Berg River	Greenstone with dolomite and chert lenses
Boland	Porterville	Grit and greywacke
	Piketberg	Phyllite shale, schist and greywacke with dark-grey limestone. Sporadic quartzitic sandstone beds and conglomerate beds

The Kango Group is exposed north of Oudtshoorn along the southern flank of the Swartberg. On the north side the Peninsula Sandstone Formation of the Table Mountain Group rests unconformably on this group. It borders against the Enon Formation of the Uitenhage Group in the south. This contact is a fault and the group wedges out towards the west and towards the east. The entire group is slightly more than 1000m thick. It is composed of shelf carbonates, grading upward into turbidites and braided alluvial fan and alluvial plain conglomerates and sandstones.

The Kaaimans Group occupies a strip on the southern flank of the Outeniqua Mountains. Lithologically this Group comprises quartzite, phyllite and schist. The thickness of the Kaaimans Group exceeds 2550m.

The Gamtoos Formation is exposed to the west of Port Elizabeth. The lower part of this formation is calcareous and consists mainly of phyllite with lenticular shale intercalations followed by dark dolomitic limestone. The limestone is interbedded with thin calcareous and carbonaceous, pyritic, shale. This is overlain with further phyllite, shale and thinly bedded sandstone interbedded with conglomerate. This is followed by limestone with intercalations of phyllite, quartzite and sandstone. The upper part, which rests unconformably on the lower part, is composed of sandstone with interbeds of phyllitic mudstone and limestone. The thickness of this formation is not known.

The Bridgetown Suite intrusives occurs in the valley of the Berg River. The Piketberg-Worcester Fault bounds this intrusion in the northeast while the Moorreesburg Formation (Malmesbury Group) bounds it in the southwest. The suite is composed largely of dark greyish-green greenstone, which weathers readily, with associated dolomite and limestone, as well as chert, shale and phyllite (Visser, 1989). These rocks may represent remnants of oceanic crust emplaced into the Malmesbury rocks (Visser, 1989).

Approximately 25 bodies (Visser, 1989) of granitoid plutons of the Cape Granite Suite have intruded the rocks of the Saldania Belt. Plutons of the Cape Granite Suite intruded the anticlinal fold hinges in the Malmesbury Group, and show strong alignment with the dominant NW-SE tectonic trend developed during the Saldanian Orogeny (~550 to ~510 Ma). In some places they form prominent features like the Paarl Mountain. Scholtz (1947) divided the intrusions geographically into the southwestern plutons (between St Helena Bay and Cape Agulhas) and the eastern plutons (between Mossel Bay and Steytlerville) (**Table 4**).

Table 4: Geographical division of intrusions (After Scholtz 1947).

Southwestern plutons	Eastern plutons
Cape Peninsula	Baviaans Kloof
Darling	George
Malmesbury	Woodville
Onrus	
Paardeberg	
Robertson	
Saldanha-Langebaan	
Stellenbosch - Kuils River	
Swellendam	
Wellington	

The southwestern plutons are mainly exposed north to northwest of the Malmesbury area and east of Cape Town within the main Malmesbury Group exposure. The granitoids of the Cape Granite Suite have been interpreted as having been intruded into a continental-arc environment during or shortly after the onset of the main phase of Pan-African collisional tectonics, and have been subdivided into three groups (Kister *et al*, 2002):

- an older suite of syn- to late-tectonic S-type granites (~550 - ~540 Ma) in the Tygerberg Terrane;
- a younger suite of largely post-tectonic I-type granites (~540 - ~520 Ma) in the Swartland and Boland Terranes; and
- a suite of volumetrically subordinate A-type granites (520 – 500Ma) that occur in all three Terranes.

The eastern plutons have intruded into the east-west striking Kaaimans Group in the southern Cape Fold Belt.

The Vanrhynsdorp Group was deposited on the edge of the Saldania Belt forming a foreland basin exposed over a fairly extensive area in the environs of Vanrhynsdorp. The group is classified into four formations, namely the Klipbak, Knersvlakte, Flaminkberg and Gifberg Formations. The Flaminkberg Formation is approximately 30m thick on average. In the vicinity of Nuwerus the thickness increases to between 100m and 140m. North of Bitterfontein the formation is so thin it can be differentiated. The Knersvlakte formation is approximately 500m thick.

The Klipheuwel Formation is fairly widespread in the western part of the Cape. These predominantly Early- to Mid-Cambrian (~ 510Ma), coarse clastic, rift-type rocks were deposited in the same geosynclinal basin as the Malmesbury Group, but lie unconformably on the latter. The rocks are not intensely deformed and show a slight northeasterly regional dip. The formation is composed of conglomerate at the base, followed by sandstone with intercalations of conglomerate and grit. This is followed by sandstone, with interbedded shale and greywacke. Although approximately 2200m thick around the town of Klipheuwel, it becomes thinner towards the north. North of Piketberg it is only 300m to 375m thick.

4.1.2 Cape Supergroup

The sediments of the Cape Supergroup were deposited from early Ordovician to early Carboniferous times, approximately between 500 and 340 million years ago (de Beer, 2002). This sequence is exposed along the entire length of the Cape Fold Belt, the 280-220 million year old orogenic belt straddling the west and south coasts of South Africa from Vanrhynsdorp in the west to Port Elizabeth in the east. It is classified into three groups, namely the Table Mountain, Bokkeveld and Witteberg Groups.

The Table Mountain Group (TMG) occurs within the Western and Eastern Cape Provinces of South Africa, extending from just north of Nieuwoudtville to Cape Agulhas and then eastwards to Algoa Bay, a linear outcrop distance of over 900km. The group attains a maximum thickness of 4 400m in the Western Cape Province, whilst the thickness decreases rapidly towards the north to 900m in the vicinity of Nieuwoudtville. A large percentage of the TMG consists of quartzitic sandstones. The sediments were deposited in a shallow, but extensive, intra-cratonic basin on a fairly stable continental shelf (Visser, 1989). These sandstones are of Ordovician to Silurian age (500 My).

The Group is divided into six units. A summary of the lithostratigraphy of these units is given in **Table 5**. The Piekenierskloof Formation unconformably overlies the phyllites and quartzites of the Malmesbury Group as well as the sediments of the Klipheuwel Group (de Beer, 2002). The Piekenierskloof Formation is confined to the West Coast area. The Graafwater Formation attains a maximum thickness of 420m west of Clanwilliam but shows severe thickness changes across the Cape Fold Belt. South of Ceres the formation is only 30m thick. On the eastern Cape coast, approximately 15km west of Port Elizabeth, an outcrop of the Sardinia Bay Formation occurs (Shone, 1983). According to de

Beer (2002) this formation could be a lateral equivalent to the Graafwater Formation in the Eastern Cape.

The *Piekenierskloof Formation* thins rapidly to the south of the study area and varies in thickness from 390m at Piketberg to only 10m at Kasteelberg. The unit consists of a basal conglomerate that is overlain by coarse-grained sandstone. It is very similar in appearance to the Peninsula Formation and some confusion in identification can arise where underlying and overlying stratigraphic units are concealed by overburden.

The *Graafwater Formation* follows conformably on the Piekenierskloof Formation and also thins towards the south of the study area. This unit is characterised by purple shale, with thinly bedded layers of quartzite and clay pellet conglomerates at the base. The unit is ~440m thick in the Graafwater and Piekenierskloof areas to the north of the study area, and thins rapidly to the south and east, where in the Cape Peninsula it is only 65m thick (Visser, 1989).

The *Peninsula Formation* is the thickest in the TMG units and together with the Nardouw Subgroup forms the high mountain ranges of the Western Cape. This Formation comprises at least 50% of the TMG and it is composed of a monotonous succession of medium- to coarse-grained, thickly bedded, greenish grey sandstone, which weathers to a whitish colour.

The *Cedarberg Formation* is on average 50 to 120m thick. The shale is greenish when fresh and is extremely fine-grained and sericitic. It is a good marker-horizon as it weathers deeply resulting a smooth outcrop compared to the rough outcrop of the surrounding quartzitic rocks.

The *Nardouw Subgroup* is considerably similar to the Peninsula Formation, but on small lithological differences it is subdivided into the Goudini, Skurweberg and Rietvlei Formations. The rocks of this Subgroup are generally weather to a more brownish colour than those of the Peninsula Formation, whilst shale intercalations are more plentiful and they become more feldspathic toward the top (Visser, 1989).

Three subgroups of the Bokkeveld Group have been recognised (**Table 6**). The lower or Ceres subgroup consists of alternating fossiliferous shale and sandstone formations and occurs throughout the Cape Basin. The subgroup is considerably thicker in the east, approximately 1620m, than in the west where it only reaches a thickness of approximately 625m.

Table 5: Stratigraphy of the Table Mountain Group.

SUBGROUP	FORMATION	MAXIMUM THICKNESS (m)	LITHOLOGY
Nardouw	Rietvlei	280	Light grey feldspathic sandstone, siltstone and micaceous shale bands
	Skurweberg	390	Light grey, massively bedded, quartzitic sandstone; thin lenticular conglomerate and grit beds
	Goudini	230	Red-brown weathering, thin bedded quartzitic sandstone; thin shale beds and places
	Cedarberg	120	Shale, aranaceous shale, tillite, grit and conglomerate
	Pakhuis	40	Grey-blue, massively bedded diamicite with erratics
	Peninsula	1800	Light-grey quartzitic sandstone with thin siltstone, shale and polymictic conglomerate lenses
	Graafwater	420	Thinly bedded sandstone, siltstone and mudstone; mainly reddish
	Piekenierskloof	900	Grey to reddish quartzitic sandstone with minor grit, conglomerate and reddish shale lenses

In the west the Bidouw Subgroup, also fossiliferous, consists of alternating bands of shale and sandstone. This subgroup is approximately 540m in thickness. In the east the Traka Subgroup is equivalent to the Bidouw Subgroup. The Traka Subgroup is mainly argillaceous and poorly fossiliferous. It is much thicker than the Bidouw Subgroup at approximately 2200m.

The Witteberg Group is subdivided into the Weltevrede and Lake Mentz Subgroups. These subgroups occur above and below the Witpoort Formation (**Table 7**). The Lake Mentz Subgroup attains a thickness of approximately 260m while the Witpoort Formation is approximately 310m in thickness. The Weltevrede Subgroup is approximately 770m thick.

In the eastern part of the basin the various formations of the Weltevrede Subgroup merge into a single formation. In the east the Kommadagga Subgroup, which attains a thickness of approximately 445m, follows conformably on the Lake Mentz Subgroup (approximately 660m thick). In the west the Kommadagga Subgroup has not developed. The Witpoort Formation is approximately 850m thick while the Weltevrede Formation is approximately 850m thick.

Table 6: Stratigraphy of the Bokkeveld Group (After Visser, 1989).

WESTERN PART OF CAPE BASIN			EASTERN PART OF CAPE BASIN		
SUB-GROUP	FOR-MATION	LITHOLOGY	SUB-GROUP	FOR-MATION	LITHOLOGY
Bidouw	Karoopoort	Siltstone and orthoquartzite, with shale interbeds	Traka	Sandpoort	Reddish shale, siltstone and orthoquartzite
	Osberg	Feldspathic sandstone and orthoquartzite		Adoplhs-poort	Siltstone and orthoquartzite
	Klipbokkop	Mudstone, greywacke and subgreywacke		Karies	Shale, siltstone, orthoquartzite
	Wupperthal	Orthoquartzite, subgrey-wacke and siltstone			
	Waboom-berg	Siltstone, orthoquartzite, shale; black shale near top			
Ceres	Boplaas	Orthoquartzite, subgreywacke	Ceres	Boplaas	Feldspathic sandstone, orthoquartzite and mudstone
	Tra-tra	Mudstone, siltstone, subordinate sandstone		Tra-tra	Mudstone, siltstone, sandstone
	Hex River	Arkose, subgreywacke, orthoquartzite		Hex River	Subgreywacke, orthoquartzite, siltstone, mudstone
	Voorste-hoek	Siltstone, shale, fine-grained sandstone		Voorste-hoek	Siltstone, shale, fine-grained sandstone
	Gamka	Feldspathic sandstone, orthoquartzite, mudstone		Gamka	Feldspathic sandstone, orthoquartzite, mudstone
	Gydo	Black to dark-grey shale, siltstone and thin sandstone; fossiliferous		Gydo	Shale, siltstone, fine-grained sandstone

Table 7: Stratigraphy of the Witteberg Group.

	WESTERN PART OF BASIN		EASTERN PART OF BASIN	
SUBGROUP	FORMATION	LITHOLOGY	FORMATION	LITHOLOGY
Kommadagga			Dirkskraal	Feldspathic sandstone, orthoquartzite
			Soutkloof	Mudstone, shale, varved shale
			Swartwaters-poort/Miller	Sandstone, diamictite
Lake Mentz	Waaipoort	Mudstone, greywacke	Waaipoort	Greywacke, mudstone, feldpathic sandstone
	Floriskraal	Feld spathic sandstone	Floriskraal	Shale, mudstone, orthoquartzite
	Kweekvlei	Black fissile shale	Kweekvlei	Shale, siltstone
	Witpoort	Orthoquartzite, rare shale lentils	Witpoort	Orthoquartzite, rare shale lentils
Weltevrede	Swartruggens	Siltstone, shale, interbedded sandstone	Weltevrede	Shale, siltstone, thick orthoquartzite
	Blinkberg	Orthoquartzites		
	Wagen Drift	Shale, siltstone, interbedded sandstone		

4.1.3 Karoo Basin

The Karoo Sequence is confined to the following geographically demarcated areas within the study area:

- the main Karoo basin extending from the western Cape Province eastward toward the Indian Ocean; and
- a small area south and southeast of Worcester.

Within the study are the Karoo Sequence is represented by the Dwyka Formation, the Ecca Group and part of the Beaufort Group.

The advent of glaciers from the north, northwest and possibly east resulted in deposition of the Dwyka Formation. This formation is about 600m thick and consists mainly of tillite with subordinate lenses of shale, diamictite and sandstone.

The Ecca Group attains a thickness in excess of 2000m and within the study area it may be subdivided into the southern Karoo and the western to northwestern Karoo. In the southern Karoo the Prince Albert, Whitehill, Collingham, Vischkuil, Ripon and Laingsburg Formation are indicated as one unit. In the north and northwestern parts the Prince Albert, Whitehill, Tierberg, Skoorsteenberg, Kookfontein and Carnavon Formations are grouped.

The Beaufort Group may be subdivided into two subgroups, namely the Adelaide and the Tarkastad Subgroups. The Adelaide Subgroup is approximately 5000m thick while the Tarkastad Subgroup is approximately 850m thick.

4.1.4 Cenozoic Deposits

During Tertiary sea-level transgressions and regressions, gravel, sand and clayey deposits of the Elandsfontyn, Saldanha and Varswater Formations were deposited. The overlying Quaternary sediments consist primarily of aeolian sand and comprise the Springfontyn, Langebaan and Witzand Formations. These sediments are grouped together under the term Cenozoic (**Table 8**).

Table 8: Lithostratigraphy of the Cenozoic Sediments

Epoch	Age	Litho-stratigraphic Unit		Description	Depositional Environment
		Formation	Member		
Holocene - Pleistocene	1.7	Bredasdorp	Witzand / Yzerfontein	Calcareous dune sands.	Aeolian
			Langebaan Limestone	Calcretized limestone.	Aeolian
			Velddrif / Milnerton	Shelly sand.	Marine
			Springfontyn/ Noordhoek / Papkuils	Silica to peaty sand.	Aeolian
Pliocene	5.2	Varswater	CSM	Calcareous sands.	
			PPM (Duynefontein)	Muddy sands with pelletal phosphorite.	Marine
			QSM	Quartzose sand.	Marine
			SGM (Silwerstroom)	Shelly gravel.	Marine
Late Miocene	10	'Saldanha'	-	Gravels	Marine
Miocene	22	Elandsfontyn	-	Predominantly coarse sand and gravel, interbedded silty, clayey and peaty layers.	Fluviatile

Notes:
CSM – Calcareous Sand Member, PPM – Pelletal Phosphorite Member
QSM – Quartzose Sand Member, SGM – Shelly Gravel Member

A subtropical to tropical climate during the Palaeogene caused the deep weathering of the basement rocks. The thick sericitic- and kaolinitic-rich clay deposits that cap the Malmesbury and Cape Granites, respectively originate from these processes.

The coarse-grained Elandsfontyn sand and gravel were deposited in a number of high-energy, palaeo-river channels. Sea levels during this period must have been much lower than at present, as evidenced by deeply incised, palaeo-channels of up to 50m below current mean seal-level along the west coast (Timmerman, 1988). Because of the fluviatile nature of the deposits, the coarse sand and gravel alternate with peat and clay layers which were deposited in the floodplain and swamp environments of the system.

The Pliocene marine transgression reached its maximum level of at least +90m above the present sea level. The Varswater Formation was deposited during the subsequent cycles of marine transgression and regression. The complete Quaternary sequence, which consists mainly of unconsolidated aeolian deposits associated with re-worked Varswater sediments, has been named the 'Bredasdorp Formation' (Rogers, 1980, 1982).

4.2. STRUCTURAL/TECTONIC DOMAINS OF THE TABLE MOUNTAIN AND BOKKEVELD GROUPS

The outcrop areas of the Table Mountain and Bokkeveld Groups within the Cape Fold Belt (CFB) were subdivided into 9 regional structural – tectonic domains by Mr. C. de Beer of the Council for Geosciences, based on their folding and fracturing characteristics. The domains are shown in **Figure 6**, whilst their characteristics are summarized in (**Table 9**). Folding during the Permo-Triassic Cape Orogeny and the fragmentation of Gondwana during the Mesozoic led to extensive fracturing and strong enhancement of porosities within these rocks.

Domains 1 and 2 essentially encompass the western branch of the CFB, and Domains 8 and 9 the southern branch of the CFB outside the syntaxis domain. The TMG outlier of the Cape Peninsula is tentatively grouped into Domain 2 (i.e. the western branch) because it mainly displays NW-SE striking faults. Its NE-SW open folding, however, points towards its location within the syntaxis and elements of Domain 5 folding.

The syntaxis is composed of Domains 3 to 7, where Domains 3 and 5 still display many features of the western branch, and Domains 4 to 6 many of the characteristics of the southern branch. Domain 7 comprises the highly deformed and possibly thrusted sequences between Hermanus and Cape Agulhas.

The Worcester Fault subdivides the syntaxial area of the CFB (Domains 3 to 7) into two areas with strong differences in the trend and intensity of faults. The southern part (Domains 5 and 6) displays interplay between NW-SE, E-W and NE-SW faults, most of which are major structures. This results in the southern syntaxis being the most intensely fractured part of the whole CFB. Faults in Domains 3 and 4 trend WNW-ESE in harmony with the general trend of the Worcester Fault. The general absence of NE-SW faults in the latter areas implies that faults of this trend south of the Worcester Fault must have formed either contemporaneous with the mega-fault, or after it.

Domains 8 and 9 are essentially the southern branches proper, with zonal variations in shortening intensity and the presence of a major continent-wide normal fault system, the Kango Fault, within Domain 8. Shortening intensity reaches a maximum in the Outeniqua Mountain Ranges (70%) and thrusting is conspicuous within the mountain ranges to the north of Plettenberg Bay and Port Elizabeth.

The ability of rocks in the Table Mountain and Bokkeveld Groups to contain water is determined by the amount of fractures that can create secondary porosity. As most of these rocks are remarkably densely packed with intense secondary overgrowths of quartz on grains within the arenites, such porosity can only be formed through deformation and faulting. Cleavage can enhance porosity, but is not indispensable, as shown by high yields in units of the Bokkeveld Group close to the Table Mountain Group in Domain 3.

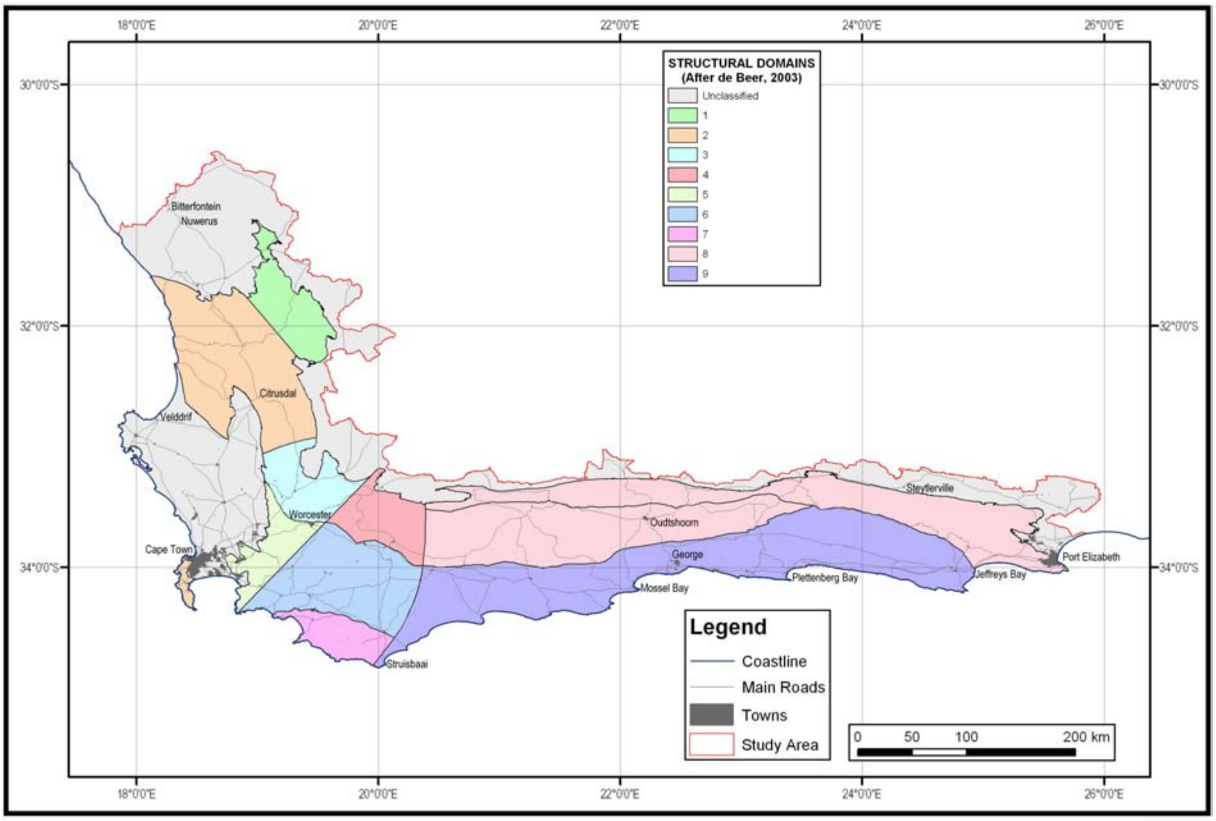


Figure 6: Structural – Tectonic Domains of the TMG and Bokkeveld Groups within the Cape Fold Belt

Table 9: Summary of the structural character of the Table Mountain and Bokkeveld Groups in the Cape Fold Belt (After de Beer, 2003).

DOMAIN	FOLDS	% SHORTENING	PELITE CLEAVAGE	METAMORPHISM	FAULTS
1	No discernable folding	Very low	None	Diagenetic	None
2	NW-SE, zonal development, kinks, λ= 40 km, open folding	Variable, < 15%	None	Lowest grades	Major NW-SE, shorter E-W and minor NE-SW faults
3	Major N-S and NE-SW folds, minor NW-SE, interference, λ= 20 km, open to tight folding, no overturning	Low, <25%	Weak to nonexistent, but strongly fractured	Lowest grades, little neoformed micas	WNW-ESE, slightly less major faults than Domain 1
4	E-W, local northwards overturning, minor NE-SW	>35%	Well-developed, axial planar	Low grade, abundant neoformed mica	WNW-ESE and WSW-ENE
5	NW-SE and NE-SW, open folding, no overturning	< 25%	Weak to non-existent	Lowest grades, little neoformed mica	Major NE-SW, lesser NW-SE
6	NE-SW and E-W folding, some overturning	>35%	Strongly developed, axial planar	Low grade, abundant neoformed mica	NE-SW and E-W
7	E-W, overturning common	>35%, thrusting	Strongly developed, often crenulations	Low grade	Curved thrusts, E-W normal faults
8	E-W, locally overturned	40-30%	Well-developed, axial planar	Low grade	E-W major faults
9	E-W, mostly overturned	70-40%	Well-developed, axial planar, crenulated	Low grade, quartz recrystallized, phyllites common	E-W major faults, thrusts

4.3. HYDRO-GEOMORPHIC DOMAINS

The TMG Aquifer outcrop and sub-outcrop area can be broadly divided into two hydro-geomorphological domains:

(i) Intermontane.

(ii) Coastal.

Except where there may be natural barriers to groundwater flow, such as the Cedarberg Formation or impermeable faults, the two domains are interconnected. The domains are, however, inhomogeneous in that the major formations within the TMG have different hydrogeological properties and groundwater development potential.

4.3.1 Intermontane Domain

This domain covers all of the inland outcrop and sub-outcrop areas and the main characteristics of the domain are the following:

- Deep groundwater circulation
- Enhanced groundwater potential in adjacent formations
- High direct recharge from both rainfall and snow-melt
- There are visible targets for borehole siting.
- Occurrence of hot springs.
- Artesian boreholes are common.
- Associated alluvial deposits are important for direct groundwater supply and indirect recharge.
- The associated groundwater has very low electrical conductivity (EC), is corrosive, and often contains excessive Fe, posing biofouling problems.
- Confined and unconfined aquifer conditions may occur.

The overlying formation of the TMG Aquifer System in Intermontane areas is usually the Bokkeveld Group. Where fault controlled, it may be the Enon Formation or granite. The main areas in this respect are Agter Witzenberg, Ceres Basin, Hex and Theewaterskloof Valleys.

4.3.2 Coastal Plain

This domain is mainly developed along the Southern Cape Coast between Cape Hangklip to Mossel Bay and from Oyster Bay to Port Elizabeth and comprises a wave-cut platform, bounded inland by the foothills of the coastal mountain ranges or differing geological formations. The characteristics of this domain are as follows:

- Relatively flat-lying terrain.
- There is usually a covering of Quaternary sands and calcrete.
- Shallower groundwater occurrence.
- Lack of visible targets for borehole siting.
- Possibility of seawater intrusion.
- Moderate to poor groundwater quality.
- Indirect recharge.
- Associated with cold springs.

4.4. HYDROGEOLOGICAL DOMAINS

The TMG occurs within the Western and Eastern Cape Provinces, extending from just north of Nieuwoudtville to Cape Agulhas and then eastwards to Algoa Bay, a linear outcrop distance of over 900 km. A large percentage of its total thickness consists of quartzitic sandstones. These sandstones are of Ordovician to Silurian age and because of their age and having undergone low-grades of regional metamorphism, essentially possess zero primary permeability. However, due to a combination of favourable factors, such as structure and climate, they form one of the major fractured rock aquifers in South Africa.

The physiographic setting of the TMG Aquifer is extremely varied, generally mountainous, rough and often inaccessible. The northern outcrops border on desert areas with <150 mm/a of precipitation, while around Worcester and Ceres, precipitation is >2000 mm/a. In the latter mountainous areas, elevations reach >2000 m, while at Elands Bay and along the Southern and Eastern Cape coast, wave-cut platforms occur at present sea level.

The TMG Aquifer System was previously sub-divided into five main characteristic hydrogeological domains, namely:

- Western Area, i.e. CAGE-type (Umvoto-SRK 2000);
- Central Area, i.e. Agter Witzenberg-Ceres-Hex – Koo Valleys and Villiersdorp (Rosewarne 1984, Rosewarne & Kotze 2000, Weaver *et al* 1999);
- Coastal Belt, i.e. from Kleinmond to Mossel Bay (Rosewarne 1997 and 2002);
- Klein Karoo (Kotze 1995 and 2001);
- Eastern Cape, Plettenberg Bay to Port Elizabeth.

Extensive hydrogeological studies have been carried out in areas i), ii) and iv), but less in areas iii) and v). The project will provide a more detailed subdivision of the study area into hydrogeological domains based upon analyses conducted.

Only potentially aquiferous formations have been considered in this research. The Graafwater and Cedarberg/Packhuis Formations have been considered in terms of their forming important aquitards and aquifer boundaries.

The Bokkeveld Group is included in the study area as in some areas these rocks are hydraulically interconnected with the TMG Aquifer System. It is also often the major aquifer in terms of direct exploitation in such areas as the Agter Witzenberg, Hex Valley and the Theewaterskloof areas. There would appear to be a number of reasons for this, namely:

- *Situated in the syntaxis area.*
- *Greatest development of arenaceous units in these areas.*
- *Good recharge from the mountainous TMG Aquifer.*

Elsewhere, the Bokkeveld is predominantly argillaceous in character and, at best, acts as an aquitard.

4.5. SPRINGS

An abundance of springs characterise the TMG Aquifer System (**Figure 5, Table 10**). Three kinds of springs can be distinguished (Meyer 2002):

1) Fault and major structure controlled, generally deep circulating hot springs, often with large constant flow-rates. Examples of these hot springs are Brandvlei (constant yield of 127 l/s), Calitzdorp (constant yield of 11.6 l/s), Uitenhage with an average flow rate of 44.7 l/s and yield fluctuation varying between 44.4 and 45.2 l/s.

2) Lithologically controlled, relatively shallow circulating springs. These springs issue due to the presence of impeding shale layers such as the Cedarberg Formation. Examples are the Marnewicks Spring in the Kammanassie Mountains and the Humansdorp Spring. The yield of the former varies between 9 and 19 l/s whilst the latter has an average flow rate of 28 l/s but seasonal yield fluctuations vary between 16 and 40 l/s. Yields from these springs are less constant and seasonal yield fluctuations are a distinctive feature. The bulk of the perennial springs issuing from the TMG are likely to be lithologically controlled.

3) Ephemeral springs or seeps issuing from numerous small fractures and joints. These are very evident during and shortly following rainy periods and are responsible for the myriad of springs in the TMG. However, they are highly seasonal and cease to exist with the onset of dry weather conditions.

Nine thermal springs occur in the Cape Supergroup rocks in the study area, namely (temperature in brackets) the Baths (43^{0}C), Goudini (37^{0}C), Brandvlei (64^{0}C), Caledon (38^{0}C), Montagu (43^{0}C), Baden (39^{0}C), Warmwaterberg (45^{0}C), Calitzdorp (50^{0}C) and the Toverwater (44^{0}C) hot springs. They are all fault related and are associated with both TMG sandstone and Bokkeveld shale. Water circulates from between approximately 1600 m (1200 m below sea level) at Caledon, to about 3800 m (3600 m below sea level) at Brandvlei. The Brandvlei thermal spring has the distinction of being both the hottest and strongest yielding thermal spring in the country.

The combined discharge from 74 thermal springs in South Africa is 36 290 m^3/d (Kent, 1949). Although only eight of these springs are situated in the rocks of the TMG Aquifer, the daily discharge amounts to 42% of the total thermal springs output countrywide.

Five of the thermal springs occur in the syntaxis domain, a relatively limited area, which is indicative of a greater frequency of fracturing compared to the rest of the TMG area (Meyer, 2002). The area east of 23^0E is devoid of thermal springs, indicating a region of shallower groundwater circulation.

4.6. EXISTING GROUNDWATER USAGE

Over 30 major users of the TMG Aquifer System have been identified, ranging from municipalities to agriculture. Areas where significant volumes (>100 000 m^3/a) of groundwater are abstracted from the TMG Aquifer System are shown on **Figure 7** and listed in **Table 10**. These include those where actual abstraction is from the Bokkeveld Group but the main recharge is via interconnection with the TMG Aquifer System, e.g. Agter Witzenberg, Ceres, Hex and Theewaterskloof Valleys. These are in fact the areas of highest groundwater abstraction in the TMG Aquifer outcrop area. In the Hex Valley, for example, ~20 million m^3/a is abstracted from the TMG/Bokkeveld Aquifer System.

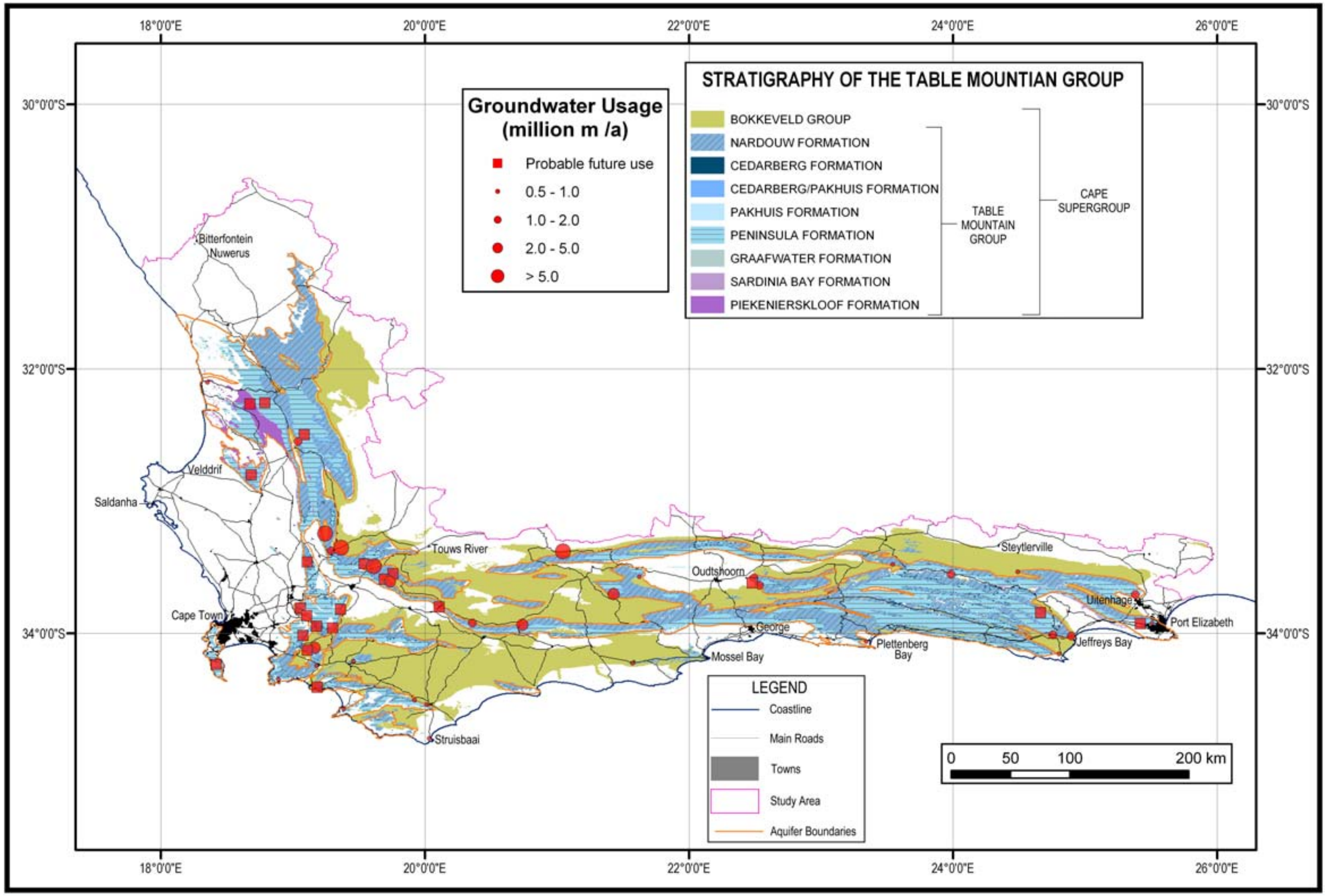
The main areas where future large-scale abstraction is likely to take place is from the TMG Catchments adjacent to the Cape Metropolitan Council area, namely (Umvoto, 2001):

- Wemmershoek
- La Motte
- Franschhoekberg Tunnel Zone
- Franschhoek Pass Area
- Villiersdorp Brandvlei
- Groenlandberg
- Voëlvlei

It is assumed that only the first three areas will be developed, with a combined estimated yield of 70Mm^3/a. Development of this full supply level (if attainable) will take eight to ten years.

Table 10: Localities where large-scale groundwater abstraction (>100 000 m^3/a) from the TMG Aquifer System takes place (from DWAF data).

Locality/Area	Approximate abstraction (10^6 m^3/a)			Locality/Area	Approximate abstraction (10^6 m^3/a)		
	Urban	Agriculture	Recreational		Urban	Agriculture	Recreational
Agter-Witzenberg Valley		11		Montague Area		0.3	
Albertinia	0.1			Napier	0.2		
Barrydale Area		4.4		Picketberg	0.1		
Bredasdorp	0.5			Plettenberg Bay	0.7		
Calitzdorp	0.1			Prince Albert	0.1		
Calitzdorp Spa			0.24	Scheepers Area		1	
Cape St Francis	0.1			St Albans		0.2	
Ceres Basin		8		St Francis Bay	0.55		
Citrusdal	1			Stanford/De Kelders	1.4		
Dysseldorp	2.3			Steytlerville	0.1		
Hermanus				Stilbaai	0.7		
Hex Valley		20		Struisbaai	0.3		
Humansdorp	1.1			Studtis		1.9	
Jeffreys Bay	1.85			Toverwater Hot Spring			0.36
Kandelaars River		1.6		Uitenhage (USGWCA)	1.1	5.7	
Klein Swartberg Valley		6.34		Van Wyksdorp Area		2.3	
Klip River		1.3		Vermaaks River	0.5		
Koo Area		2		Vyeboom Area		4.1	
Leeublad Area		1.5		Willowmore (Wanhoop)	0.22		


STRATIGRAPHY OF THE TABLE MOUNTIAN GROUP
BOKKEVELD GROUP
NARDOUW FORMATION
CEDARBERG FORMATION
CEDARBERG/PAKHUIS FORMATION
PAKHUIS FORMATION
PENINSULA FORMATION
GRAAFWATER FORMATION
SARDINIA BAY FORMATION
PIEKENIERSKLOOF FORMATION
TABLE MOUNTAIN GROUP
CAPE SUPERGROUP
Groundwater Usage (million m /a)
Probable future use
0.5 - 1.0
1.0 - 2.0
2.0 - 5.0
> 5.0
LEGEND
Coastline
Main Roads
Towns
Study Area
Aquifer Boundaries
0 50 100 200 km
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
30°0'0"S
32°0'0"S
34°0'0"S
Bitterfontein
Nuwerus
Velddrif
Saldanha
Cape Town
Touws River
Oudtshoorn
Steytlerville
Uitenhage
Port Elizabeth
Jeffreys Bay
George
Mossel Bay
Plettenberg Bay
Struisbaai

CHAPTER FIVE

5. GROUNDWATER DEVELOPMENT POTENTIAL

5.1. INTRODUCTION

Groundwater resource potential is of particular concern to the planner, developer and groundwater exploiter. According to Struckmeier (1989) groundwater resource potential embraces the following:

- Accessibility – aquifer depth and drilling risk.
- Exploitability – yield and pumping height.
- Availability – resource and recharge.
- Suitability – chemistry and risk pollution.
- Conservation – size and hydrodynamic situation.

A number of existing spatial datasets have been used to assess the groundwater development potential of the study, i.e. WRC's Groundwater Resources – Borehole Prospects, DWAF's Groundwater Harvest Potential, and 1/500,000 scale Hydrogeological maps. The aim was to develop an exploitation potential map and an exploration potential map, which could then be intersected 'geospatially' and reclassified to produce the development potential map that will essentially indicate areas where large-scale abstraction schemes should receive high priority. The exploitation map will essentially consider the resource and recharge while the exploration map will assess the accessibility and success of drilling. The conservation/ecological importance of the area is considered in **Chapter 6**.

5.2. EXPLOITATION POTENTIAL

With a dwindling of surface water resources in the region, groundwater supply has come to play a major role in future growth of the region because of its relative cost effectiveness, particularly in diffuse supply situations. Reliable assessments of exploitable groundwater resources are therefore essential, particularly for sustainable development. Sustainable groundwater abstraction depends upon adequate recharge to replace the water being removed from the aquifer system. In this section, aquifer recharge refers to the amount of precipitation that infiltrates into the vadose zone and then actually enters into the main underlying aquifer system. The estimated volumes of rainfall recharge therefore already account for evapotranspiration losses.

Owing to the difficulty of modelling such complex processes associated with recharge, the quantification is expressed as a percentage of mean annual precipitation. The Mean Annual Effective Recharge (R_e) from rainfall was estimated using the Mean Annual Precipitation (MAP). , percentage Coefficient of Variance (CV) of MAP, %-Terrain Slope and Lithological-Recharge Factor raster-datasets for the study area. The %-slope grid, computed using ArcView Spatial Analyst, was constructed from a 240mX240m grid-cell digital elevation model (DEM) supplied by the Western Cape Nature Conservation Board. The MAP was interpolated from the CCWR's 1'x1' grid data (Schultze, 1998) and varies between 79.4mm and 3713.7mm (**Figure 3**). The percentage CV of the year-to-year rainfall (Schultze, 1998) on the study area was also sourced from the CCWR, and shows a variation of 15% to 40%. The influence of lithology on rainfall recharge was also taken into account by applying a lithological factor that was subjectively determined based on the rock types present within each lithostratigraphic unit.

The following GIS-based spatial-modelling process was used to simulate the mean annual volumes of recharge for the study area:

- *A variable recharge rate (R_f) was estimated for each 240mX240m grid-cell in the study area, where R_f increases with increasing MAP as follows $R_f(\%)$ = [MAP (mm) / 10 000].*

  This methodology is based on the widely used Maxey-Eakin empirical method. An empirical precipitation-recharge relationship was developed by Maxey-Eakin (1949) from mass-balance estimates for basins in southern Nevada. Their premise was that just as annual precipitation increases with increasing altitude, so does the percentage of precipitation that becomes groundwater recharge. Using this relationship Maxey and Eakin assumed that no recharge occurs where mean annual precipitation is less than about 200mm, or elevation is lower than 1700m. Other investigators working in different parts of the Basin developed similar "are-altitude" classes for their studies (Walker & Eakin, 1963; Miller, 1977; Malmberg & Eakin, 1962; Malmberg, 1967; Winograd & Thordarson, 1975; Harrill, 1986). Each investigator noted the method's empiricism and pointed out that isohyetal methods ignore differences in lithology, soils, climate, vegetation and topography. However, subsequent studies (Miller, 1977) showed that the Maxey-Eakin method was too simplistic and should be modified to consider other critical factors such as rock type, soil, permeability and slope aspect.

The Maxey-Eakin method was refined to be more sensitive to the critical factors. The additional potential recharge indicators were included as described below.

- *The effect of terrain slope on the relationship between rainfall infiltration and runoff was accounted for using a Slope Factor:* $S_f = 100 - [\%Slope / 100]$.

- *The positive or negative effects of the various lithological units on rainfall recharge were accounted for using a Lithological Factor (L_f), summarised in **Table 11**.*

In the case of variable geology, the recharge values were multiplied by a weighted factor (**Table 11**) according to the underlying geology. The recharge was either enhanced or reduced depending on the lithology. For example, the quartzitic sandstones of the Peninsula Formation were multiplied by a factor of 1.3 indicating enhanced recharge potential while the Malmesbury shale was multiplied by a factor of 0.65 indicating reduced recharge potential.

Table 11: Lithological recharge factors.

Lithology	Lithological Recharge Factor
Malmesbury Group	0.65
Granites	0.85
Namaqua Metamorphic Complex	0.85
Vanrhynsdorp Group	0.80
Gamtoos Formation	0.85
Kaaimans Group	0.85
Kango Group	0.85
Peninsula Formation	1.30
Piekenierskloof Formation	0.90
Graafwater Formation	0.80
Pakhuis Formation	0.70
Cedarberg Formation	0.70
Nardouw Formation	1.10
Sardinia Bay	1.00
Bokkeveld Group	0.80
Witteberg Group	0.95
Ecca Group	0.70
Dwyka Formation	0.75
Uitenhage Group	0.60
Enon Formation	0.80
Adelaide Subgroup	0.85
Suurberg Group	0.60
Fluvial Deposits	0.85
Various Coastal Deposits	1.00

- *Mean annual depth of groundwater recharge (R_e) from rainfall were estimated for each 240mX240m grid-cell in the study area, as follows: R_e (mm/annum) = MAP x R_f x S_f x L_f*

- *The recharge estimates obtained in the above, were adjusted upwards and downward to provide an upper and lower limit, respectively, according to the coefficient of variation (CV) in the annual rainfall.*

The R_e for the entire study area is estimated at 3 777 x 10^6 m^3 (an average recharge rate of 6.4% of MAP). This is expected to decline to 2 794 x 10^6 m^3 during droughts (**Table 12**). The R_e was determined for each of the 314 Quaternary Drainage Regions in the study area (**Figure 8** and **Appendix III**).

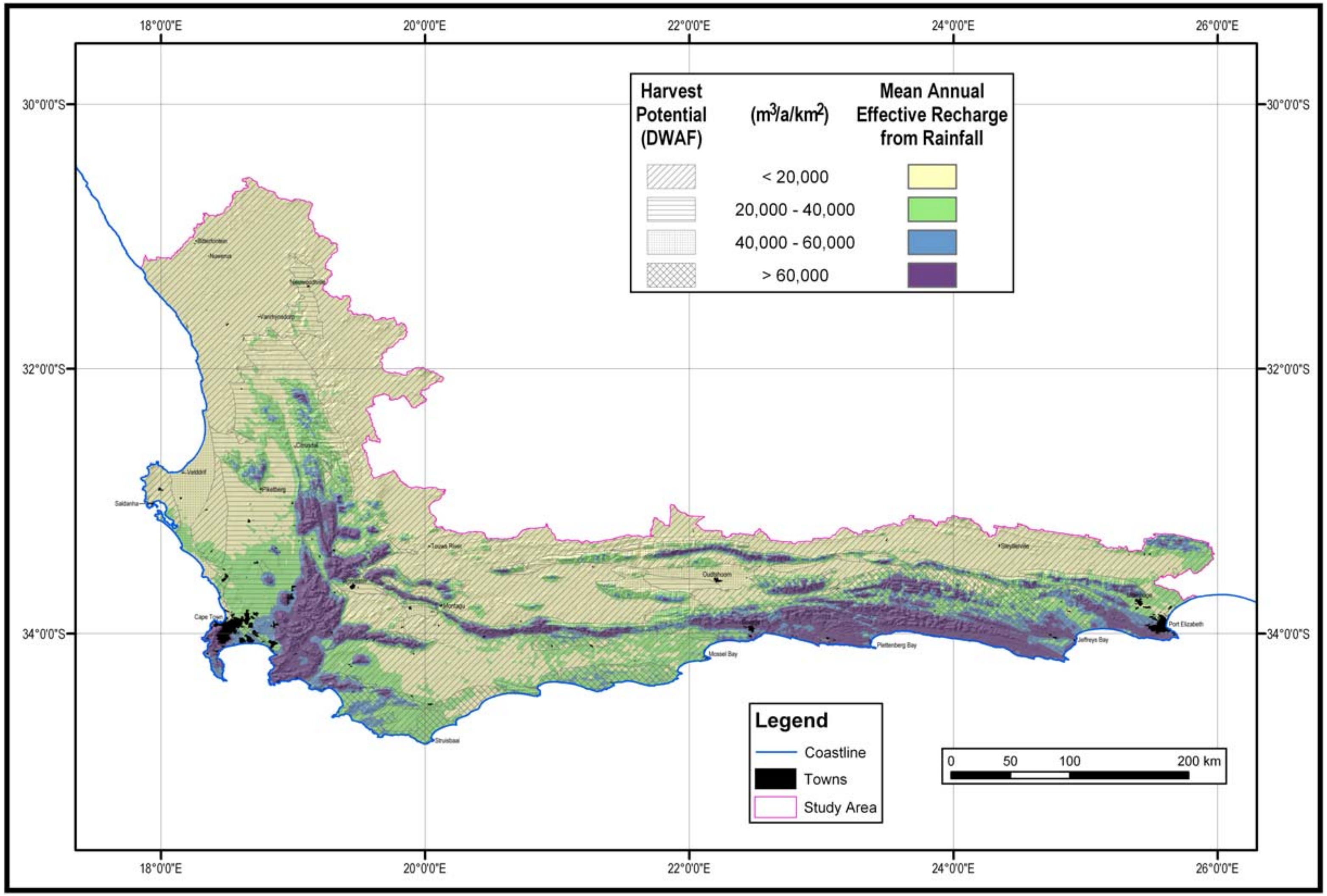
The resulting R_e dataset was then compared to DWAF's Groundwater Harvest Potential Map (**Figure 8**). The Harvest Potential Map provides an assessment of the harvest potential of groundwater from aquifer systems in South Africa. However, for this study DWAF's Harvest Potential Map is too broad a classification and since it is vector based it is less accurate for use in raster or grid-based GIS modelling. The R_e gives more detailed information for further analysis by taking into account the effects of slope and lithology. The exploitation map (**Figure 9**) is a qualitative ranking of the mean annual effective groundwater recharge from rainfall dataset that was reclassified. It shows the potential of an area to sustain large-scale abstraction.

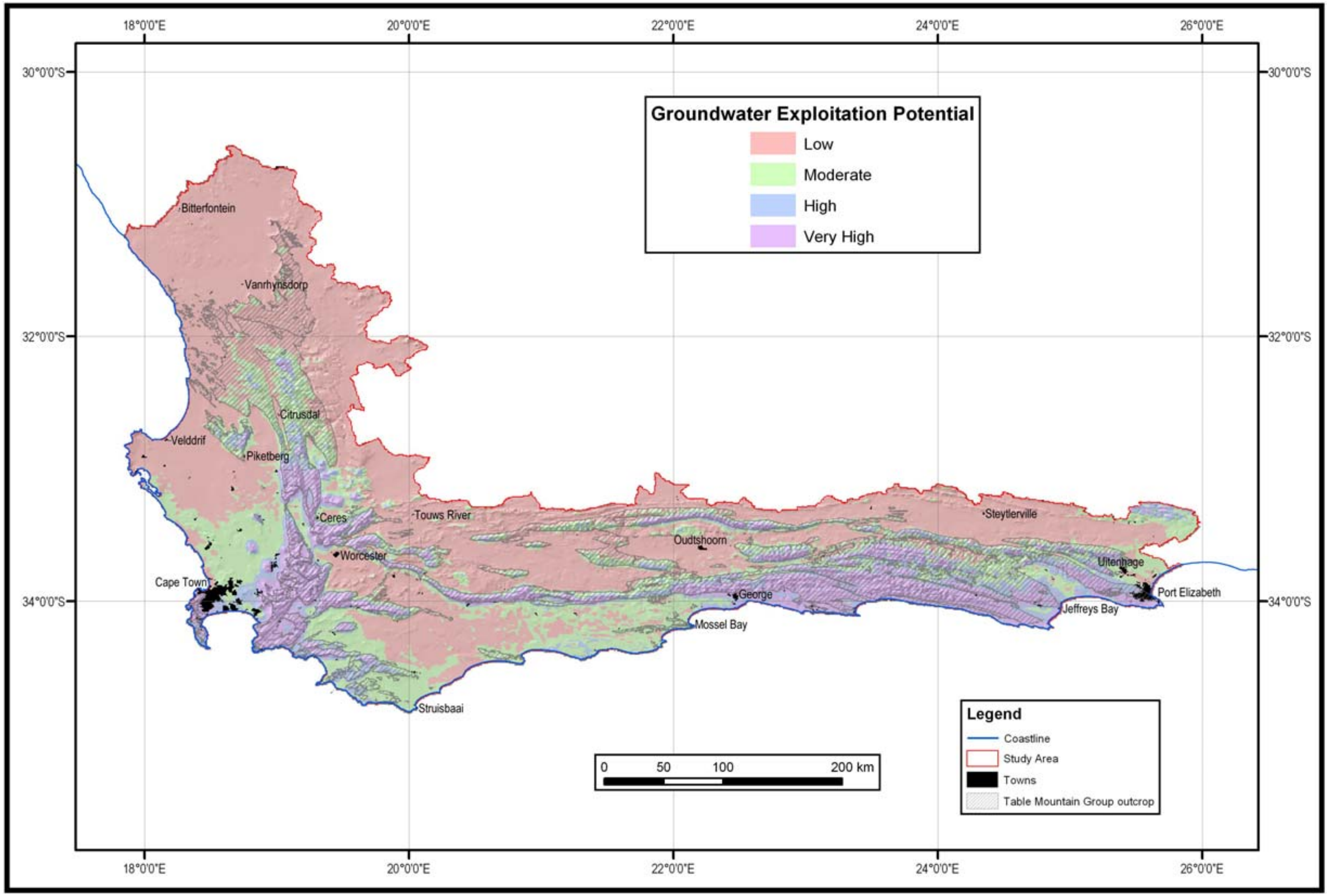
From the resulting exploitation map it is evident that large areas of high potential for large-scale abstraction exist to the east of Cape Town and extending further north toward Citrusdal in the mountainous regions, coinciding with the occurrence of Table Mountain Group rocks. This area is being explored in a current project running parallel with this project and forming an integral part of the future research is the City of Cape Town's Feasibility Study and Pilot Project investigating the TMG Aquifer for bulk water supply. This project started in mid-2002. Seven provisional target zones were identified (Ninham Shand-Umvoto, 2002) in the Wemmershoek, Franschhoek, Villiersdorp and Voëlvlei areas. A pilot wellfield will be established in the most promising area to test borehole siting, drilling, construction and operation techniques and abstraction scenarios. Also evident from the map is the occurrence of the largely untapped groundwater resources between George and Port Elizabeth.

In general, production boreholes sited in groundwater units with higher rates of rainfall recharge should be able to sustain higher abstraction rates. However, it may not always be possible to find suitable drilling targets to actually site production boreholes capable of delivering the required yields. It is therefore important to also consider the potential for locating, siting and obtaining a successful borehole – which is referred to as the groundwater exploration potential.

Table 12: Summary of Effective Annual Recharge from Rainfall for Study Area.

Description	Value
Mean Recharge (x 10^6 m^3/yr)	3 770
Recharge Factor (%)	6.4%
Upper recharge limit (x 10^6 m^3/yr)	4 746
Lower recharge limit (x 10^6 m^3/yr)	2 794


Harvest Potential (DWAF)
(m³/a/km²)
Mean Annual Effective Recharge from Rainfall
< 20,000
20,000 - 40,000
40,000 - 60,000
> 60,000
Legend
Coastline
Towns
Study Area
0 50 100 200 km
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
30°0'0"S
32°0'0"S
34°0'0"S
Cape Town
Port Elizabeth
Mossel Bay
Plettenberg Bay
Jeffreys Bay
Oudtshoorn
Saldanha
Struisbaai



18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
30°0'0"S
32°0'0"S
34°0'0"S
Groundwater Exploitation Potential
Low
Moderate
High
Very High
Bitterfontein
Vanrhynsdorp
Citrusdal
Velddrif
Piketberg
Ceres
Touws River
Worcester
Cape Town
Oudtshoorn
Steytlerville
Uitenhage
Port Elizabeth
Jeffreys Bay
George
Mossel Bay
Struisbaai
0 50 100 200 km
Legend
Coastline
Study Area
Towns
Table Mountain Group outcrop

5.3. EXPLORATION POTENTIAL

The groundwater exploration potential provides a qualitative indication (i.e. low, moderate, high) of the potential for siting and drilling of successful production boreholes. The higher the rating of a particular area, the greater the anticipated immediate yield of an exploration borehole. The groundwater exploration potential is dependent on the following parameters:

Terrain Accessibility – it may be assumed that areas with a percentage slope in excess of 15% would be difficult to traverse with 4x4 vehicles and inaccessible, without considerable road building, to drilling-rigs.

The influence of lithology, either positive or negative, on the potential yield of boreholes needs to be considered using a weighting factor i.e. a factor greater than one would increase the probability of drilling a successful borehole and vice versa. This factor should be based on the anticipated regional hydraulic characteristics of a particular lithostratigraphic sequence.

In order to assess the relative availability of drilling-targets within a site-specific study area, the structural density and expected water-bearing potential of various lineaments should be taken into account using a structural weighting factor.

According to Vegter (1995) the extent to which hard rock formations act as aquifers, or the prospect of obtaining a supply from them, may be established by an analysis of the yield distribution of an adequate number of randomly spaced boreholes. In partial emulation of Struckmeier's concept Vegter and Seymour (1995) produced the Borehole Prospects Map (**Figure 10**). The accessibility and exploitability maps, each of which was compiled separately, were combined to generate the Borehole Prospects Map.

Vegter and Seymour (1995) use a matrix to rate the probability of a successful borehole i.e. yielding > 2ℓ/s (exploitability) against the probability of a borehole success (accessibility). The map is depicted by means of a matrix of six colours each of three shades. The shades are indicative of the probability of drilling a successful borehole i.e. a borehole yielding at least 0.1ℓ/s. The dark shades imply that of every 10 holes drilled, 6 or more will yield at least 0.1ℓ/s i.e. a success rate of > 60%. The intermediate shades indicate a success rate of between 40% and 60% while the pale shades represent success rates of < 40%. The six colours ranging from red to purple indicate the probability that a successful borehole may have a yield > 2.0ℓ/s. For the purpose of presenting the exploration potential for the development of large-scale abstraction schemes the matrix has been simplified into a 3X3 matrix, which was further simplified to show the qualitative rating (**Table 13**) of the area in terms of the probability of drilling high yielding production boreholes with a high success rate (**Figure 11**).

The probability is based on statistical analysis of results on drilling sites that were not selected scientifically. According to Vegter (1995) these statistics are a better reflection of the overall water-bearing properties than statistics of drilling results on scientifically selected sites since scientific siting tends to rule out areas where the chances of striking water would be poorer.

The exploration map is not an indication of the magnitude of the groundwater resource i.e. groundwater availability, volume of water held in storage nor of its replenishment. It is however, an indication of the measure of ease or difficulty with which groundwater may be encountered by drilling.

The resultiing map shows that approximately 58% of the study area has a high to very high probability of drilling high yielding production boreholes with a high success rate. This area encompasses rocks of the Cape Supergroup extending from north of Citrusdal to Worcester and eastward towards George. Only 19% of the area favours a moderate probability of drilling high yielding production boreholes with a high success rate, while 23% of the area favours a low to very low probability of drilling a high yielding production borehole with a high success rate. The moderate areas are mainly areas comprising Cenozoic deposits, while the low to very low probability areas include outcrops of the Cape Granite Suite and of the Uitenhage and Suurberg Groups.

The borehole data from the Department of Water Affairs National Groundwater Database (**Figure 12**) was statistically analysed to verify the exploration potential. The result of this analysis is presented in **Table 14**. Areas that have been classified as high to very high have higher yields than areas classed as very low to low.

Table 13: Matrix showing Vegter and Seymour's (1995) borehole prospects and the simplification of the matrix to produce a qualitative rating

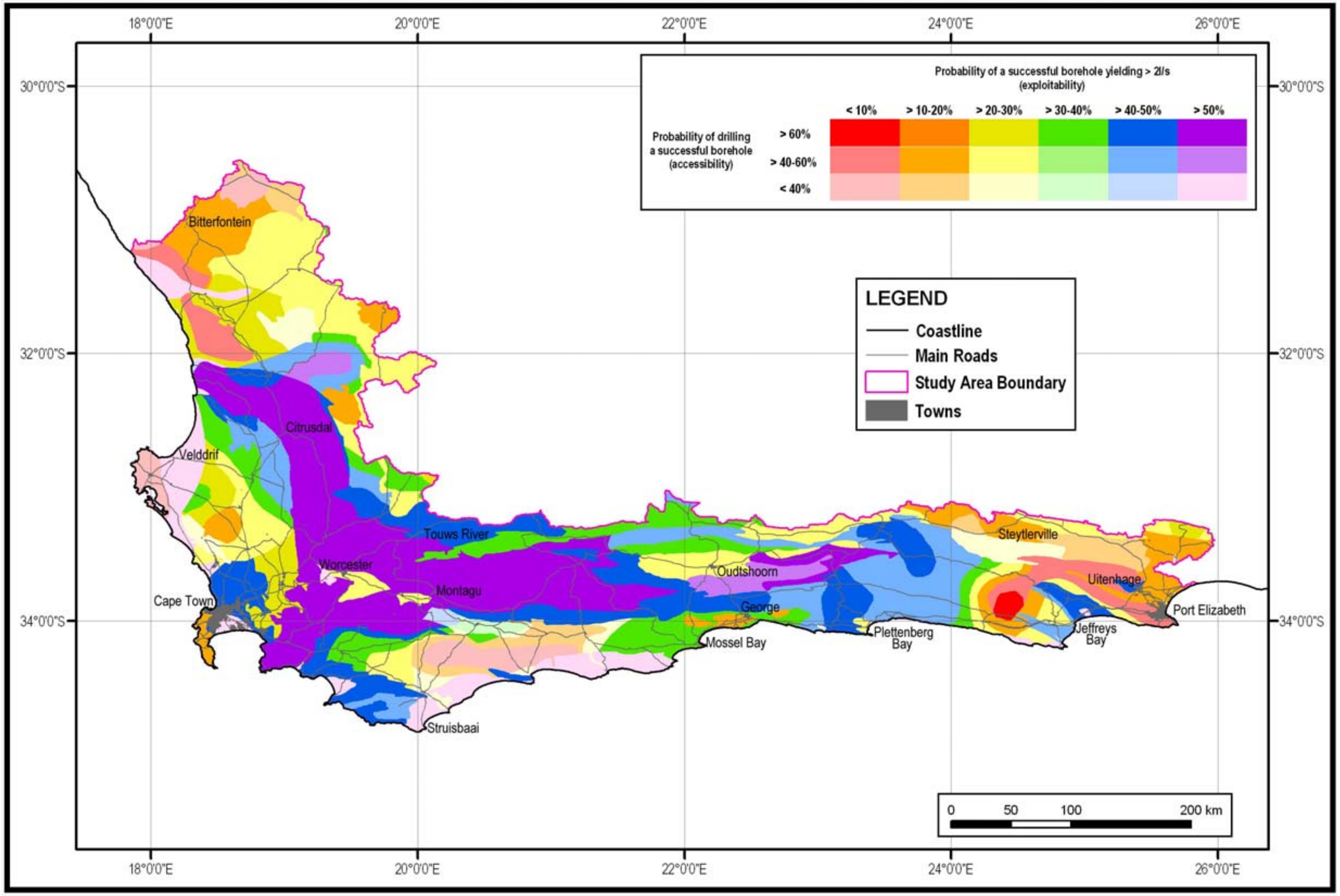
			PROBABILITY OF BOREHOLE SUCCESS YIELDING > 2ℓ/s (EXPLOITABILITY)					
			< 10%	10 – 20%	20 – 30%	30 – 40%	40 – 50%	> 50%
			red	orange	yellow	green	blue	purple
BOREHOLE SUCCESS PROBABILITY (ACCESSIBILITY)	> 60%	dark	1	1	4	4	7	7
	40 – 60%	medium	2	2	5	5	8	8
	< 40%	pale	3	3	6	6	9	9

		PROBABILITY OF BOREHOLE SUCCESS YIELDING > 2ℓ/s (EXPLOITABILITY)		
		< 20%	20 – 40%	> 40%
BOREHOLE SUCCESS PROBABILITY (ACCESSIBILITY)	< 40%	**1** (1)	**2** (4)	**3** (7)
	40 – 60%	**2** (2)	**3** (5)	**4** (8)
	> 60%	**3** (3)	**4** (6)	**5** (9)

1. Very Low
2. Low
3. Moderate
4. High
5. Very High

Table 14: Statistical Analysis of the boreholes of the National Groundwater Database, DWAF.

Exploration Potential Rate	No. of Boreholes	Minimum Yield (l/s)	Maximum Yield (l/s)	Median (l/s)	Average Yield (l/s)	Standard Deviation
Very Low	573	0.01	45	0.38	2.13	4.70
Low	1823	0.01	244	0.45	1.79	7.27
Moderate	1799	0.01	142	1.00	3.23	6.56
High	2318	0.01	804	1.30	5.41	25.88
Very High	3052	0.01	705	2.70	5.79	19.60



18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
30°0'0"S
32°0'0"S
34°0'0"S
Probability of a successful borehole yielding > 2l/s (exploitability)
< 10%
> 10-20%
> 20-30%
> 30-40%
> 40-50%
> 50%
Probability of drilling a successful borehole (accessibility)
> 60%
> 40-60%
< 40%
LEGEND
Coastline
Main Roads
Study Area Boundary
Towns
Bitterfontein
Citrusdal
Velddrif
Touws River
Worcester
Montagu
Cape Town
Oudtshoorn
George
Mossel Bay
Plettenberg Bay
Steytlerville
Uitenhage
Port Elizabeth
Jeffreys Bay
Struisbaai
0
50
100
200 km

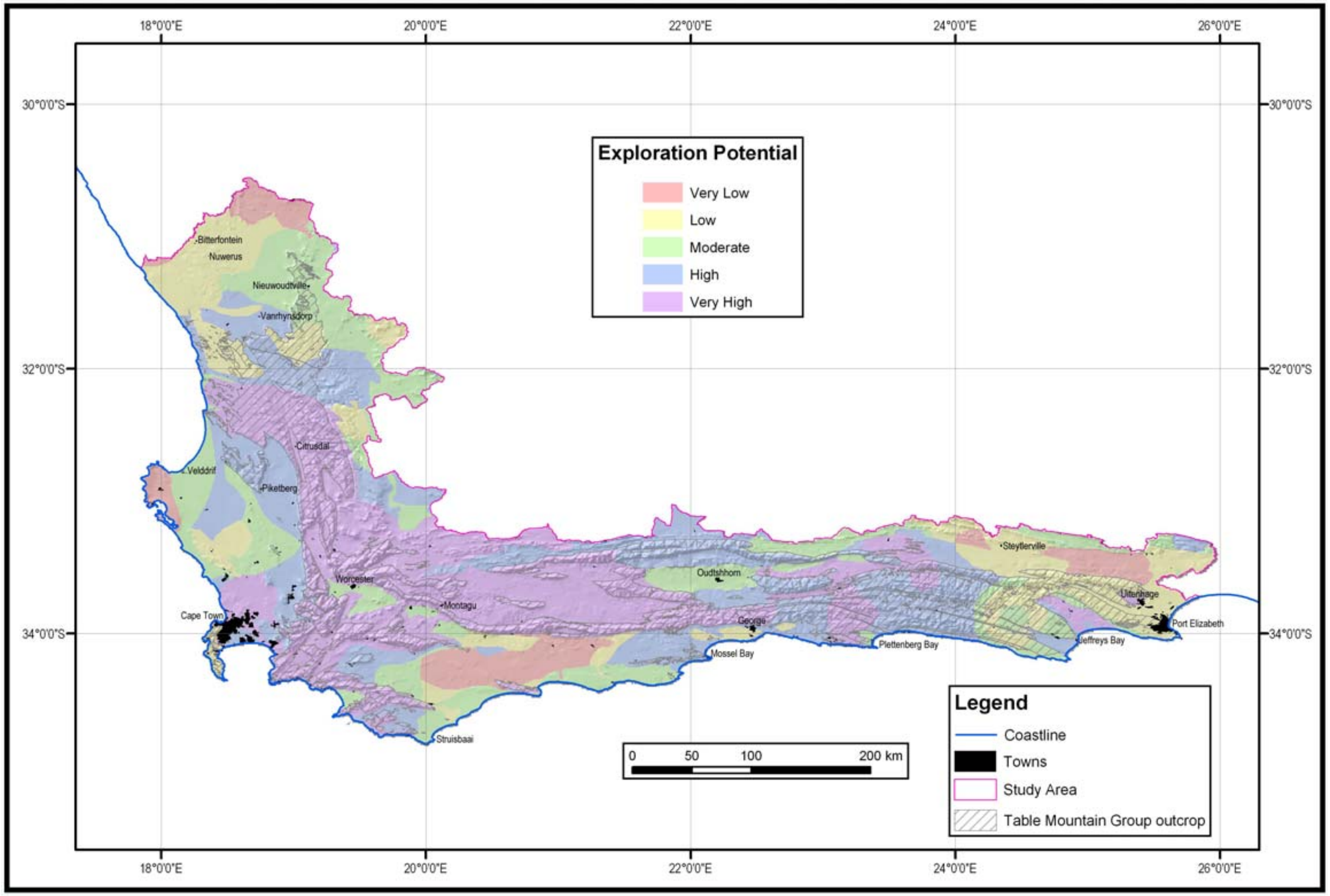


Figure 11: Exploration Potential map showing the qualitative rating of the study area in terms of the probability of drilling high yielding production boreholes with a high success rate.

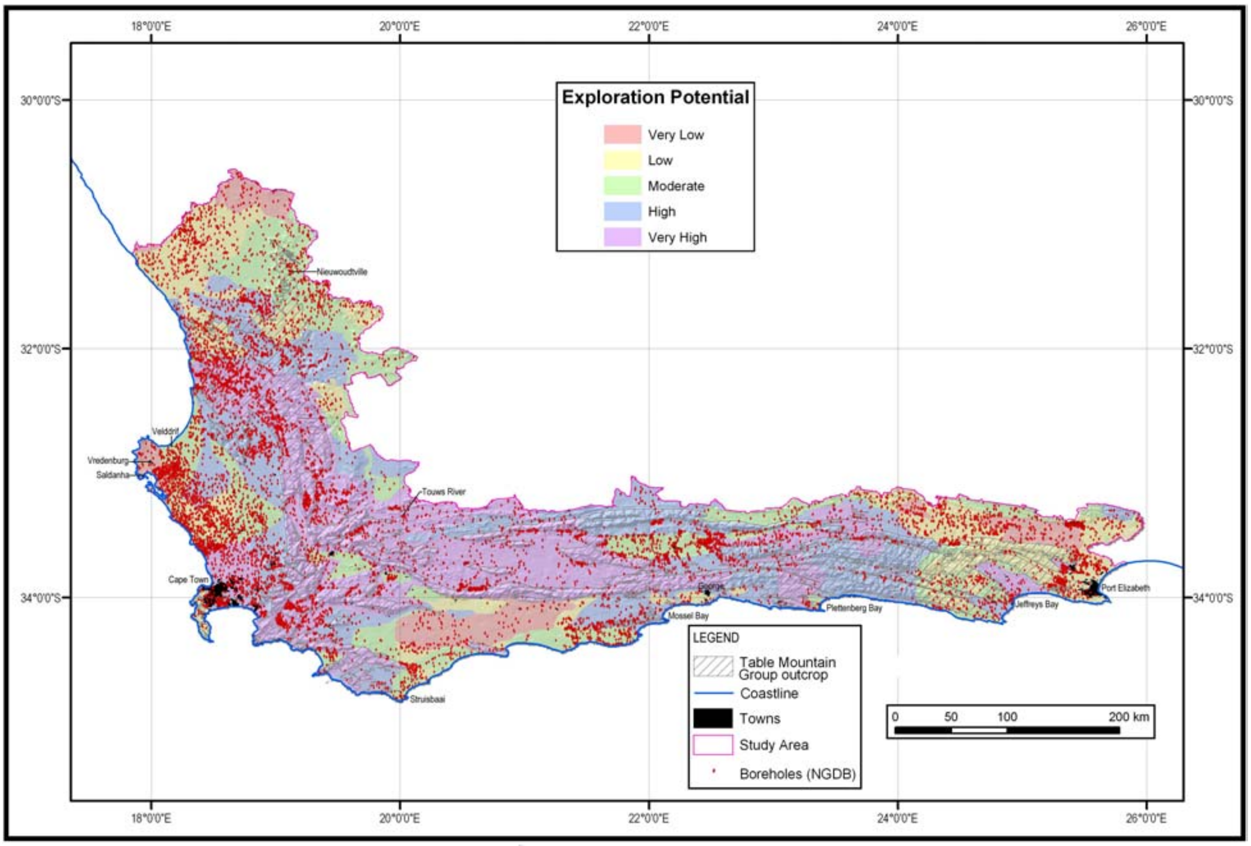


Figure 12: Distribution of boreholes within the study area

5.4. DEVELOPMENT POTENTIAL

The ultimate aim of this map is to indicate areas where large-scale abstraction of groundwater should receive high priority considering all the available factors. The development potential map was generated by 'geospatially' intersecting the exploitation and exploration maps, each of which was compiled separately as discussed previously. The map was reclassified to qualitatively rank the potential of an area to sustain large-scale abstraction as follows:

- Low
- Moderate
- High
- Very High

Only 14% of the study area has a very high groundwater development potential rating while 34% of the study area favours a high development potential rating. The areas with a very high rating consist of rocks of the Table Mountain Group only whereas the high category encompasses rocks of all the groups of the Cape Supergroup. The areas of moderate rating cover all the geological orders while the low rated areas are comprised of rocks of the Namibian Erathem. A strong geological influence on the groundwater development potential is evident.

Although only 14% of the area favours a very high rating it supplies most of the mean recharge per annum (**Table 15**) for the study area. The mean annual effective rainfall ranges from 500mm/a to values exceeding 1500mm/a (**Figure 3**) for the most topographically elevated areas. According to the groundwater recharge map (**Figure 8**) the mean annual effective recharge from rainfall exceeds 50mm/a reaching a maximum of 1500mm/a. The areas of very low development potential accounts for 17% of the total area while the moderate rating accounts for 35%. Although the area of low to moderate development potential constitutes the greater part of the study area, it only adds a minimal amount of mean annual recharge.

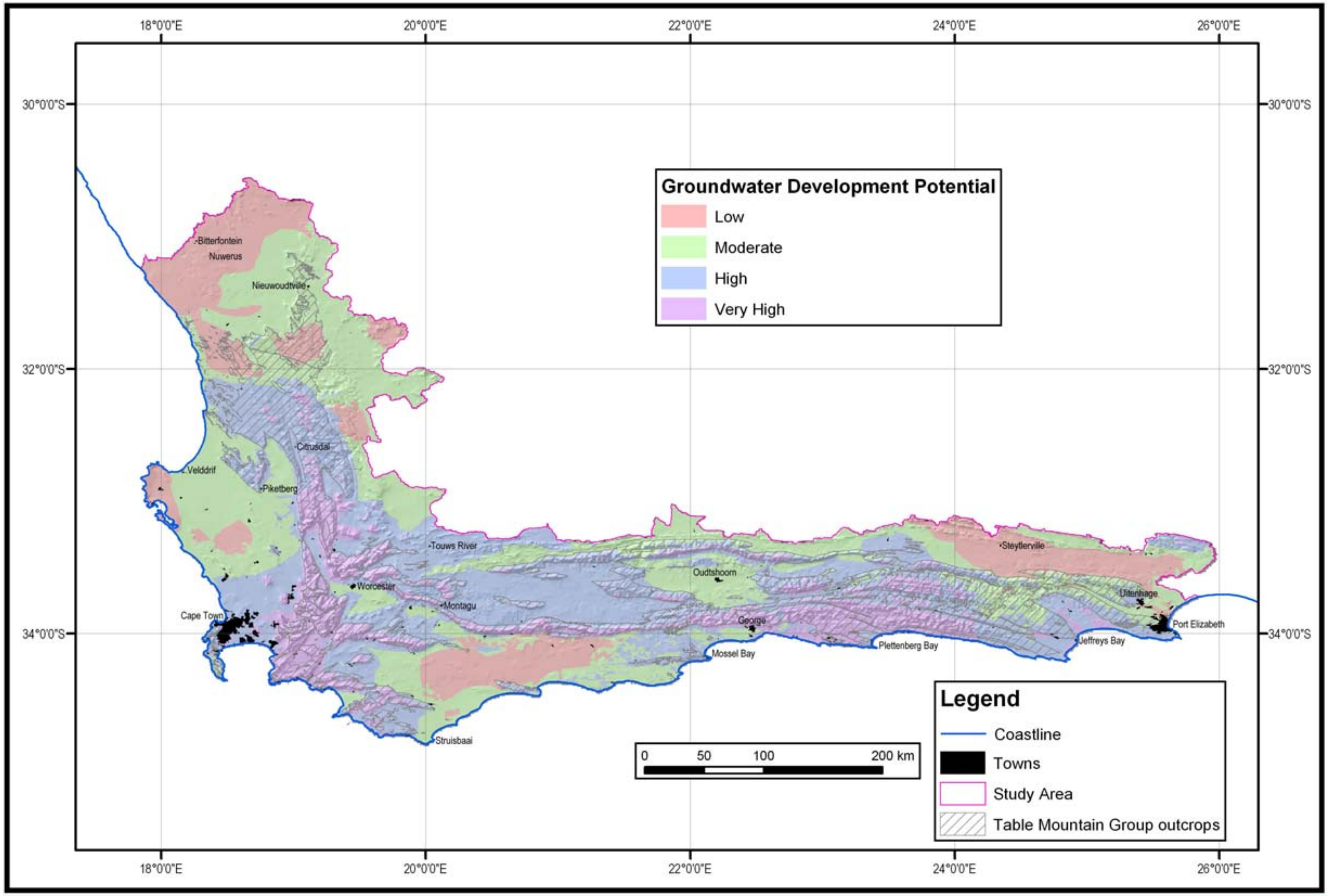
Table 15: Summary of Effective Annual Recharge from Rainfall for the various categories of development potential.

Description	1	2	3	4
	Low	**Moderate**	**High**	**Very High**
Mean Recharge (x 10^6 m^3/yr)	192	579	1119	1880
Recharge Factor (%)	3.2%	3.9%	5.5%	11.4%
Upper recharge limit (x 10^6 m^3/yr)	280	835	1573	2430
Lower recharge limit (x 10^6 m^3/yr)	137	422	855	1600

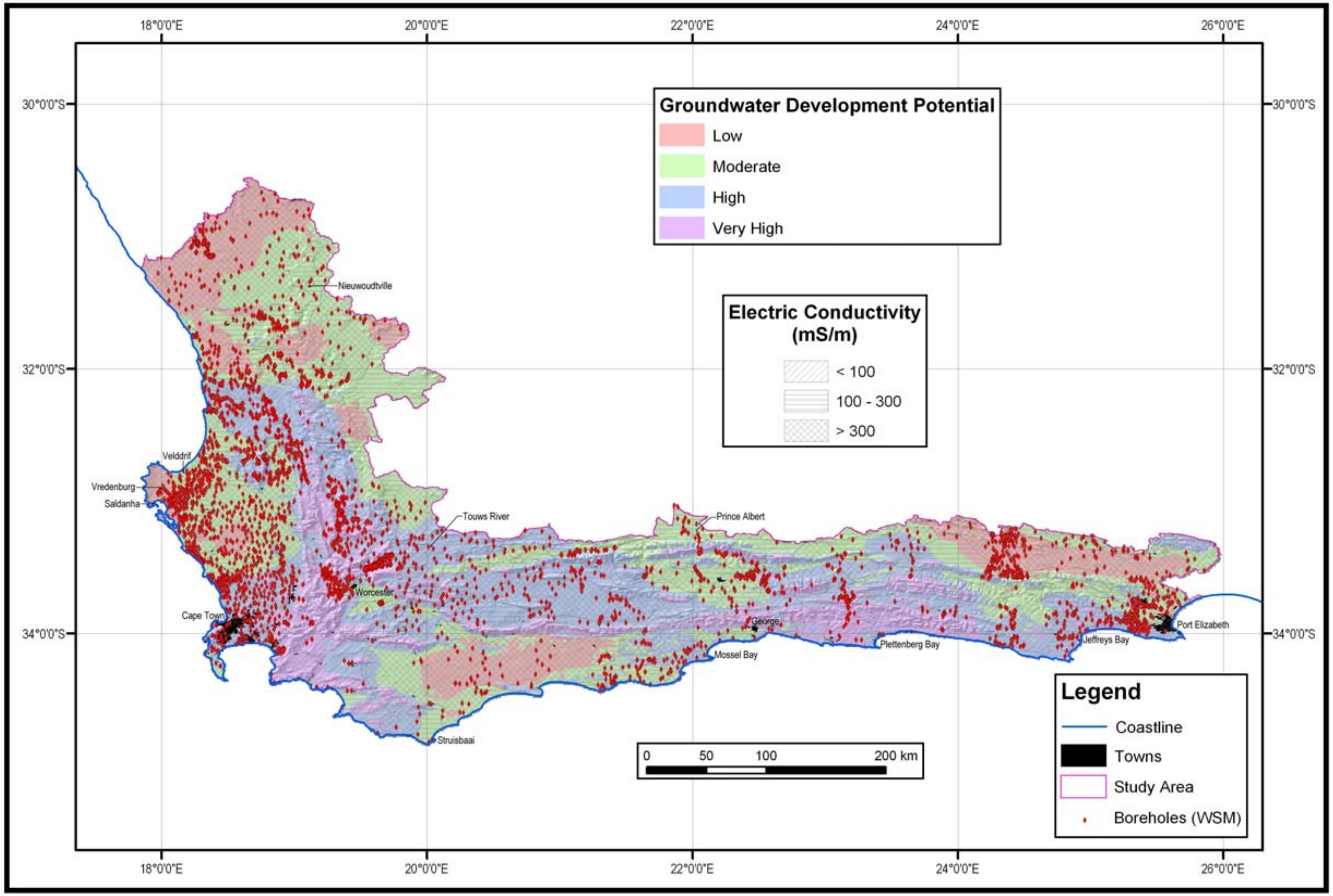
The TMG Aquifers generally yield groundwater of high quality, i.e. it has a very low salinity. The electrical conductivity rarely exceeds 100 mS/m with a median value in the 20- to 50mS/m range (Smart *et al*, 2002). The recommended limit for human consumption is 70 mS/m with most of the TMG areas conforming to this. It is well within the maximum acceptable limit of 300 mS/m for domestic supply. The Electrical Conductivity (Ec) (mS/m) of the study area was overlain on the groundwater development potential map (**Figure 14**). Although a particular area may favour a high to very high development potential, the quality of the water may be of such a nature that development for human consumption would not be considered. **Table 16** indicates that there are areas in the high to very high zones that experience a maximum electrical conductivity in excess of the maximum allowable limit of 300 mS/m for town supply.

Table 16: Statistical Analysis of the Electrical Conductivity for the various Development Potential Ratings.

Development Potential Rate	No. of Boreholes	Minimum Ec (mS/m)	Maximum Ec (mS/m)	Average Ec (mS/m)	Standard Deviation	Median (mS/m)
Low	1088	3	7076	526	507	400
Moderate	2307	2	14994	298	478	171
High	2039	1	3830	139	203	79
Very High	432	1.8	439	54	71	24



18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
30°0'0"S
32°0'0"S
34°0'0"S
Groundwater Development Potential
Low
Moderate
High
Very High
Bitterfontein
Nuwerus
Nieuwoudtville
Citrusdal
Velddrif
Piketberg
Touws River
Worcester
Montagu
Cape Town
Oudtshoorn
George
Mossel Bay
Plettenberg Bay
Steytlerville
Uitenhage
Port Elizabeth
Jeffreys Bay
Struisbaai
0
50
100
200 km
Legend
Coastline
Towns
Study Area
Table Mountain Group outcrops


Groundwater Development Potential
Low
Moderate
High
Very High
Electric Conductivity (mS/m)
< 100
100 - 300
> 300
Legend
Coastline
Towns
Study Area
Boreholes (WSM)
0 50 100 200 km
Nieuwoudtville
Velddrif
Vredenburg
Saldanha
Touws River
Prince Albert
Worcester
Cape Town
George
Mossel Bay
Plettenberg Bay
Jeffreys Bay
Port Elizabeth
Struisbaai
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
30°0'0"S
32°0'0"S
34°0'0"S

CHAPTER SIX

6. IDENTIFICATION OF ECOLOGICALLY IMPORTANT ZONES

6.1. INTRODUCTION

This section provides an analysis of ecological importance at a regional level. This scale is too small to permit the identification and rating of specific groundwater dependent ecosystems for ecological importance but it does establish the significance of broad ecosystems. In this it is essential that analysis take into consideration the nature and functioning of ecosystems across groundwater dependent ecosystem boundaries.

6.2. DATASET ACQUISITIONS

A number of electronic datasets were acquired for the ecological study, namely:

- *Vegetation types*, derived from the new vegetation map of South Africa (National Botanical Institute – Mucina and Rutherford, in prep.)
- *Broad Habitat Units* (BHU's) and *Irreplaceability Values* used in the Cape Action for People and the Environment (C.A.P.E.) (Cape Planning Unit (CPU), Western Cape Nature Conservation Board)
- *Transformed areas* – those areas transformed by agriculture, urbanisation and woody alien infestation (CPU). Some 26 % of the CFR has been transformed by these factors (Cowling *et al*., 1999)
- *Ecological processes and corridors*: those areas where special ecological processes and corridor linkages were important (CPU)
- Conservation areas (CPU)
-

6.3. DETERMINATION OF CRITERIA AND IMPORTANCE RATINGS FOR ECOLOGICAL IMPORTANCE

In order to rate areas for ecological importance, subjective ratings were provided for a number of criteria (**Table 17**) relating to the general state of the environment. These were then inserted into a simple model and added to give a rating for each VT.

Table 17: Summary of criteria and importance ratings for ecological importance.

CRITERIA	DESCRIPTION	RATINGS			
		0	1	2	3
Size susceptibility	Size of each polygon within each vegetation unit (VU). The higher the value, the more robust and secure the vegetation type.	-	> 10000ha	1000 - 10000ha	< 1000ha
Transformation	Area of each polygon/vegetation type transformed (urbanisation, agriculture, alien infestation, plantations). The more transformed the vegetation type, the more susceptible to impact.	-	< 10%	10 - 50%	> 50%
Edge Effect	Whether a polygon is intersected or abutted by an area of transformation. The greater the degree effect, the greater the potential impact.	No intersection	< 10%	10 - 50%	> 50%
Natural Fragmentation	The greater the natural fragmentation, the greater the potential impacts.	None	1 - 5 polygons	6 - 50 polygons	> 50 polygons
Artificial Fragmentation	Human impact. The greater the artificial fragmentation, the greater the potential impacts.	None	1 - 5 polygons	6 - 50 polygons	> 50 polygons
Processes/ Gradients	This was linked with the vertebrates layer and reflects processes	None	-	-	Process

The presence of a conservation area confers greater security for a particular area. Although such an area usually, but not always, reflects the presence of ecological importance, it is not a measure of ecological importance *per se*. Conservation area was therefore omitted from the analysis, but can be used as an adjunct factor, for example where areas of high abstraction potential and ecological importance occur.

A model for ecological importance was developed by intersecting the above criteria with those of the new vegetation types of South Africa layer (Mucina & Rutherford, in prep.), and adding the net values for each polygon representing all or part of a vegetation type (**Figure 15**). All values were unweighted, except for a 2X weighting given for fragmentation through human impact. Highest values indicate areas of greatest ecological significance. Values were divided into 5 classes using a 20% range for each (**Table 18**).

Table 18: Classes and values derived from the analysis of criteria for ecological importance

Qualitative Rating	Values and class divisions (no.)	Ecological importance class (%) (to nearest 20% division)
Very Low	0 – 5	0 – 20%
Low	6 – 10	>20 – 40%
Moderate	11 – 14	>40 – 60%
High	12 – 19	>60 – 80%
Very High	20 – 24	>80 – 100%

The irreplaceability values developed for the C.A.P.E. project (Cowling *et al*., 1999) were used to check the importance ratings obtained in the study. Any major deviation (lower or higher) in value would require evaluation and amendment if necessary.

6.4. DESCRIPTION OF AREAS OF HIGH ECOLOGICAL IMPORTANCE

Given the ecological complexity of the CFR, areas of highest ecological importance (>60%) were identified and classified into a number of subregions (**Table 19**) (Low, 2003). Geology follows that of the 1:250 000 series for South Africa (Geological Survey, various years), whilst vegetation type nomenclature follows that of Mucina & Rutherford (in prep.). In each subregion, only the dominant geology and vegetation type is presented. Although several of the subregions do not occur on the TMG Aquifer System, they nevertheless are regarded as part of the study area due to linkages between different geological substrates within particular quaternary catchments.

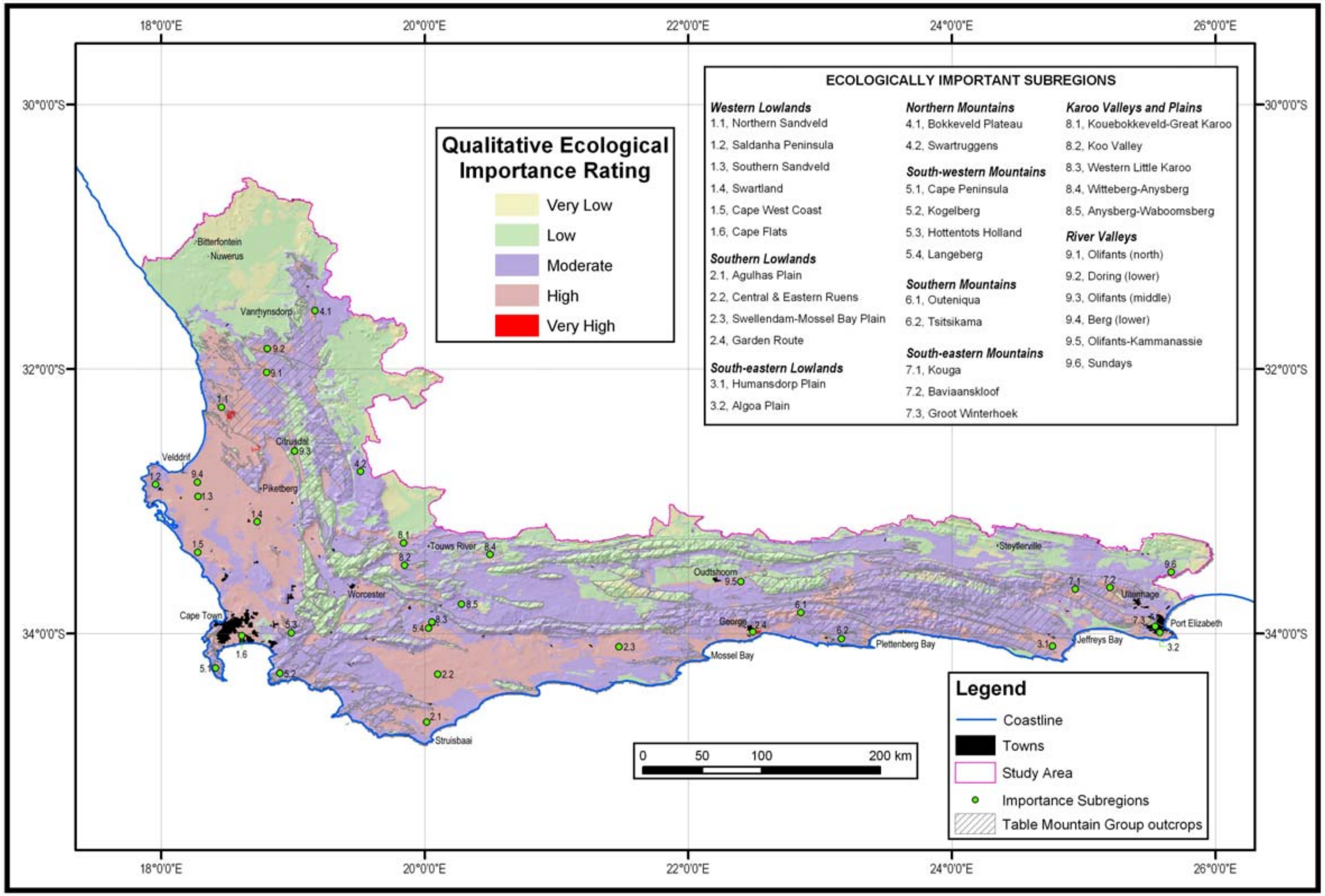

Qualitative Ecological Importance Rating
Very Low
Low
Moderate
High
Very High
ECOLOGICALLY IMPORTANT SUBREGIONS
Western Lowlands
1.1, Northern Sandveld
1.2, Saldanha Peninsula
1.3, Southern Sandveld
1.4, Swartland
1.5, Cape West Coast
1.6, Cape Flats
Southern Lowlands
2.1, Agulhas Plain
2.2, Central & Eastern Ruens
2.3, Swellendam-Mossel Bay Plain
2.4, Garden Route
South-eastern Lowlands
3.1, Humansdorp Plain
3.2, Algoa Plain
Northern Mountains
4.1, Bokkeveld Plateau
4.2, Swartruggens
South-western Mountains
5.1, Cape Peninsula
5.2, Kogelberg
5.3, Hottentots Holland
5.4, Langeberg
Southern Mountains
6.1, Outeniqua
6.2, Tsitsikama
South-eastern Mountains
7.1, Kouga
7.2, Baviaanskloof
7.3, Groot Winterhoek
Karoo Valleys and Plains
8.1, Kouebokkeveld-Great Karoo
8.2, Koo Valley
8.3, Western Little Karoo
8.4, Witteberg-Anysberg
8.5, Anysberg-Waboomsberg
River Valleys
9.1, Olifants (north)
9.2, Doring (lower)
9.3, Olifants (middle)
9.4, Berg (lower)
9.5, Olifants-Kammanassie
9.6, Sundays
Legend
Coastline
Towns
Study Area
Importance Subregions
Table Mountain Group outcrops
0 50 100 200 km
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
30°0'0"S
32°0'0"S
34°0'0"S
Bitterfontein
Nuwerus
Vanrhynsdorp
Citrusdal
Velddrif
Piketberg
Touws River
Worcester
Cape Town
Oudtshoorn
Steytlerville
Uitenhage
Port Elizabeth
George
Mossel Bay
Plettenberg Bay
Jeffreys Bay
Struisbaai

Table 19: Ecologically important subregions occurring in the study area.

REGION NO.	SUBREGION	MAIN GEOLOGICAL TYPE	TMG?
Cape Lowlands			
1. Western lowlands			
1.1	Northern Sandveld	Springfontyn/Piekenierskloof	Yes
1.2	Saldanha Peninsula	Cape Granite/Langebaan	No
1.3	Southern Sandveld	Springfontyn/Cape Granite	No
1.4	Swartland	Malmesbury	No
1.5	Cape West Coast	Springfontyn/Langebaan/Witzand	No
1.6	Cape Flats	Springfontyn/Witzand	No
2. Southern lowlands			
2.1	Agulhas Coastal Plain	Bredasdorp	No
2.2	Central & Eastern Ruens	Bokkeveld	No
2.3	Swellendam-Mossel Bay Plain	Bokkeveld/Bredasdorp	No
2.4	Garden Route	Peninsula/Tchando/Kaaimans	Yes
3. South-eastern lowlands			
3.1	Humansdorp Plain	Bokkeveld/Peninsula	Yes
3.2	Algoa Plain	Peninsula/Nanaga/Witzand	Yes
Mountains			
4. Northern mountains			
4.1	Bokkeveld Plateau	Peninsula	Yes
4.2	Swartruggens	Witteberg	No
5. South-western mountains			
5.1	Cape Peninsula	Peninsula	Yes
5.2	Kogelberg	Peninsula/Nardouw	Yes
5.3	Hottentots Holland	Peninsula/Nardouw	Yes
5.4	Hex-Kwadouwsberg	Peninsula/Nardouw/Bokkeveld	Yes
6. Southern mountains			
6.1	Outeniqua	Peninsula/Tchando/Kouga	Yes
6.2	Tsitsikama	Peninsula	Yes
7. South-eastern mountains			
7.1	Kouga	Peninsula/Tchando/Kouga	Yes
7.2	Baviaanskloof	Peninsula/Goudini	Yes
7.3	Groot Winterhoek	Peninsula/Goudini/Skurweberg	Yes
Karoo			
8.1	Kouebokkeveld-Great Karoo	Bokkeveld	No
8.2	Koo Valley	Bokkeveld	No
8.3	Western Little Karoo	Bokkeveld	No
8.4	Anysberg-Waboomsberg	Bokkeveld	No
8.5	Witteberg-Anysberg	Witteberg	No
River Valleys			
9.1	Olifants (north)	Tertiary/Quaternary	No
9.2	Doring	Skurweberg	Yes
9.3	Olifants (middle)	Quaternary	
9.4	Berg (upper)	Malmesbury/Bredasdorp	No
9.5	Olifants-Kammanassie (south)	Gydo/Quaternary	No
9.6	Sundays	Quaternary	No

6.4.1 Coastal Lowlands

Western Lowlands

A broad band of ecologically important areas stretches from the Cape Flats in the south to the Sandveld in the north. This region has suffered much transformation from urbanisation and agriculture, and is highly fragmented, one of the reasons for its high ecological rating.

In the **Northern Sandveld** (1.1)[1], geology is chiefly neutral to acid sands of the Springfontyn Formation, supporting Leipoldtville Sand Fynbos (Leipoldtville Sand Plain Fynbos). This is a key area that has received a much bigger rating than the CAPE Irreplaceability Layer (CIL). It represents the northwestern limit of the Piekenierskloof Formation and is home to a variety of endemic vegetation types and habitats, as well as several endemic and rare plant species. The area is already severely impacted by groundwater abstraction (Conrad, 2003; Low & Pond, 2003).

The **Saldanha Peninsula** (1.2) is a mosaic of Cape Granite and calcrete and limestone of the Langebaan Formation. The vegetation ranges from Saldanha Granite Strandveld (= Renosterveld in this case (Low & Pond, pers.obs.) to Saldanha Calcrete Flats Strandveld, Saldanha Limestone Strandveld and Langebaan Dune Strandveld (Langebaan Fynbos/Thicket mosaic). The area is rated highly for its concentration of both rare and endemic species (Boucher & Rode, 1997; Low, 2003), and restricted vegetation types (Mucina & Rutherford, in prep.). Although impacted by agriculture, much natural vegetation remains. The CIL rates this area as of low significance, possibly due to poor or inadequate data that indicated the Saldanha Peninsula to be highly transformed (Cowling *et al*., 1999).

In the **Southern Sandveld** (1.3), the Springfontyn Formation is still dominant with Hopefield Sand Fynbos (Hopefield Sand Plain Fynbos) the main vegetation type. As with the northern Sandveld, the area is heavily abstracted for

[1] Refers to localities in **Figure 15**

groundwater. Again there are a number of rare species and habitats, and the vegetation type is fairly restricted in distribution. The high rating concurs with that of the CIL.

Malmesbury shale is the dominant geology in the **Swartland** (1.4), with vegetation comprising Swartland Shale Renosterveld (Swartland Coast Renosterveld). The Swartland represents one of the most transformed areas in the CFR (Cowling *et al*., 1999), with most natural vegetation having been removed for agriculture. The highly fragmented nature of a landscape containing much species and habitat rarity gives the subregion its high value. The CIL also rates high for the subregion.

Sands of the Springfontyn and Witzand formations are dominant on the **Cape West Coast** (1.5) and support three broad vegetation types: Langebaan Dune Strandveld, Hopefield sand Fynbos and Swartland Granite Renosterveld (Langebaan Fynbos/Thicket mosaic, Hopefield Sand Plain Fynbos and Swartland Coast Renosterveld). Like the Swartland, much of the Cape West Coast has been transformed by agriculture and alien vegetation (Wood *et al*., 1994; Cowling *et al*., 1999; Cowling & Heijnis, 2001. It receives a high importance for the presence of rare habitats and species, as well as marked fragmentation, concurring with the CIL rating.

The **Cape Flats** subregion (1.6) is dominated by calcareous sands of the Witzand and acid sands of the Springfontyn Formations. Vegetation is Cape Flats Dune Strandveld and Cape Flats Sand Fynbos, respectively (Cape Flats Fynbos/Thicket mosaic and Blackheath Sand Plain Fynbos). Highly urbanised, little is left of this subregion's natural vegetation. Fragmentation is marked with ongoing impacts from urbanisation, agriculture and alien vegetation (McDowell *et al*. 1991; Wood *et al*., 1994). The area has an extremely high concentration of endemic and rare species (Low *et al*., submitted), with fragmentation being extremely marked. Both this study and the CIL give high rankings for importance.

Southern Lowlands

Like its western counterpart, the southern lowlands have seen major transformation, chiefly from agriculture. Fragmentation is thus marked and, coupled with a high proportion of rare and endemic species, this area is of ecological importance.

The **Agulhas Coastal Plain** (2.1) is dominated by limestones and sands of the Bredasdorp Formation. Vegetation is predominantly Agulhas Dune Strandveld and Agulhas Limestone (Agulhas Fynbos/Thicket mosaic and Hagelkraal Limestone Fynbos). The subregion is renowned for its great habitat and plant diversity (Cowling & Holmes, 1992), with many rare and endemic species. This rarity, coupled with marked transformation and impacts from alien vegetation confers upon the area both a high ecological importance as well as CIL rating.

The **Central and Eastern Ruens** (2.2) is underlain by Bokkeveld shales which, under the moderate rainfall for the subregion and, like its West Coast analogy, the Swartland, produces conditions conducive to colonisation by renosterveld. Central Ruens Renosterveld (Overberg Coast Renosterveld) dominates throughout the landscape. As with the Swartland this subregion has been heavily impacted and fragmented by farming activities (Kemper *et al*., 1999). High rarity and endemism in both species and habitats, together with marked fragmentation, produces a high ecological importance as well as CIL.

East of the Central & Eastern Ruens is found the **Swellendam-Mossel Bay Plain** (2.3). This is the eastern extension of the former subregion and comprises Mossel Bay Shale Renosterveld (Riversdale Coast Renosterveld) and Swellendam Silcrete Fynbos, largely found on Bokkeveld shale. Impacts from farming activity continue into this region resulting in great fragmentation and rarity. The area is regarded in the CIL as being highly irreplaceable, concurring with the high ecological importance found in this study.

Further to the east the **Garden Route** (2.4) represents a zone of great diversity. This is the site of the largest patch of Afromontane Forest in the CFR (Low & Rebelo, 1996) with the coastal vegetation dominated by Garden Route Granite

Fynbos on Cape Granite. The area forms an interesting interplay between coastal and inland mountains and is a crucial corridor along this coastline. Although not an equivalent, the dominant BHU is Knysna Afromontane Forest. This is one of the areas where the CIL rating is low to very low, compared with that of the current study.

South-Eastern Lowlands

Although farming activity shifts towards grazing in this region mainly due to increased grassiness under a summer rainfall regime, impacts are nevertheless high. Transformation is also evident although there is less clearing of land for agriculture.

The **Humansdorp Plain** (3.1) represents an area of marked diversity, rarity and endemism (Cowling *et al*., 1992). The subregion represents a meeting point of several floras, again with a marked coastal to inland mountain gradient, largely influenced by rainfall and substrate, here being dominated by the Bokkeveld Group. Typical VT's are Kouga Sandstone Fynbos, Tsitsikama Sandstone Fynbos and Humansdorp Shale Renosterveld. BHU's occurring in the area includes Humansdorp Grassy Fynbos and Kromme River Fynbos/Renosterveld Mosaic. The high ecological importance for this subregion is supported only in part by the CIL, where the coastal areas receive priority ranking.

In the extreme east of the CFR is found the **Algoa Plain** (3.2) where Algoa Dune Strandveld and Algoa Sandstone Fynbos predominate on recent coastal sands and Peninsula sandstone, respectively. BHU types include Alexandria Indian Ocean Forest and St Francis Fynbos/Thicket Mosaic. Much of the area has been impacted by urbanisation and related activities, giving it a high ecological importance. This largely concurs with the very high rating accorded by the CIL.

6.4.2 Mountains

The mountains of the CFR are far less impacted than the adjacent lowlands, suffering less from urbanisation and agriculture, but nevertheless subject to abstraction, alien vegetation and grazing pressures.

Northern Mountains

The **Bokkeveld Plateau** (4.1) is the northern-most point of the CFR and is the centre of a major ecotone (transition) between the West Coast and arid interior. Its narrowness makes it highly susceptible to impacts, with farming playing a key role. Vegetation is largely Bokkeveld Sandstone Fynbos (Nardouw Formation), flanked by Vanrhynsdorp Shale Renosterveld, Nieuwoudtville Shale Renosterveld and Hantam Karoo (Bokkeveld Mountain Fynbos Complex, Nieuwoudtville Inland Renosterveld and Western Mountain Vygieveld). Despite its high ranking in this study, the region in general is poorly rated in the CIL, where, apart from a few exception which are rated at >20%, it receives low priority.

The **Swartruggens** Mountains (4.2) lie to the south of the Bokkeveld Mountains. These represent the crucial divide between the well-watered inland plains and the dry Tankwa Karoo. The subregion forms the meeting point for two fynbos floras – Cederberg Sandstone Fynbos and Swartruggens Sandstone Fynbos - occurring on Peninsula/Nardouw and Witteberg Formations respectively, closely allied with the BHU Cederberg and Swartruggens Mountain Fynbos Complexes. Although the general region between the Bokkeveld and Swartruggens receives moderate to high ecological ranking, the CIL accords the subregion its lowest value (<20%).

South-western Mountains

The **Cape Peninsula** (5.1) is one of the highest centres of plant species diversity and endemism in the CFR (Simmons & Cowling, 1996) and yet, despite its protection under National Park status, nevertheless is severely threatened on its boundaries (Trinder-Smith *et al*., 1996). Its predominately sandstone composition (Peninsula Formation) provides the substrate for Peninsula Sandstone Fynbos (Cape Peninsula Mountain Fynbos). Its ecological importance is supported by the CIL, which rates the northern Peninsula as 100% irreplaceable.

To the east, the **Kogelberg** (5.2) mountain complex contains a not too dissimilar flora and vegetation, here termed Kogelberg Sandstone Fynbos (Kogelberg Mountain Fynbos Complex) (Nardouw and Peninsula Formations), abutted by Elgin Shale Fynbos (Elgin Shale Fynbos/Renosterveld) (Bokkeveld shale). As with the Peninsula, this is an area of great diversity, rarity and endemism. (Oliver *et al*., 1983) and therefore of great ecological importance, borne out in both this study as well as the CIL.

Situated just north of the Kogelberg is the **Hottentots Holland** mountain complex (5.3) with geological types by and large comprising the Peninsula Formation and Cape Granite. Its fynbos vegetation is similar to that of the Kogelberg (Kogelberg Sandstone Fynbos (Franschhoek Mountain Fynbos Complex)) but it is surrounded by the rare Boland Granite Fynbos (Boland Coast Renosterveld) and Elgin Shale Fynbos (Overberg Coast Renosterveld). Given its proximity to the Kogelberg, and its concomitant gradients in both soil type and rainfall, it is to be expected that species richness and endemism is also high, a fact confirmed by Oliver *et al*. (1983). Correspondingly both this study and that of the CIL rank this subregion highly for ecological importance and irreplaceability.

Southern mountains

The southern mountains stretch along the Langeberg to the Outeniqua and Tsitsikama ranges. Their uniqueness is underpinned by the presence of intermontane valleys, north-and south-facing slopes, and, on occasions, proximity to the sea. This is coupled with a marked coast to inland variation in rainfall patterns and juxtaposed sandstone and shale substrates. Here the vegetation becomes increasingly influenced by summer rainfall and subsequent changes in the respective floras.

The **Outeniqua** Mountains (6.1) form an inland range stretching between the Langeberg and Tsitsikama Mountains. Vegetation comprises North and South Outeniqua Sandstone Fynbos (Outeniqua Mountain Fynbos Complex). These ranges form important corridors for east-west moving species as well as a barrier to the hinterland floras. The differences in flora between the south- and north-facing slopes as well as the southern (fynbos/renosterveld) and northern (karoo) plains are equally abrupt (McDonald, 1993; McDonald, 1999). The high ecological importance rating for this subregion is not matched by the CIL, which attributes a very low value to the subregion.

Situated east of the Outeniquas, the **Tsitsikama** mountains (6.2) attract some of the highest rainfall for this coastline, hence providing suitable conditions for forest and wet fynbos growth. Vegetation is Tsitsikama Sandstone Fynbos (Tsitsikama Mountain Fynbos Complex) and is fairly intact given the poor soils (Peninsula and Nardouw Formations) underlying this subregion. It is, however, a region of high diversity, to a certain extent echoing the case of the Outeniqua range, but with a climate which is much less harsh and a higher rainfall. The CIL rating is only locally high, differing substantially from the findings of this report.

South-eastern Mountains

The south-eastern mountains represent the summer rainfall extreme of the CFR, with virtually no precipitation in winter. Vegetation and flora thus changes radically from that in the west, with true Thicket becoming more prominent (Low & Rebelo, 1996).

The vegetation of the **Kouga** (7.1) range largely comprises Kouga Sandstone Fynbos (Cockscomb Mountain Fynbos Complex) and overlies sandstone and quartzitic sediments of the Peninsula and Nardouw Formations. The range parallels the Baviaanskloof Wilderness Area to the north-east. Only parts of the subregion receive a high ranking in the CIL irreplaceability study.

The adjacent **Baviaanskloof** (7.2) echoes much of the character of the Kouga, with an extensive declared wilderness area. Substrates are largely dominated by the Peninsula Formation which, again, supports Kouga Sandstone Fynbos (Cockscomb Mountain Fynbos Complex). This is one of the few mountain ranges in the study area which has been highly ranked almost in its entirety. As with the Kouga, the CIL rating is low.

Located just north of Port Elizabeth, the **Groot Winterhoek** (7.3) range is also underlain by Peninsula Formation sediments but the vegetation changes to Algoa Sandstone Fynbos (Algoa Grassy Fynbos), the latter indicating the dominance of grasses due to a persistent summer rainfall pattern. This subregion represents the extreme south-east of the study area and therefore the TMG Aquifer Systems. Rating by the CIL is moderate.

6.4.3 Karoo Valleys and Plains

The Karoo areas in this study depict two major regions: the valleys between mountain ranges of the Cape Fold Belt, and the plains lying inland of the edge of the Cape Fold Belt. As the name suggests, these are the driest parts of the study area and harbour a range of succulent and thicket vegetation.

The **Kouebokkeveld-Great Karoo** (8.1) forms a connection between the western arm of the Cape Fold Belt and the Great Karoo. Its prime value therefore is as an ecological corridor, linking two regions with very different floras and vegetation types. The corridor overlies sediments of the Bokkeveld Group with a vegetation dominated by Matjiesfontein Shale Renosterveld (Tankwa Vygieveld). The subregion has a generally low CIL rating, but in this study is ranked highly due to the presence of a corridor and the linkage between wet and dry ecosystems.

The **Koo Valley** complex (8.2) lies on the central inland edge of the CFR, juxtaposed between the Langeberg and Hex River Mountains. Underlain by sediments of the Bokkeveld Group, the vegetation is characterised by Matjiesfontein Shale Renosterveld (Tanqua Vygieveld, Touws Vygieveld) which abut North Hex Sandstone Fynbos (Matroosberg Mountain Fynbos Complex). The subregion includes the upper Touws River which cuts through part of the Little Karoo, but forms a bridge between the latter and the Great Karoo. The site rates highly due to its link between the CFR mountains and adjacent Karoo, with an ecotone linking mountain fynbos and succulent karoo, mediated by renosterveld. However, the CIL ranking is generally low.

To the south of the above, lies the Little Karoo proper, where shale and other fine-grained soils dominate the intermontane valleys. Here the **Western Little Karoo** (8.3) overlies the Bokkeveld Group with vegetation being Breede River Shale Renosterveld (Ashton Inland Renosterveld). By inference, the Breede River Valley is closely associated with this subregion and provides a valuable west-east conduit between the surrounding mountains. Ecological importance for the area is high, with a number of localities exhibiting very high ranking. With a few exceptions the CIL rates the subregion as low to moderate.

The Karoo between the **Witteberg and Anysberg** (8.4) is underlain by the Witteberg Group with Matjiesfontein Shale Renosterveld (Little Karoo Broken Veld) dominating. The area is subject to agricultural pressures and is important for species diversity, particularly now that the eastern and western Little Karoos are regarded as being floristically different (Mucina & Rutherford, in prep.). The Karoo plains also represent an important linkage between the Witteberg and Anysberg and consequently attract a high ecological rating. The value as a corridor is recognised in the CIL where a very high irreplaceability index is given.

The **Anysberg-Waboomsberg** (8.5) occurs on Bokkeveld shale with Montagu Shale Renosterveld (Montagu Inland Renosterveld) the dominant vegetation type. Again this is an area subject to farming impacts but with an important linking function between the Anysberg and Waboomsberg. Despite its high ecological importance ranking, the CIL generally rates the subregion as very low.

6.4.4 River Valleys

Areas within the "river valley" unit have generally attracted high ecological importance due to their corridor function and the presence of habitats which are essential for the survival of aquatic animal species. Some important river stretches have been included with the Karoo Valleys (see above).

The Olifants is one of the two biggest rivers in the CFR, and acts as a conduit between the inland mountains and the upper West Coast. The **Olifants (north)** section (9.1) is located in the arid north of the CFR and overlies the northern and north-western Peninsula and Graafwater Formation outliers of the TMG. Vegetation correspondingly is Graafwater Sandstone Fynbos (Olifants River Mountain Fynbos Complex) and an arid form of Cederberg Sandstone Fynbos (Gifberg Mountain Fynbos Complex) whilst Leipoldtville Sand Fynbos is found on deeper colluvial and alluvial sands. Apart from several localised linkages, the CIL ranking for the subregion is low.

Just south of the above, the **Lower Doring** (9.2) enters the Olifants. Here it is east-west striking and occurs on exposed sediments of the Nardouw Formation Two major vegetation types are found here: Bokkeveld Sandstone Fynbos (Gifberg Mountain Fynbos Complex) on wetter sites, and Doring River Succulent Karoo (Klawer Vygieveld) on dry sites within the river valley. Apart from its linkage value, the major environmental gradients between river valley and adjacent ridges are thought to provide a dynamic template for speciation (pers.obs., Cederberg-Tankwa Karoo). The model used in this study recognises the importance of both the corridor function as well as these transitions along the length of the river. The CIL rating, although low for the general subregion, does attribute a high value for the river *per se.*

South of this, the **Middle Olifants** (9.3) not only plays an invaluable corridor function, but also forms a link between the wetter Cederberg and drier

Olifantsberg Mountains. Although the river is flanked along this stretch by strata of the Peninsula and Nardouw Formations, its substratum is almost exclusively deep Quaternary alluvium. The vegetation is Leipoldtville Sand Fynbos (Olifants River Mountain Fynbos Complex) and occurs in a narrow strip flanking the river. The high ecological importance for much of the subregion is echoed in the CIL.

Another section of river with a valuable corridor function is the **Upper Berg** (9.4), which forms an important link between the northern and southern Sandveld. Its estuary in particular is a valuable breeding ground for birds, whilst the river meanders through an ecologically important area (see sections 1.1 and 1.3). The river is underlain by a variety of Quaternary coastal deposits which merge with the sands of the Springfontyn Formation. Terrestrial vegetation is Hopefield Sand Fynbos (Langebaan Fynbos/Thicket Mosaic). Parts are accorded very high status in the CIL analysis, although the Sandveld generally has received low ranking in the latter.

In the central plains of the CFR rivers tend to be east-west trending due to the physiography of the surrounding mountains. The **Olifants-Kammanassie** system (9.5) lying east of Oudsthoorn, is found on sandstones and conglomerates of the Enon Formation. Due to its distance from the surrounding mountains, the subregion is fairly arid and supports succulent vegetation of the Muscadel Alluvial Vegetation (Oudtshoorn Brokenveld). Only the upper part of the system is regarded as highly irreplaceable (CIL).

Situated in the extreme east of the CFR, the **Sundays River** (9.6) forms an ecological conduit between the coast and the inland plains and mountains of an area dominated by thicket vegetation. The dominant plant cover is Albany Alluvial Vegetation, a thicket type found on alluvium over sediments of the Uitenhage and Suurberg Groups. The CIL study rates the subregion very highly, slightly more than the current study.

6.5. CONCLUSION

This approach is not as robust as that adopted in the CAPE terrestrial layer (Cowling *et al*., 1999), whose ultimate aim was the setting of conservation targets for biodiversity pattern and process in the CFR, where rigorous testing of a comprehensive set of data layers was used to determine areas and degrees of irreplaceability (Cowling *et al*, 1999). However, as regards the present study, the CAPE approach has two major weaknesses: the northern Saldanha-Sandveld region received a low conservation priority rating despite several reports that attest to the rarity and uniqueness of this region (e.g. Boucher & Rode, 1997). More recent reports (Low, 2003; Low & Pond, 2003) confirm this situation. Secondly, the BHU's are regarded as being too coarse for planning at the 1:250 000 scale (CPU, pers.comm.). This dictated the need for a method which;

- concentrates on data which are consistent across the CFR and,
- highlighted those areas of ecological importance only.

The model therefore "plugs the gaps" and focuses on the TMG Aquifer System as a special ecological component of the CFR.

CHAPTER SEVEN

7. IDENTIFICATION AND PRIORITISATION OF 'TYPE AREAS'

7.1. INTRODUCTION

The ecological sensitivity map and the groundwater development potential were 'geospatially' intersected to produce a map that is indicative of the interaction between the two. The resulting map (**Figure 17**) shows the qualitative ranking of how the development of groundwater would affect the ecology. The sensitivity and groundwater potential are depicted by means of a matrix (**Figure 16**) of five colours, each one in four shades. The four shades are indicative of the success rate of developing groundwater, while the five colours, ranging from red to purple, indicate the sensitivity of the ecological systems present.

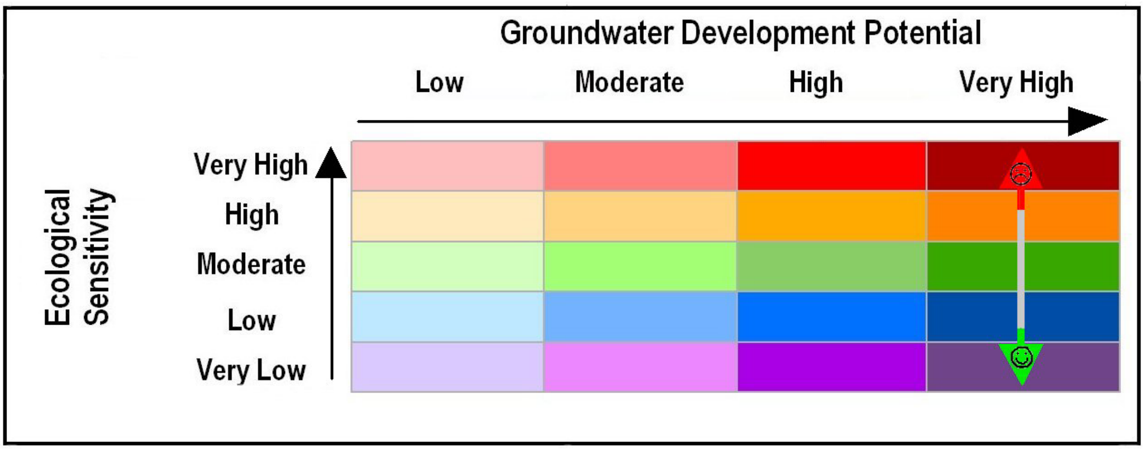


Figure 16: Matrix showing the qualitative ranking of ecological sensitivity and groundwater development potential.

The intersected map of ecological importance and groundwater development potential was related to Quaternary catchments so that the final data could reflect DWAF's approach of depicting data per Quaternary catchment, for example, the WR90 data. The potential for development of large-scale groundwater abstraction within the various Quaternary catchments is summarised in **Appendix III**.

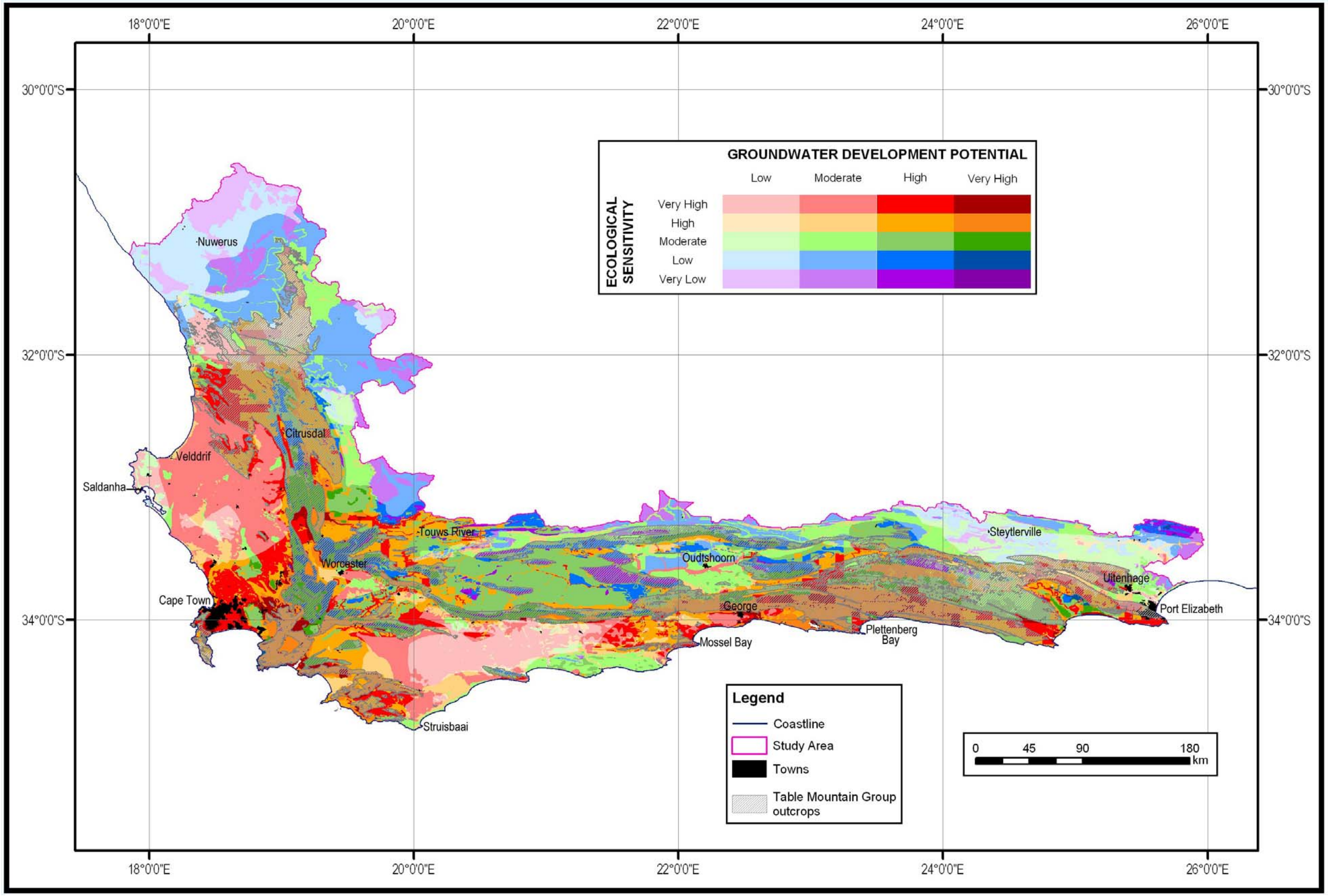


Figure 17: Map showing the coincidence of the Ecological Importance and Groundwater Development Potential.

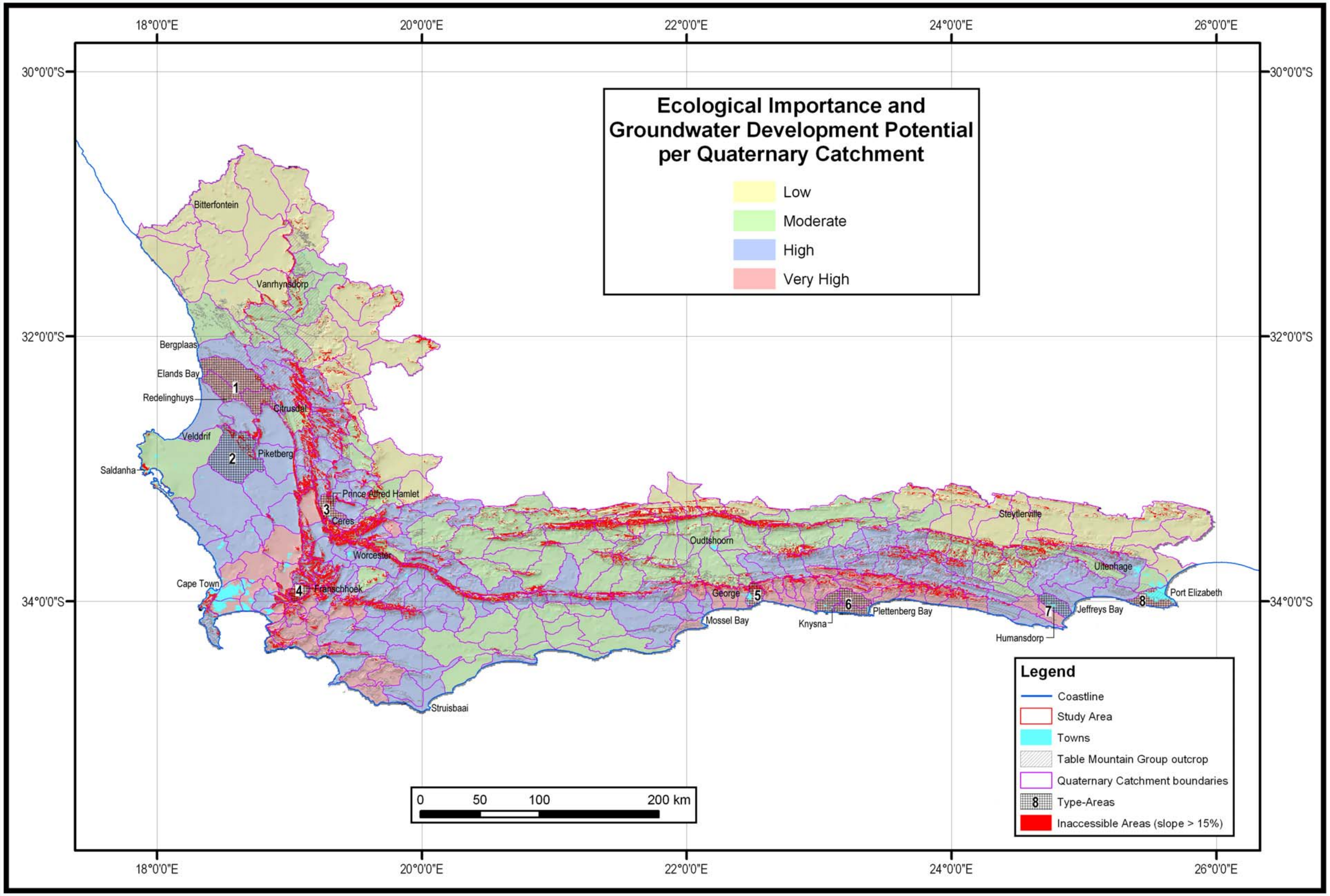


Figure 18: Map showing the qualitative rating of Ecological Importance and Groundwater Development Potential for each Quaternary Catchment (i.e. indicates high ecological importance and high groundwater development potential).

The qualitative rating of Quaternary catchments (**Figure 18**, **Appendix III**) indicates that 65 catchments rate very high for large-scale groundwater abstraction and ecological importance, while 124 catchments occur within the high category for large-scale groundwater abstraction. Eighty catchments rate moderate, while 45 Quaternary catchments rate low for large-scale groundwater abstraction. Most of the catchments that rate high to very high comprise outcrops of the Table Mountain Group. Eight 'type areas' have been identified based on the possibility of future development of the groundwater in the area for towns that are in close proximity. In choosing the 'type areas' the accessibility and recharge potential of the area was also considered as well as the water quality. The characteristics of the 'type areas' are described below and summarised in **Table 20**.

Table 20: Statistical summary of 'type areas'.

TYPE AREA	QUATERNARY CATCHMENT(S)	AREA (km^2)	MEAN RECHARGE ($X10^6 m^3/yr$)	RECHARGE RATE (%)	AVERAGE YIELD (l/s) [STD DEV]	AVERAGE BOREHOLE DEPTH (m) [STD DEV]	AVERAGE EC (mS/m) [STD DEV]	COMMENT
Northern Sandveld	G30C, G30E, G30F	1496	21	4.6	5 [7.98]	76.6 [48.74]	60.6 [70.26]	EC for G30C & G30F. Region severely impacted.
Piketberg	G10K	1186	23	5.1	1.4 [1.34]	102 [25.2]	254.5 [377.9]	
Ceres-Prince Alfred Hamlet	H40C	273.5	42	18	4.5 [5.68]	150	12.27 [7.4]	
Franschhoek	G10A	173.1	69	21	32 [3.93]	48 [47]	15 [12]	
George	K30C	190.4	17	9.4	0.7 [0.5]	110 [30]	252.5 [75.7]	
Knysna-Plettenberg Bay	K50B, K60F, K60G	611.9	56	10	1.75 [2.12]	88 [33.8]	22.5 [21.4]	
Humansdorp	K90F	250.3	17	8.4	1.23 [1.27]	425	151 [221]	
Port Elizabeth	M20A	361.5	24	8.4	4 [1.04]	107 [53.02]	167 [126]	

7.2. KEY 'TYPE AREAS'

7.2.1 NORTHERN SANDVELD

Along the West Coast, south of Bergplaas, in the Elands Bay and Redelinghuys area, three Quaternary catchments show a high rating for groundwater development and very high for ecological importance, and is home to a variety of endemic vegetation types and habitats. It also houses several endemic and rare plant species. The three catchments included in this area are G30C, G30E and G30F, covering approximately 1496km^2. Approximately 60% of the catchments include TMG outcrops and the entire area is accessible, i.e. slope <15% (**Figure 18**), with a combined mean recharge of 21X10^6 m^3/yr at an average recharge rate of 4.6% of MAP (**Appendix III**).

Statistics from the National Groundwater Database (DWAF) (**Appendix IV**) show that a combined 666 boreholes have been drilled in the three catchments of which 305 boreholes deliver an average yield of 5ℓ/s (standard deviation of 7.98). Boreholes in this area have an average depth of 76.64m (standard deviation of 48.74) and a maximum depth of 250m. However, in terms of ecological importance, the area falls within the Northern Sandveld area, which is already being severely impacted by groundwater abstraction, which corresponds with the high to very high rating for ecological importance.

7.2.2 PIKETBERG

The Piketberg area (G10K) depicts a high potential for groundwater development and a moderate to high rating for ecological importance (**Figure 18**) and has an approximate area of 1186km^2. The area has a mean recharge of 23X10^{6}m^3/yr at an average recharge rate of 5.1% of MAP (**Appendix III**). The north to northeastern region of the catchment comprises TMG outcrop, covering approximately 30% of the surface area of the catchment. Groundwater quality is generally good and EC does not exceed 70 mS/m.

This area forms part of the Swartland which represents one of the most transformed areas in the CFR (Cowling *et al*., 1999), with most natural vegetation having been removed for agriculture. The highly fragmented nature of a landscape containing much species and habitat rarity gives the subregion its high value.

There are about 140 existing boreholes in the TMG rocks of the G10K Quaternary catchment according to DWAF's National Groundwater Database (NGDB). Statistics from 44 boreholes show an average yield of 1.43 ℓ/s (standard deviation 1.34). The average borehole depth is 102m (63 records, standard deviation 25.2), whilst the average depth to the waterlevel is 46.5m (38 records, standard deviation 29.7). A number of free flowing or artesian boreholes have also been drilled in this area. Most of these boreholes penetrate the Peninsula Formation and have been drilled in the Vergesig – Heideland – Pomono area, north of Piketberg. There are numerous potential target zones for drilling in terms of faults and the synclinal fold axis. However, accessibility is a problem in large parts of this TMG outcrop area.

Presently, the Piketberg area abstracts approximately 0.1 $X10^6$ m^3/a.

7.2.3 CERES-PRINCE ALFRED HAMLET

The H40C Quaternary catchment has been highlighted in the Ceres area for detailed research. According to Rosewarne (2002) the area has two aquifer systems, namely the sandstones of the TMG and shales and sandstones of the Bokkeveld Group. Seven successful boreholes were drilled in the TMG Aquifer west of Ceres delivering a combined operation yield of 48 ℓ/s. Three boreholes were drilled in the Bokkeveld Aquifer delivering a combined operational yield of 50 ℓ/s. DWAF's National Groundwater Database (NGDB) indicates that 29 boreholes have been drilled in the catchment of which 24 boreholes indicate an average yield of 4.5 ℓ/s and a maximum yield of 23.9 ℓ/s (standard deviation 5.68). The boreholes in the TMG Aquifer realises an average borehole depth of 150m while the Bokkeveld Aquifer has an average borehole depth of 70m (Rosewarne 2002). Rosewarne (2002) indicates that the TMG groundwater has a very low electric conductivity (EC) of 2.8 to 3.5 mS/m and a pH less than 6. The Bokkeveld Aquifer has a more variable quality with an EC ranging from 20 to 148 mS/m.

The catchment is approximately 273.5km^2 and delivers a mean recharge in the order of 9X10^6 m^3/yr at a recharge rate of 18% of MAP (**Appendix III**). At Ceres, drilling and pump testing showed that the main aquifer in terms of borehole yield, quality and economics is the Bokkeveld Group (Rosewarne, 2001).

Presently, 8X10^6 m^3/a groundwater is being abstracted from the Ceres Basin for agricultural purposes, while in the Agter-Witzenberg Valley approximately 20X10^6 m^3/a is being abstracted.

This area acts as an ecological corridor, linking two regions with very different floras and vegetation types. Prvious studies have ranked the area as generally low, but owing to the presence odf the corridor and the linkage between wet and dry ecosystems it ranks highly in this study.

7.2.4 FRANSCHHOEK

The 'type area' comprises the G10A Quaternary catchment and is located about the town of Franschhoek bordering on, and partially included, is the northern extent of the Hottentots-Holland Nature Reserve. Also included is the Franschhoek Tunnel Zone, which has been earmarked for future abstraction (Umvoto, 2001). The catchment is approximately 173.1km^2 with the TMG outcropping in approximately 60% of the catchment. However, accessibility to these areas may be problematic as most of the slope of the outcrop areas is in excess of 15% (**Figure 18**).

Appendix III details the statistics of the recharge analysis undertaken for this project. The recharge for this catchment is 69X10^6 m^3/yr at a recharge rate of 21% of MAP. The borehole depth, yield and electric conductivity (EC) statistics of the catchment is detailed in **Appendix IV**. In summary, the NGDB indicates 58 boreholes have been drilled in the catchment. Statistics show that 26 of these boreholes deliver an average yield of 3.2 ℓ/s with a maximum yield of 16.3 ℓ/s (standard deviation 3.93). The boreholes average a depth of 48m and a maximum depth of 185m (standard deviation 47). The Water Systems Management (WSM) water quality database indicates 7 boreholes that have data included indicating an average EC of 15 mS/m and a maximum EC of 42mS/s (standard deviation 12). This value is well below the recommended limit for human consumption of 70 mS/m.

Owing to its inclusion in the Hottentots-Holland Nature Reserve and its species richness and endemism, this area rates high for ecological importance.

7.2.5 GEORGE

The 'type area' comprises the K30C Quaternary catchment and is located about the town of George along the southeastern coast. The catchment extends from the Outeniqua Mountain range toward the ocean and is approximately 190.4km^2. The TMG outcrops in the north covering approximately 50% of the surface area of the catchment north of George. The south facing slopes of the outcrop area is less than 15%, which means it is accessible.

The recharge for this catchment is 17X10^6 m^3/yr at a recharge rate of 9.4% of MAP (**Appendix III**). The borehole depth, yield and electric conductivity (EC) statistics of the catchment is detailed in **Appendix IV**. In summary, the NGDB indicates 6 boreholes have been drilled in the catchment. Statistics show that these boreholes deliver an average yield of 0.7 ℓ/s with a maximum yield of 1.3 ℓ/s (standard deviation 0.5). The boreholes attain an average depth of 110m and a maximum depth of 139m (standard deviation 30). The Water Systems Management (WSM) water quality database indicates 2 boreholes that have data, indicating an average EC of 252.5 mS/m and a maximum EC of 306 mS/s (standard deviation 75.7). This value exceeds the recommended limit for human consumption of 70 mS/m and the recommended limit for town supply of 300mS/m.

In terms of ecological importance this area rates high to very high as it represents a zone of great diversity. The area is an important corridor along the coastline and forms an intriguing interaction between the coastal and inland mountains.

7.2.6 KNYSNA-PLETTENBERG BAY

The 'type area' comprises the K50B, K60F and K60G Quaternary catchments and is located about the towns of Knysna extending to Plettenberg Bay in the east. The catchments extends from the Outeniqua Mountain range toward the ocean and has a combined surface area of approximately 611.9km^2 with TMG outcrops covering approximately 80% of the surface area of the catchments. The outcrop areas are accessible with slopes mostly less than 15% (**Figure 18**).

The main TMG rock formations outcropping in this area are the Peninsula and Nardouw Formations. In coastal TMG Aquifers, fractures and bedding planes extend into the sea and there is free interconnectivity between fresh groundwater inland and seawater. Coastal areas are thus susceptible to seawater intrusion.

The combined mean recharge for the three catchments is 56X10^6 m^3/yr at a recharge rate of 10% of MAP (**Appendix III**). The borehole depth, yield and electric conductivity (EC) statistics of the catchment is detailed in **Appendix IV**. In summary, the NGDB indicates 40 boreholes have been drilled in the catchment. Statistics show that 32 of these boreholes deliver an average yield of 1.75 ℓ/s (standard deviation 2.12). The boreholes average a depth of 88m and a maximum depth of 200m (standard deviation 33.8). The Water Systems Management (WSM) water quality database indicates 7 boreholes that have data indicating an average EC of 22.5 mS/m and a maximum EC of 48.5 mS/s (standard deviation 21.4). This average EC values are well below the recommended limit for human consumption of 70 mS/m.

Presently, 0.7X10^6 m^3/a groundwater is being abstracted in the Plettenberg Bay area for urban purposes.

7.2.7 HUMANSDORP

The 'type area' comprises the K90F Quaternary catchment and is located about the town of Humansdorp extending toward the ocean (**Figure 18**). The 'type area' is approximately 250.3km^2 with the TMG outcropping in the northern half covering approximately 50% of the surface area of the catchment. The slope of the outcrop areas is mostly less than 15% making it accessible to drilling rigs.

The recharge for this catchment is 17X10^6 m^3/yr at a recharge rate of 8.4% of MAP (**Appendix III**). The borehole depth, yield and electric conductivity (EC) statistics of the catchment is detailed in **Appendix IV**. In summary, the NGDB indicates 83 boreholes have been drilled in the catchment. Statistics show that 40 of these boreholes deliver an average yield of 1.23 ℓ/s with a maximum yield of 4.26 ℓ/s (standard deviation 1.27). The boreholes average a depth of 425m. The Water Systems Management (WSM) water quality database indicates 37 boreholes have data attributed, indicating an average EC of 151 mS/m and a maximum EC of 970mS/s (standard deviation 221). This average EC value is within the recommended limit for town supply of 300 mS/m.

Presently, 1.1X10^6 m^3/a groundwater is being abstracted in the Humansdorp area for urban purposes. East of Humansdorp the Jeffreys Bay area abstracts approximately 1.85X10^6 m^3/a.

According to Cowling et al. (1992) the Humansdorp Plains represents an area of diversity, rarity and endemism, and rates highly for ecological importance.

7.2.8 PORT ELIZABETH

The 'type area' comprises the M20A Quaternary catchment and is located about the town of Port Elizabeth along the Eastern Cape coast (**Figure 18**). The catchment is approximately 361.5km^2. The TMG outcrops in and around the town of Port Elizabeth covering approximately 40% of the surface area of the catchment. All of the outcrop area is less than 15% making it accessible (**Figure 18**).

The recharge for this catchment is $24X10^6$ m^3/yr at a recharge rate of 8.4% of MAP (**Appendix III**). The borehole depth, yield and electric conductivity (EC) statistics of the catchment is detailed in **Appendix IV**. In a study by Rosewarne (2001) it was found that there are approximately 300 boreholes in the Port Elizabeth municipal area and the annual groundwater abstraction is estimated to be $390X10^3$ m^3. In summary, the NGDB indicates 48 boreholes have been drilled in the catchment. Statistics show that 29 of these boreholes deliver an average yield of 0.9 ℓ/s with a maximum yield of 4 ℓ/s (standard deviation 1.04). The boreholes average a depth of 107m and a maximum depth of 222m (standard deviation 53.02).

Rosewarne (2001) concluded that the groundwater quality in the Port Elizabeth municipal area is generally atypical of the TMG Aquifers elsewhere. Sporadic intrusion of seawater in boreholes closest to the sea was found. The Water Systems Management (WSM) water quality database indicates 14 boreholes that have data attributed to them, indicating an average EC of 167 mS/m and a maximum EC of 475 mS/s (standard deviation 126). The average EC is well within the recommended limit for town supply (300 mS/m) but in excess of the recommended limit for human consumption (70 mS/m).

Since most of the area has been impacted by urbanisation and related activities, it receives a high ecological importance rating.

7.3. CONCLUSION

In this chapter the methodology behind the selection of key 'type areas' is outlined and each of the selected 'type areas' is described. Each of these areas rates high to very high for ecological importance and have been chosen for the possibility of future development of the groundwater in the area for towns that are in close proximity. In choosing the 'type areas' the accessibility and recharge potential of the area are also considered as well as the water quality. The impact of groundwater abstraction from the TMG Aquifer Systems on the surrounding ecology can thus be further studied in these areas and a management plan not only for groundwater but also for the ecology can be put into practice.

CHAPTER EIGHT

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. INTRODUCTION

The maps generated during the process of determining 'type areas' for large-scale groundwater abstraction give a broad panoramic view rather than site-specific detail.

The TMG Aquifer System has the potential to be an important supply of water. Although the aquifer system is used to some extent, a number of aspects relating to the aquifer system are poorly understood and unquantified. This study aimed to take into consideration the importance of different ecosystems, which is essential in predicting the effects of groundwater abstraction. However, the ecological requirements of systems that depend on groundwater are poorly understood. This project identifies 'type areas' for further detailed research into the impacts of large-scale groundwater abstraction from TMG Aquifer Systems based on the nature and functioning of ecosystems across groundwater dependent ecosystem boundaries of a regional scale.

Various datasets were collected from various institutions and collated into a GIS database. These GIS datasets were evaluated to assess the key parameters used in determining the variation in the characteristics of the TMG Aquifer Systems and ecosystems. GIS-based spatial modelling techniques were employed to correlate, compare, verify and analyse various datasets for the identification of the 'type areas'. The main characteristics defining each 'type area' were then described.

8.2. RESEARCH OUTCOMES

The model employed in the ecological importance aspect of the study provides a useful means of establishing which parts of the TMG Aquifer System are likely to contain important ecosystems. The analysis has considered a number of key parameters – size of vegetation type, transformation, fragmentation and ecological processes/gradients. However, this approach is not as robust as that adopted in the CAPE terrestrial layer (Cowling *et al*., 1999), whose ultimate aim was the setting of conservation targets for biodiversity pattern and process in the CFR, where rigorous testing of a comprehensive set of data layers was used to determine areas and degrees of irreplaceability (Cowling *et al*, 1999). However, as regards the present study, the CAPE approach has two major weaknesses: the northern Saldanha-Sandveld region received a low conservation priority rating despite several reports that attest to the rarity and uniqueness of this region (e.g. Boucher & Rode, 1997). More recent reports (Low, 2003; Low & Pond, 2003) confirm this situation. Secondly, the BHU's are regarded as being too coarse for planning at the 1:250 000 scale (CPU, pers.comm.). This dictated the need for a method which;

- concentrates on data which are consistent across the CFR and,
- highlighted those areas of ecological importance only. The model therefore "plugs the gaps" and focuses on the TMG-AS as a special ecological component of the CFR.

It is crucial to note that regardless of the ecological importance of a particular site – here the focus has been on an ecological importance rating of >60% - each area should be treated as unique. In this regard an environmental impact assessment for every area considered for abstraction should be undertaken. The model has been based upon a series of data layers with scales ranging between 1:10 000 and 1:250 000 and serves to highlight the importance of certain areas within the study area. However, since a majority of the information is at a coarser (1:250 000) scale it is therefore suitable for planning at a regional scale (Anon, 2003), with more detailed approaches requiring an environmental impact assessment. However, the model serves to highlight general areas of ecological importance, and does not, for example, indicate those areas in which groundwater and related systems might occur.

All models employed in the determination of ecological importance and ranking for conservation priority have, almost by implication, a built in subjectivity. This subjectivity revolves around factors such as choice and rating of criteria and is invariably encumbered by weaknesses caused by lack of data or, even worse, lack of consistency in data across a particular study area. The model employed in this study has used data, which by and large are consistent throughout the CFR. Given the accuracy and detail of the new vegetation map of South Africa (Mucina & Rutherford, in prep.), the model has provided a useful means of determining zones of ecological importance in the study area, but at a strategic, regional level.

Generating exploitation and exploration potential maps of the study area assessed the groundwater development potential of the TMG Aquifer Systems. These maps were then 'geospatially' intersected to produce a map showing a qualitative rating for large-scale abstraction schemes.

The exploitation potential map considers the resource and recharge to show the potential of an area to sustain large-scale abstraction. The mean annual effective recharge was estimated from rainfall using raster-based grid analysis. The results show that high recharge coincides with TMG outcrop areas in mountainous regions and the accessibility to these regions may be problematic where the slope is in excess of 15%. The resulting recharge was checked and verified using Harvest Potential map developed by DWAF. The two datasets are very similar with the recharge determined for this study. This study takes the Mean Annual Precipitation (MAP), percentage Coefficient of Variance (CV) of MAP, %-Terrain Slope and Lithological-Recharge Factor raster-datasets for the study area into account, whereas the Harvest Potential map classification is broader.

Boreholes sited in groundwater units with higher rates of rainfall recharge should be able to sustain higher abstraction rates. It may not always be possible to find suitable drilling targets to site production boreholes capable of delivering the required yields. It is therefore essential that the potential for locating, siting and obtaining a successful borehole be considered. The exploration potential map assesses the accessibility and drilling success of a borehole according to a reclassification of Vegter's Borehole Prospects map.

The 'geospatial' intersection of the exploitation and exploration potential maps produced the groundwater development potential map. This map was reclassified to qualitatively rank the potential of an area to sustain large-scale abstraction. Results show that only 14% of the study area rates very high and 34% high for groundwater development potential, it is these areas that supply the greater mean effective recharge per annum for the area. The areas that rate low to moderate, although constituting the greater surface area, only adds a minimal amount to the mean annual recharge.

The groundwater development potential map and the ecological importance map were 'geospatially' intersected to produce a map showing the coincidence of the two, depicted using a matrix. The coincidence map was then related back to the Quaternary catchments, qualitatively rating each catchment within the study area. This map indicates that 65 catchments rate very high for large-scale groundwater abstraction and ecological importance, while 124 catchments occur within the high category for large-scale groundwater abstraction. Eighty catchments rate moderate, while 45 Quaternary catchments rate low for large-scale groundwater abstraction. Most of the catchments that rate high to very high comprise outcrops of the Table Mountain Group. Eight 'type areas' were identified based on the possibility of future development of the groundwater in the area for towns that are in close proximity. In choosing the 'type areas' the accessibility and recharge potential of the area was also considered as well as the water quality. The eight 'type areas' are as follows:

- Northern Sandveld
- Piketberg
- Ceres – Prince Alfred Hamlet
- Franschhoek
- George
- Knysna – Plettenberg Bay
- Humansdorp
- Port Elizabeth

8.3. RECOMMENDATIONS

A more detailed investigation of ecological importance should be undertaken at the level of groundwater dependent ecosystems, targeting rivers, seeps and related systems in one of the subregions rated as highly important. This should be viewed as a pilot study to test the robustness of the model and determine ground rules for more focussed studies of this nature.

In many of the subregions identified as ecologically important, virtually pristine rivers leave a mountain catchment only to suffer at the hands of over–abstraction on entering farmland. A pilot study is strongly recommended whereby the baseflow and ecological characteristics (water chemistry and nutrient loading, plant and animal species and communities) of a number of abstracted and non-abstracted (control) rivers are compared. A monitoring programme to determine ecological trends in rivers that are severely abstracted should follow this. One of the outcomes would be a programme aimed at rehabilitating rivers that have experienced marked abstraction levels for sometime.

Regardless of ecological importance, each potential abstraction area should be the subject of an environmental impact assessment (EIA) (Environment Conservation Act, 1983; regulations of 1997) or at least the principles laid down in the National Environmental Management Act (NEMA) (Act 107 of 1998). In order to determine whether a water resource is being used sustainably, the National Water Act (Act 36 of 1998) should be consulted.

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APPENDIX I

SUMMARY OF BIOMES AND VEGETATION TYPES IN THE STUDY AREA

Biome (Low & Rebelo, 1996)	Vegetation type (Low & Rebelo, 1996)	Equivalent Vegetation Type (Mucina & Rutherford, in prep.)*
Fynbos	Mountain Fynbos, Grassy Fynbos	Albany Succulent Thicket, Algoa Sandstone Fynbos, Altimontane Fynbos, Baviaanskloof Shale Renosterveld, Bokkeveld Sandstone Fynbos, Boland Granite Fynbos, Cederberg Sandstone Fynbos, Ceres Alluvium Fynbos, Eastern Cederberg Shale Bands, Fynbos Altimontane Mires, Graafwater Sandstone Fynbos, Grootrivier Quartzite Fynbos, Hangklip Sand Fynbos, Hawekwas Sandstone Fynbos, Kogelberg Sandstone Fynbos, Kouebokkeveld Shale Fynbos, Kouga Sandstone Fynbos, Loerie Shale Fynbos, North Hex Sandstone Fynbos, North Kammanassie Sandstone Fynbos, North Langeberg Sandstone Fynbos, North Outeniqua Sandstone Fynbos, North Rooiberg Sandstone Fynbos, North Sonderend Sandstone Fynbos, North Swartberg Sandstone Fynbos, Northern Cederberg Shale Bands, Olifants Sandstone Fynbos, Overberg Sandstone Fynbos, Peninsula Granite Fynbos, Peninsula Sandstone Fynbos, Piketberg Sandstone Fynbos, Potberg Sandstone Fynbos, South Hex Sandstone Fynbos, South Kammanassie Sandstone Fynbos, South Langeberg Sandstone Fynbos, South Outeniqua Sandstone Fynbos, South Rooiberg Sandstone Fynbos, South Sonderend Sandstone Fynbos, South Swartberg Sandstone Fynbos, Suurberg Shale Fynbos, Swartruggens Quartzite Fynbos, Swartruggens Sandstone Karoo, Tsitsikamma Sandstone Fynbos, Vanrhynsdorp Shale Renosterveld, Western Cederberg Shale Bands, Winterhoek Sandstone Fynbos
	Laterite Fynbos	Elim Laterite Fynbos
	Limestone Fynbos	Agulhas Limestone Fynbos, Albertinia Sand Fynbos,
	Sand Plain Fynbos	Atlantis Sand Fynbos, Cape Flats Sand Fynbos, Hopefield Sand Fynbos, Leipoldtville Sand Fynbos
	Central Mountain Renosterveld	Breede Alluvium Fynbos, Breede Quartzite Fynbos, Breede Sand Fynbos, Breede Shale Fynbos, Breede Shale Renosterveld, Ceres Shale Renosterveld, Matjiesfontein Quartzite Fynbos, Matjiesfontein Shale Fynbos, Montagu Shale Fynbos, Montagu Shale Renosterveld, Robertson Granite Fynbos, Robertson Granite Renosterveld, Swartberg Shale Fynbos, Swartberg Shale Renosterveld
	Escarpment Mountain Renosterveld	Roggeveld Karoo, Roggeveld Renosterveld
	South & South-West Coast Renosterveld	Agulhas Sand Fynbos, Central Ruens Shale Renosterveld, Eastern Ruens Shale Renosterveld, Elgin Shale Fynbos, Greyton Shale Fynbos, Humansdorp Shale Renosterveld, Kango Fynbos, Kango Renosterveld, Langkloof Shale Renosterveld, Mossel Bay Shale Renosterveld, Potberg Silcrete Fynbos, Ruens Silcrete Renosterveld, Swellendam Silcrete Fynbos, Uniondale Shale Renosterveld, West Ruens Shale Renosterveld
	West Coast Renosterveld	Cape Winelands Shale Fynbos, Lourensford Alluvium Fynbos, Peninsula Shale Renosterveld, Swartland Alluvium Fynbos, Swartland Granite Renosterveld, Swartland Shale Renosterveld, Swartland Silcrete Renosterveld, Swartland Alluvium Renosterveld
Forest	Afromontane Forest	Garden Route Granite Fynbos, Garden Route Shale Fynbos, Knysna Sand Fynbos

Biome (Low & Rebelo, 1996)	Vegetation type (Low & Rebelo, 1996)	Equivalent Vegetation Type (Mucina & Rutherford, in prep.)*
Thicket	Dune Thicket	Agulhas Dune Strandveld, Algoa Dune Strandveld, Blombos Strandveld, Cape Flats Dune Strandveld, Groot Brak Strandveld, Lambert's Bay Strandveld, Langebaan Dune Strandveld, Saldanha Flats Calcareous Strandveld, Saldanha Granite Strandveld, Saldanha Limestone Strandveld, Southern Cape Dune Fynbos, Subtropical Strand Vegetation, Temperate Coastal Thicket
	Mesic Succulent Thicket	Baviaanskloof-Gamtoos Thicket, Bontveld
	Spekboom Succulent Thicket	Escarpment Thicket, Gamka Thicket, Groot Thicket, Western Gwarrieveld
	Valley Thicket	Albany Coastal Thornveld, Gamtoos Thicket
	Xeric Succulent Thicket	Albany Alluvial Vegetation, Albany Thickets, Noorsveld, Sundays Thicket, Suurberg Quartzite Fynbos
Succulent Karoo	Little Succulent Karoo	Breede Alluvium Renosterveld, Eastern Little Karoo, Little Karoo Quartzfields, Matjiesfontein Shale Renosterveld, Muscadel Alluvial Vegetation, Robertson Karoo, Western Little Karoo, Western Spekboomveld
	Lowland Succulent Karoo	Agter-Sederberg Succulent Shrubland, Central Knersvlakte Plains, Citrusdal Vygieveld, Doringrivier Succulent Karoo, Knersvlakte Dolomite Shrubland, Knersvlakte Quartzfields, Knersvlakte Shale Shrubland, Laingsburg-Touws Succulent Karoo, Namaqualand Arid Grassland, Namaqualand Riviere, Namaqualand Sand Fynbos, Namaqualand Spinescent Grassland, Northern Knersvlakte Plains, Southern Knersvlakte Plains, Southern Namaqualand Strandveld, Tanqua Karoo, Tanqua Sheet Wash Plains, Wes-Boesmanland Kaaingveld
	Strandveld Succulent Karoo	Namaqualand Strand Vegetation
	Upland Succulent Karoo	Bushmanland Arid Grassland, Hantam Karoo, Kamiesberg Mountain Shrubland, Namaqualand Klipkoppe, Namaqualand Klipkoppe Flats, Nieuwoudtville Dolerite Renosterveld, Nieuwoudtville Shale Renosterveld
Nama Karoo	Central Lower Nama Karoo	Eastern Lower Karoo, Eastern Gwarrieveld, Steytlerville Karoo
	Great Nama Karoo	Great Karoo, Prince Albert Succulent Karoo, Southern Karoo Riviere
Azonal aquatic systems	N/A	Arid Estuarine Salt Marshes, Subtropical Estuarine Salt Marshes, Vernal pools
5 biomes	**21 vegetation types**	**164 vegetation types**

* Represents the vegetation type in its entirety or a major proportion thereof

APPENDIX II

DETAILED VEGETATION TYPES USED TO DETERMINE THE ECOLOGICAL IMPORTANCE OF THE STUDY AREA

Vegetation type	No. of polygons	Area (ha)	% of Study Area
1. TMG fynbos & Karoo (no. = 39)			
Algoa Sandstone Fynbos	1	34,788.5	0.3
Altimontane Fynbos	58	8,885.9	0.1
Bokkeveld Sandstone Fynbos	15	137,776.3	1.2
Breede Quartzite Fynbos	75	9,877.1	0.1
Cederberg Sandstone Fynbos	14	247,286.4	2.1
Eastern Cederberg Shale Bands	182	20,964.6	0.2
Fynbos Altimontane Mires	5	500.6	0.0
Graafwater Sandstone Fynbos	10	126,624.6	1.1
Grootrivier Quartzite Fynbos	27	29,853.0	0.3
Hawekwas Sandstone Fynbos	23	105,797.9	0.9
Kogelberg Sandstone Fynbos	17	91,745.4	0.8
Kouga Sandstone Fynbos	81	654,871.7	5.6
Matjiesfontein Quartzite Fynbos	189	116,305.9	1.0
North Hex Sandstone Fynbos	5	39,672.8	0.3
North Kammanassie Sandstone Fynbos	9	33,282.6	0.3
North Langeberg Sandstone Fynbos	27	104,863.9	0.9
North Outeniqua Sandstone Fynbos	5	90,893.0	0.8
North Rooiberg Sandstone Fynbos	10	31,950.4	0.3
North Sonderend Sandstone Fynbos	20	51,625.1	0.4
North Swartberg Sandstone Fynbos	25	86,725.7	0.7
Northern Cederberg Shale Bands	51	31,373.2	0.3
Olifants Sandstone Fynbos	5	108,261.3	0.9
Overberg Sandstone Fynbos	27	118,901.9	1.0
Peninsula Sandstone Fynbos	10	23,552.7	0.2
Piketberg Sandstone Fynbos	9	46,439.3	0.4
Potberg Sandstone Fynbos	5	10,794.0	0.1
South Hex Sandstone Fynbos	6	32,272.6	0.3
South Kammanassie Sandstone Fynbos	3	30,450.9	0.3
South Langeberg Sandstone Fynbos	16	123,565.7	1.1
South Outeniqua Sandstone Fynbos	18	190,906.8	1.6
South Rooiberg Sandstone Fynbos	5	38,930.4	0.3
South Sonderend Sandstone Fynbos	9	38,320.1	0.3
South Swartberg Sandstone Fynbos	34	110,999.4	1.0
Suurberg Quartzite Fynbos	29	18,621.3	0.2
Swartruggens Quartzite Fynbos	9	157,738.1	1.4
Swartruggens Sandstone Karoo	4	51,525.3	0.4
Tsitsikamma Sandstone Fynbos	21	243,095.3	2.1
Western Cederberg Shale Bands	167	29,900.8	0.3
Winterhoek Sandstone Fynbos	4	119,377.6	1.0
Subtotal	**1230**	**3,549,317.7**	**30.4**

Vegetation type	No. of polygons	Area (ha)	% of Study Area
2. Non TMG renosterveld and fynbos on granite, shale, silcrete & dolerite: (no.=45)			
Baviaanskloof Shale Renosterveld	16	11,880.7	0.1
Boland Granite Fynbos	31	49,965.6	0.4
Breede Shale Fynbos	22	35,663.6	0.3
Breede Shale Renosterveld	100	105,521.7	0.9
Cape Winelands Shale Fynbos	30	8,708.5	0.1
Central Ruens Shale Renosterveld	9	204,276.1	1.8
Ceres Shale Renosterveld	5	49,497.2	0.4
Eastern Ruens Shale Renosterveld	25	278,061.0	2.4
Elgin Shale Fynbos	12	27,832.6	0.2
Elim Laterite Fynbos	22	70,692.6	0.6
Garden Route Granite Fynbos	13	56,234.3	0.5
Garden Route Shale Fynbos	12	61,320.0	0.5
Greyton Shale Fynbos	15	27,280.9	0.2
Humansdorp Shale Renosterveld	22	36,707.0	0.3
Kamiesberg Mountain Shrubland	2	166.1	0.0
Kango Fynbos	9	40,642.7	0.3
Kango Renosterveld	7	50,288.5	0.4
Kouebokkeveld Shale Fynbos	12	43,093.8	0.4
Langkloof Shale Renosterveld	5	20,729.0	0.2
Loerie Shale Fynbos	5	21,939.1	0.2
Matjiesfontein Shale Fynbos	11	10,619.8	0.1
Matjiesfontein Shale Renosterveld	79	200,191.6	1.7
Montagu Shale Fynbos	8	18,763.2	0.2
Montagu Shale Renosterveld	23	169,363.6	1.5
Mossel Bay Shale Renosterveld	45	83,950.0	0.7
Nieuwoudtville Dolerite Renosterveld	8	5,912.5	0.1
Nieuwoudtville Shale Renosterveld	4	16,038.4	0.1
Peninsula Granite Fynbos	14	9,149.2	0.1
Peninsula Shale Renosterveld	2	3,018.9	0.0
Potberg Silcrete Fynbos	1	4,070.2	0.0
Robertson Granite Fynbos	4	1,708.6	0.0
Robertson Granite Renosterveld	1	1,933.9	0.0
Roggeveld Renosterveld	4	896.2	0.0
Ruens Silcrete Renosterveld	416	21,430.4	0.2
Saldanha Granite Strandveld	28	23,599.4	0.2
Suurberg Shale Fynbos	36	21,895.1	0.2
Swartberg Shale Fynbos	7	7,528.8	0.1
Swartberg Shale Renosterveld	2	25,458.7	0.2
Swartland Granite Renosterveld	56	96,015.4	0.8
Swartland Shale Renosterveld	124	499,070.2	4.3
Swartland Silcrete Renosterveld	219	10,086.9	0.1
Swellendam Silcrete Fynbos	90	87,695.7	0.8
Uniondale Shale Renosterveld	9	141,581.8	1.2
Vanrhynsdorp Shale Renosterveld	9	36,228.3	0.3
West Ruens Shale Renosterveld	2	120,204.0	1.0
Subtotal	**1576**	**2,816,911.6**	**24.1**

Vegetation type	No. of polygons	Area (ha)	% of Study Area
3. Non TMG Tertiary to Recent deposits coastal thicket and fynbos (no.=23)			
Agulhas Dune Strandveld	33	38,215.7	0.3
Agulhas Limestone Fynbos	85	213,476.0	1.8
Agulhas Sand Fynbos	21	26,724.5	0.2
Albertinia Sand Fynbos	27	71,118.1	0.6
Algoa Dune Strandveld	8	22,111.1	0.2
Atlantis Sand Fynbos	17	70,417.9	0.6
Blombos Strandveld	22	5,365.1	0.0
Cape Flats Dune Strandveld	12	42,949.3	0.4
Cape Flats Sand Fynbos	6	55,284.6	0.5
Groot Brak Strandveld	18	26,627.5	0.2
Hangklip Sand Fynbos	12	8,908.4	0.1
Hopefield Sand Fynbos	7	183,801.2	1.6
Knysna Sand Fynbos	14	1,160.9	0.0
Lambert's Bay Strandveld	3	45,857.2	0.4
Langebaan Dune Strandveld	12	46,665.1	0.4
Leipoldtville Sand Fynbos	17	278,181.9	2.4
Namaqualand Strand Vegetation	5	364.2	0.0
Saldanha Flats Calcareous Strandveld	6	77,021.3	0.7
Saldanha Limestone Strandveld	4	3,602.3	0.0
Southern Cape Dune Fynbos	8	41,356.7	0.4
Southern Namaqualand Strandveld	5	139,346.0	1.2
Subtropical Strand Vegetation	2	564.8	0.0
Temperate Coastal Thicket	9	7,376.5	0.1
Subtotal	**353**	**1,406,496.1**	**12.1**
4. Non TMG inland sand & alluvial deposits (no.=10)			
Albany Alluvial Vegetation	23	57,942.3	0.5
Baviaanskloof-Gamtoos Thicket	1	25.8	0.0
Breede Alluvium Fynbos	4	47,795.3	0.4
Breede Alluvium Renosterveld	18	50,145.4	0.4
Breede Sand Fynbos	10	9,342.7	0.1
Ceres Alluvium Fynbos	9	18,130.3	0.2
Lourensford Alluvium Fynbos	1	5,571.6	0.0
Namaqualand Sand Fynbos	2	37,527.8	0.3
Swartland Alluvium Fynbos	12	47,349.1	0.4
Swartland Alluvium Renosterveld	2	6,306.5	0.1
Subtotal	**82**	**280,136.6**	**2.4**
5. Non TMG thicket, karroid and succulent vegetation (chiefly shale & sansdatone) (no.=44)			
Agter-Sederberg Succulent Shrubland	8	119,525.5	1.0
Albany Coastal Thornveld	2	19,618.2	0.2
Albany Succulent Thicket	1	980.3	0.0
Albany Thickets	1	14,455.3	0.1
Bontveld	12	18,447.6	0.2
Bushmanland Arid Grassland	2	23.3	0.0
Central Knersvlakte Plains	2	29,504.2	0.3
Citrusdal Vygieveld	10	8,021.0	0.1
Doringrivier Succulent Karoo	2	47,887.2	0.4
Eastern Gwarrieveld	25	256,792.7	2.2

Vegetation type	No. of polygons	Area (ha)	% of Study Area
5. Non TMG thicket, karroid and succulent vegetation (chiefly shale & sansdatone) (no.=44) CONTINUED			
Eastern Little Karoo	22	154,063.3	1.3
Eastern Lower Karoo	3	8,303.8	0.1
Escarpment Thicket	1	44.7	0.0
Gamka Thicket	37	118,956.7	1.0
Gamtoos Thicket	7	88,340.2	0.8
Great Karoo	3	15,883.9	0.1
Groot Thicket	31	198,141.6	1.7
Hantam Karoo	6	131,727.8	1.1
Knersvlakte Dolomite Shrubland	1	7,239.8	0.1
Knersvlakte Quartzfields	6	104,512.5	0.9
Knersvlakte Shale Shrubland	2	89,368.2	0.8
Laingsburg-Touws Succulent Karoo	8	23,677.2	0.2
Little Karoo Quartzfields	8	3,265.7	0.0
Muscadel Alluvial Vegetation	16	69,656.7	0.6
Namaqualand Arid Grassland	5	49,571.6	0.4
Namaqualand Klipkoppe	18	196,364.6	1.7
Namaqualand Klipkoppe Flats	3	4,599.4	0.0
Namaqualand Riviere	2	47,684.8	0.4
Namaqualand Spinescent Grassland	4	56,838.8	0.5
Noorsveld	4	16,136.0	0.1
Northern Knersvlakte Plains	5	145,920.4	1.3
Prince Albert Succulent Karoo	19	49,482.8	0.4
Robertson Karoo	38	61,668.2	0.5
Roggeveld Karoo	2	7,758.5	0.1
Southern Karoo Riviere	5	36,944.3	0.3
Southern Knersvlakte Plains	5	108,555.6	0.9
Steytlerville Karoo	39	78,773.3	0.7
Sundays Thicket	21	239,919.9	2.1
Tanqua Karoo	18	357,460.1	3.1
Tanqua Sheet Wash Plains	4	75,802.5	0.6
Wes-Boesmanland Kaaingveld	2	2,737.6	0.0
Western Gwarrieveld	4	71,475.2	0.6
Western Little Karoo	8	417,712.9	3.6
Western Spekboomveld	7	3,904.8	0.0
Subtotal	**429**	**3,557,748.3**	**30.5**
6. Non TMG aquatic systems (no. = 3)			
Arid Estuarine Salt Marshes	2	3,660.8	0.0
Subtropical Estuarine Salt Marshes	6	3,391.9	0.0
Vernal pools	1	0.9	0.0
Subtotal	**9**	**7,053.5**	**0.1**
7. Unassigned polygons	**9**	**47,801.6**	**0.4**
TOTAL	**3688**	**11,665,465.4**	**100.0**
TOTAL NO. OF VEGETATION TYPES = 164			

APPENDIX III

MEAN ANNUAL EFFECTIVE RECHARGE FOR THE DRAINAGE REGIONS

Catch-ment No.	Area (km^2)	Cells	CCWR Map (mm/yr)	Mean Recharge ($x10^6$ m^3/yr)	Mean Recharge (mm/yr)	Recharge Factor (%)	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ $m^3/a/km^2$)	Harvest Potential ($x10^3$ $m^3/a/km^2$)	Groundwater Development Potential Rating
E10A	134.7	2149	1071.6	16.18	120.5	11.2%	145.0	19.47	96.0	12.89	6.58	120.48	87.33	High
E10B	203.4	3287	856.9	16.04	78.1	9.1%	96.3	19.78	59.9	12.29	7.49	78.07	73.47	High
E10C	193.9	3122	697.8	10.04	51.5	7.4%	65.8	12.83	37.2	7.25	5.58	51.46	71.49	High
E10D	236.7	3825	619.9	9.56	40.0	6.4%	51.9	12.40	28.1	6.72	5.68	39.98	37.55	High
E10E	368.6	5894	520.1	10.51	28.5	5.5%	37.6	13.85	19.5	7.18	6.67	28.54	32.78	Moderate
E10F	388.8	6231	499.8	10.25	26.3	5.3%	34.8	13.54	17.9	6.96	6.57	26.32	35.51	High
E10G	512.5	8219	496.7	14.15	27.6	5.5%	36.3	18.66	18.8	9.64	9.02	27.55	36.10	High
E10H	163.4	2647	611.1	6.75	40.8	6.7%	53.1	8.79	28.5	4.72	4.07	40.83	34.22	High
E10J	472.2	7557	425.3	9.39	19.9	4.7%	26.5	12.52	13.2	6.26	6.27	19.88	35.29	High
E10K	237.4	3820	345.4	3.03	12.7	3.7%	17.2	4.10	8.2	1.96	2.13	12.69	30.75	Moderate
E21A	191.2	3099	736.1	11.28	58.2	7.9%	72.2	13.99	44.3	8.57	5.41	58.24	18.65	High
E21B	224.7	3605	608.2	8.21	36.5	6.0%	46.9	10.57	26.0	5.86	4.72	36.46	12.48	High
E21C	234.7	3790	563.0	7.41	31.3	5.6%	40.7	9.63	21.9	5.18	4.45	31.27	12.67	High
E21D	243.5	3920	749.2	13.97	57.0	7.6%	71.3	17.46	42.8	10.47	6.99	57.01	35.35	High
E21E	294.7	4728	426.4	5.44	18.4	4.3%	24.5	7.23	12.3	3.64	3.58	18.39	17.45	Moderate
E21F	381.0	6098	357.7	4.79	12.6	3.5%	17.0	6.46	8.2	3.12	3.34	12.58	15.21	Moderate
E21G	268.0	4301	585.4	8.79	32.7	5.6%	42.5	11.43	22.8	6.14	5.29	32.69	38.34	Very High
E21H	407.2	6513	522.0	11.34	27.9	5.3%	36.8	14.96	19.0	7.71	7.25	27.85	44.35	High
E21J	318.9	5101	415.0	5.33	16.7	4.0%	22.4	7.13	11.1	3.53	3.60	16.73	27.50	High
E21K	332.7	5456	440.4	7.10	20.8	4.7%	27.7	9.44	14.0	4.76	4.68	20.81	30.23	High
E21L	196.2	3124	278.1	1.46	7.5	2.7%	10.2	1.99	4.7	0.92	1.07	7.47	11.53	Low
E22C	492.4	7892	409.6	9.01	18.3	4.5%	24.0	11.83	12.6	6.20	5.63	18.27	11.86	Moderate
E22D	498.4	8026	287.4	4.26	8.5	3.0%	11.5	5.76	5.5	2.75	3.01	8.49	5.55	Low
E22E	1019.1	16262	268.7	7.88	7.8	2.9%	10.5	10.62	5.1	5.13	5.49	7.75	7.73	Low
E22G	369.4	5885	220.9	1.79	4.9	2.2%	6.7	2.46	3.1	1.12	1.34	4.87	7.54	Low
E24A	256.5	4131	513.6	7.12	27.6	5.4%	36.4	9.40	18.8	4.84	4.55	27.57	31.61	High
E24B	470.9	7538	357.1	5.62	11.9	3.3%	16.2	7.61	7.7	3.64	3.97	11.93	9.59	Low

Catch-ment No.	Area (km²)	Cells	CCWR Map (mm/yr)	Mean Recharge ($x10^6$ m^3/yr)	Mean Recharge (mm/yr)	Recharge Factor (%)	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ m^3/a/km^2)	Harvest Potential ($x10^3$ m^3/a/km^2)	Groundwater Development Potential Rating
E24D	1003.2	15977	232.2	5.05	5.1	2.2%	6.9	6.90	3.2	3.20	3.70	5.06	4.57	Low
E24E	675.7	10841	263.2	4.15	6.1	2.3%	8.4	5.68	3.9	2.63	3.06	6.13	8.53	Low
E24F	585.9	9325	253.7	3.35	5.7	2.3%	7.9	4.57	3.6	2.12	2.45	5.74	7.82	Low
E24G	637.0	10192	230.2	3.11	4.9	2.1%	6.7	4.27	3.1	1.94	2.33	4.88	5.79	Low
E24H	485.7	7750	251.7	2.88	5.9	2.4%	8.1	3.94	3.7	1.81	2.13	5.94	3.13	Low
E24J	1085.6	17382	323.2	11.83	10.9	3.4%	14.6	15.90	7.1	7.75	8.15	10.89	12.87	Low
E24K	656.8	10550	301.1	5.77	8.8	2.9%	11.9	7.87	5.6	3.68	4.19	8.75	16.38	Moderate
E24L	519.8	8314	374.6	8.26	15.9	4.2%	21.2	11.03	10.6	5.48	5.55	15.89	30.52	Moderate
E24M	533.0	8530	331.0	6.20	11.6	3.5%	15.7	8.39	7.5	4.00	4.39	11.62	30.35	Moderate
E31H	731.9	11709	188.4	2.36	3.2	1.7%	4.5	3.26	2.0	1.45	1.81	3.22	1.65	Low
E32E	1008.9	16086	247.8	6.32	6.3	2.5%	8.6	8.62	4.0	4.02	4.59	6.29	13.05	Low
E33A	1366.6	21857	170.4	3.62	2.7	1.6%	3.7	5.03	1.6	2.21	2.82	2.65	0.6805	Low
E33B	708.0	11339	141.7	1.31	1.8	1.3%	2.6	1.82	1.1	0.80	1.02	1.84	1.50	Low
E33C	988.4	15837	172.0	2.88	2.9	1.7%	4.0	3.97	1.8	1.78	2.19	2.91	6.45	Low
E33D	1573.8	25181	163.5	3.85	2.5	1.5%	3.4	5.34	1.5	2.36	2.98	2.45	1.56	Low
E33E	1294.4	20716	155.6	2.97	2.3	1.5%	3.2	4.12	1.4	1.82	2.30	2.29	1.25	Low
E33F	730.8	11696	270.9	5.46	7.5	2.8%	10.1	7.41	4.8	3.50	3.91	7.47	12.42	Low
E33G	902.5	14466	233.7	4.97	5.5	2.4%	7.5	6.81	3.5	3.13	3.68	5.50	8.30	Low
E33H	725.7	11563	166.4	1.93	2.7	1.6%	3.7	2.68	1.6	1.18	1.50	2.67	2.14	Low
E40C	534.0	8557	359.5	6.55	12.3	3.4%	16.6	8.86	7.9	4.24	4.61	12.25	16.46	Moderate
E40D	548.2	8771	356.8	7.03	12.8	3.6%	17.3	9.50	8.3	4.56	4.93	12.82	24.83	Moderate
F60B	322.8	5146	162.7	0.82	2.6	1.6%	3.5	1.14	1.6	0.50	0.63	2.55	2.93	Low
F60D	485.2	7751	151.3	1.08	2.2	1.5%	3.1	1.50	1.4	0.66	0.84	2.23	2.24	Low
F60E	801.8	12729	144.3	1.65	2.1	1.4%	2.9	2.29	1.3	1.00	1.29	2.07	4.31	Low
G10A	173.1	2774	1833.3	68.92	397.5	21.7%	459.9	79.74	335.1	58.10	21.64	397.52	159.55	Very High
G10B	126.9	2053	1423.2	28.04	218.6	15.4%	255.4	32.76	181.8	23.32	9.44	218.56	191.44	High
G10C	330.6	5287	1120.1	43.00	130.1	11.6%	154.6	51.07	105.7	34.93	16.14	130.14	51.64	Very High

Catch-ment No.	Area (km^2)	Cells	CCWR Map (mm/yr)	Mean Recharge ($x10^6$ m^3/yr)	Mean Recharge	Recharge Factor (%)	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ $m^3/a/km^2$)	Harvest Potential ($x10^3$ $m^3/a/km^2$)	Groundwater Development Potential Rating
G10D	692.9	11092	733.0	35.34	51.0	7.0%	63.5	44.02	38.5	26.67	17.35	50.98	27.76	Very High
G10E	397.0	6345	759.3	22.11	55.8	7.3%	69.5	27.56	42.0	16.67	10.88	55.76	39.02	Very High
G10F	543.5	8737	614.6	18.79	34.4	5.6%	44.1	24.08	24.7	13.49	10.59	34.40	25.16	High
G10G	187.0	3007	1143.5	26.62	141.7	12.4%	168.7	31.70	114.6	21.54	10.16	141.65	104.21	High
G10H	679.9	10881	478.9	14.00	20.6	4.3%	27.0	18.36	14.2	9.64	8.72	20.59	26.59	High
G10J	874.6	13989	525.3	23.51	26.9	5.1%	34.5	30.13	19.3	16.89	13.24	26.89	25.77	High
G10K	1186.3	18974	446.9	22.92	19.3	4.3%	25.5	30.25	13.1	15.58	14.67	19.32	28.68	High
G10L	1770.6	28350	457.7	31.86	18.0	3.9%	23.9	42.28	12.1	21.44	20.84	17.98	21.12	High
G10M	2025.0	31850	355.8	24.82	12.5	3.5%	16.8	33.38	8.2	16.24	17.13	12.47	30.22	Moderate
G21A	528.3	8374	482.9	11.44	21.9	4.5%	28.9	15.14	14.8	7.73	7.41	21.85	36.35	High
G21B	306.5	4878	497.0	6.67	21.9	4.4%	28.9	8.81	14.8	4.52	4.29	21.87	46.45	High
G21C	246.2	3934	600.5	7.64	31.1	5.2%	40.3	9.91	21.9	5.38	4.53	31.09	27.22	High
G21D	488.2	7835	560.4	13.02	26.6	4.7%	34.8	17.02	18.4	9.02	8.00	26.59	24.88	High
G21E	535.1	8565	615.8	17.12	32.0	5.2%	41.4	22.14	22.6	12.10	10.03	31.99	22.93	Very High
G21F	244.5	3916	566.8	6.50	26.6	4.7%	34.7	8.49	18.5	4.52	3.97	26.56	27.78	Very High
G22A	240.2	3682	815.8	17.01	73.9	9.1%	92.4	21.27	55.5	12.77	8.50	73.92	77.76	High
G22B	110.4	1700	1150.3	14.56	137.0	11.9%	162.6	17.27	111.4	11.84	5.43	136.99	77.86	Very High
G22C	256.5	4157	724.1	12.91	49.7	6.9%	61.9	16.08	37.5	9.74	6.34	49.71	66.05	Very High
G22D	248.2	3824	871.7	18.07	75.6	8.7%	93.2	22.27	58.0	13.86	8.42	75.59	100.24	Very High
G22E	273.0	4270	668.9	10.50	39.3	5.9%	50.6	13.51	28.0	7.48	6.03	39.33	45.84	Very High
G22F	66.2	1073	1695.6	21.36	318.5	18.8%	368.6	24.72	268.4	18.00	6.72	318.51	118.46	Very High
G22G	107.2	1718	866.1	7.19	66.9	7.7%	82.6	8.87	51.2	5.50	3.37	66.93	32.10	Very High
G22H	229.1	3666	787.7	14.08	61.4	7.8%	76.4	17.51	46.5	10.64	6.87	61.44	48.96	High
G22J	129.2	2070	1181.7	21.56	166.7	14.1%	195.3	25.27	138.1	17.86	7.41	166.69	56.95	Very High
G22K	80.4	1274	945.0	7.24	90.9	9.6%	109.4	8.71	72.4	5.76	2.95	90.91	38.27	Very High
G30A	768.6	12147	308.9	7.63	10.1	3.3%	13.6	10.32	6.5	4.95	5.37	10.05	37.47	High
G30B	663.8	10635	478.5	13.25	19.9	4.2%	26.3	17.49	13.5	9.00	8.49	19.93	30.93	High

Catch-ment No.	Area (km^2)	Cells	CCWR Map (mm/yr)	Mean Recharge ($x10^6$ m^3/yr)	Mean Recharge (mm/yr)	Recharge Factor (%)	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ m^3/a/km^2)	Harvest Potential ($x10^3$ m^3/a/km^2)	Groundwater Development Potential Rating
G30C	354.2	5667	477.5	8.04	22.7	4.8%	30.1	10.65	15.3	5.43	5.22	22.71	33.78	Very High
G30D	539.2	8630	456.1	10.80	20.0	4.4%	26.4	14.26	13.6	7.35	6.91	20.03	35.43	High
G30E	355.3	5679	291.1	3.43	9.7	3.3%	13.1	4.63	6.3	2.22	2.41	9.66	21.58	Very High
G30F	787.0	12584	336.8	9.96	12.7	3.8%	17.0	13.36	8.3	6.55	6.81	12.66	26.38	Very High
G30G	653.1	10431	311.6	7.23	11.1	3.6%	15.0	9.74	7.2	4.72	5.03	11.09	22.78	High
G30H	1087.5	17335	258.4	7.91	7.3	2.8%	10.0	10.81	4.6	5.02	5.78	7.30	10.83	Moderate
G40A	72.1	1156	1337.7	13.47	186.4	13.9%	217.9	15.74	154.9	11.19	4.55	186.39	113.84	Very High
G40B	123.4	1888	1086.9	14.21	120.4	11.1%	144.4	17.04	96.5	11.39	5.65	120.42	106.73	Very High
G40C	145.7	2331	1600.1	41.87	287.4	18.0%	333.4	48.57	241.5	35.18	13.39	287.40	126.26	Very High
G40D	329.6	5268	1150.4	46.55	141.4	12.3%	167.7	55.22	115.0	37.88	17.34	141.38	118.69	Very High
G40E	279.5	4482	843.1	20.48	73.1	8.7%	90.3	25.29	56.0	15.68	9.62	73.13	67.79	Very High
G40F	425.3	6804	605.6	15.15	35.6	5.9%	46.0	19.55	25.3	10.76	8.79	35.64	21.49	High
G40G	222.1	3412	825.6	14.76	69.2	8.4%	86.4	18.41	52.1	11.11	7.31	69.22	82.24	Very High
G40H	96.6	1532	817.2	6.44	67.3	8.2%	84.3	8.07	50.4	4.82	3.25	67.29	77.00	Very High
G40J	169.6	2711	730.2	8.82	52.0	7.1%	66.1	11.20	37.9	6.43	4.77	52.03	70.67	Very High
G40K	431.8	6918	572.5	13.21	30.5	5.3%	39.8	17.20	21.3	9.21	8.00	30.54	18.46	High
G40L	387.6	6164	659.2	17.15	44.5	6.8%	57.0	21.97	32.0	12.33	9.64	44.52	74.26	High
G40M	395.5	6339	668.1	17.96	45.3	6.8%	58.3	23.09	32.4	12.83	10.26	45.33	59.13	Very High
G50A	244.0	3880	633.0	9.79	40.4	6.4%	52.3	12.68	28.5	6.92	5.76	40.39	54.83	Very High
G50B	341.2	5507	620.8	13.31	38.7	6.2%	50.2	17.27	27.2	9.36	7.91	38.67	47.54	Very High
G50C	423.7	6830	569.7	13.22	31.0	5.4%	40.5	17.29	21.4	9.14	8.15	30.96	34.19	High
G50D	575.5	9218	510.5	14.26	24.8	4.8%	32.6	18.76	16.9	9.76	9.00	24.75	21.21	High
G50E	314.8	5035	525.3	8.50	27.0	5.1%	35.5	11.18	18.5	5.82	5.37	27.01	47.84	High
G50F	291.9	4607	532.2	8.16	28.3	5.3%	37.2	10.72	19.4	5.60	5.12	28.33	55.48	High
G50G	382.2	6158	435.7	6.57	17.1	3.9%	22.8	8.76	11.4	4.38	4.38	17.07	11.70	High
G50H	893.9	14346	434.8	15.45	17.2	4.0%	23.0	20.61	11.5	10.28	10.33	17.23	15.37	Moderate
G50J	518.9	8205	426.4	9.20	18.0	4.2%	23.9	12.28	11.9	6.13	6.15	17.95	52.63	Moderate

Catch-ment No.	Area (km^2)	Cells	CCWR Map (mm/yr)	Mean Recharge ($x10^6$ m^3/yr)	Mean Recharge (mm/yr)	Recharge Factor	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ m^3/a/km^2)	Harvest Potential ($x10^3$ m^3/a/km^2)	Groundwater Development Potential Rating
G50K	163.4	2568	527.5	4.62	28.8	5.5%	37.7	6.06	19.7	3.16	2.89	28.76	55.93	High
H10A	235.2	3764	627.7	8.90	37.9	6.0%	48.2	11.35	27.5	6.46	4.88	37.85	13.48	Very High
H10B	163.5	2621	903.6	15.55	94.9	10.5%	114.7	18.78	75.2	12.31	6.47	94.91	72.32	High
H10C	261.4	4188	815.0	17.99	68.7	8.4%	85.0	22.24	52.5	13.74	8.50	68.72	64.15	Very High
H10D	97.6	1573	1157.9	14.31	145.6	12.6%	174.1	17.11	117.1	11.51	5.60	145.58	96.95	Moderate
H10E	85.4	1388	1652.6	24.75	285.3	17.3%	330.2	28.65	240.4	20.85	7.79	285.28	175.26	High
H10F	249.7	4010	955.2	23.86	95.2	10.0%	115.2	28.88	75.2	18.85	10.03	95.22	75.71	High
H10G	272.3	4384	940.1	25.76	94.0	10.0%	113.8	31.18	74.2	20.33	10.85	94.01	87.56	High
H10H	188.7	3042	1081.4	30.80	162.0	15.0%	190.5	36.22	133.5	25.37	10.85	161.99	65.70	High
H10J	215.3	3446	1847.6	85.27	395.9	21.4%	457.6	98.56	334.2	71.97	26.59	395.91	140.46	High
H10K	194.9	3110	1457.4	48.08	247.4	17.0%	288.6	56.09	206.1	40.07	16.02	247.36	141.73	High
H10L	96.4	1550	541.0	2.96	30.5	5.6%	39.6	3.84	21.4	2.08	1.76	30.51	49.00	High
H20A	141.3	2292	440.8	2.72	19.0	4.3%	25.1	3.60	12.9	1.84	1.75	18.99	26.47	Very High
H20B	125.1	2019	737.4	9.32	73.8	10.0%	89.2	11.26	58.5	7.38	3.88	73.84	55.14	High
H20C	81.1	1309	751.8	4.98	60.9	8.1%	75.8	6.20	46.1	3.77	2.43	60.92	73.28	Moderate
H20D	101.3	1630	876.2	8.53	83.8	9.6%	103.4	10.53	64.1	6.53	4.00	83.75	93.59	Moderate
H20E	95.8	1554	1237.9	18.28	188.2	15.2%	222.2	21.59	154.2	14.97	6.61	188.21	99.50	Moderate
H20F	117.3	1877	950.3	12.72	108.5	11.4%	130.7	15.34	86.2	10.11	5.23	108.47	67.70	High
H20G	85.6	1366	914.5	9.39	110.0	12.0%	131.7	11.24	88.3	7.54	3.70	109.98	62.77	High
H20H	89.6	1441	367.7	1.10	12.2	3.3%	16.4	1.48	8.0	0.72	0.75	12.22	29.11	High
H30A	285.5	4572	545.6	9.32	32.6	6.0%	41.7	11.92	23.5	6.73	5.19	32.62	31.17	High
H30B	316.5	5068	465.0	6.68	21.1	4.5%	27.8	8.82	14.4	4.55	4.26	21.10	29.74	High
H30C	328.8	5299	605.2	13.61	41.1	6.8%	52.4	17.34	29.8	9.88	7.46	41.09	48.63	High
H30D	127.8	2048	496.3	3.87	30.3	6.1%	38.4	4.91	22.2	2.84	2.07	30.25	41.70	High
H30E	154.5	2485	534.9	4.65	29.9	5.6%	38.6	6.00	21.3	3.30	2.70	29.94	40.64	High
H40A	185.4	2978	539.0	5.86	31.5	5.8%	40.8	7.59	22.2	4.13	3.45	31.49	41.34	High
H40B	241.9	3863	788.7	19.88	82.3	10.4%	99.8	24.09	64.9	15.66	8.43	82.32	56.72	Moderate

Catch-ment No.	Area	Cells	CCWR Map (mm/yr)	Mean Recharge ($x10^6$ m^3/yr)	Mean Recharge	Factor (%)	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ $m^3/a/km^2$)	Harvest Potential ($x10^3$ $m^3/a/km^2$)	Groundwater Development Potential Rating
H40C	273.5	4380	468.1	8.68	31.7	6.8%	39.6	10.83	23.8	6.52	4.31	31.70	37.08	High
H40D	182.9	2942	721.8	12.51	68.0	9.4%	82.8	15.23	53.2	9.78	5.45	68.02	46.32	High
H40E	287.3	4604	668.9	17.38	60.4	9.0%	73.9	21.25	47.0	13.51	7.74	60.41	46.94	High
H40F	342.0	5501	367.1	4.43	12.9	3.5%	17.3	5.93	8.5	2.92	3.01	12.87	15.72	Moderate
H40G	265.0	4244	555.7	9.61	36.2	6.5%	45.8	12.14	26.7	7.08	5.06	36.24	29.29	High
H40H	209.1	3347	542.7	7.53	36.0	6.6%	45.2	9.44	26.8	5.61	3.83	35.98	33.55	High
H40J	204.7	3273	485.4	5.11	25.0	5.1%	32.2	6.59	17.8	3.64	2.95	24.99	38.44	High
H40K	272.1	4394	503.5	8.91	32.5	6.4%	40.9	11.22	24.1	6.60	4.62	32.46	55.23	High
H40L	159.8	2550	435.8	3.34	21.0	4.8%	27.0	4.30	15.0	2.38	1.92	20.97	38.15	High
H50A	265.9	4265	426.3	5.47	20.5	4.8%	26.6	7.08	14.5	3.85	3.23	20.51	29.05	High
H50B	432.7	6935	461.0	9.72	22.4	4.9%	29.2	12.65	15.7	6.79	5.86	22.43	24.30	High
H60A	73.2	1187	2081.2	37.81	509.6	24.5%	587.5	43.59	431.7	32.03	11.56	509.62	145.91	Very High
H60B	211.5	3399	1340.0	41.57	195.7	14.6%	229.2	48.70	162.1	34.43	14.27	195.66	128.86	Very High
H60C	218.4	3505	1108.2	29.39	134.2	12.1%	159.9	35.03	108.4	23.75	11.29	134.16	93.33	High
H60D	228.3	3665	781.9	15.98	69.8	8.9%	85.6	19.61	53.9	12.35	7.25	69.76	59.88	Very High
H60E	171.6	2763	720.0	10.16	58.8	8.2%	72.9	12.59	44.7	7.72	4.87	58.82	48.39	Very High
H60F	165.9	2684	717.0	9.53	56.8	7.9%	70.7	11.86	42.9	7.20	4.66	56.82	51.34	Very High
H60G	142.1	2273	561.6	4.64	32.7	5.8%	42.2	5.99	23.2	3.29	2.70	32.67	17.70	High
H60H	254.4	4089	540.3	8.11	31.7	5.9%	40.6	10.36	22.9	5.85	4.52	31.72	34.34	High
H60J	294.7	4740	530.2	9.69	32.7	6.2%	41.7	12.35	23.7	7.03	5.31	32.71	27.51	High
H60K	263.5	4218	433.3	4.61	17.5	4.0%	23.3	6.14	11.7	3.08	3.06	17.48	15.26	High
H60L	231.4	3717	421.4	3.77	16.2	3.9%	21.7	5.04	10.8	2.50	2.54	16.23	13.20	High
H70A	224.8	3598	487.5	5.77	25.7	5.3%	33.0	7.42	18.4	4.13	3.29	25.67	18.20	Moderate
H70B	153.8	2467	775.5	10.52	68.2	8.8%	83.3	12.84	53.1	8.19	4.65	68.21	38.56	High
H70C	288.5	4652	468.1	6.73	23.1	4.9%	30.0	8.73	16.3	4.73	4.01	23.14	24.98	High
H70D	171.1	2753	725.9	9.95	57.9	8.0%	72.4	12.46	43.3	7.45	5.01	57.85	72.94	High
H70E	157.5	2530	805.1	11.73	74.2	9.2%	90.6	14.33	57.7	9.13	5.20	74.18	59.24	High

Catch-ment No.	Area (km^2)	Cells	CCWR Map (mm/yr)	Recharge	Mean Recharge (mm/yr)	Recharge Factor (%)	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ m^3/a/km^2)	Harvest Potential ($x10^3$ m^3/a/km^2)	Groundwater Development Potential Rating
H70F	121.4	1943	673.6	5.64	46.4	6.9%	58.1	7.06	34.8	4.22	2.84	46.44	24.56	High
H70G	654.7	10544	427.4	10.94	16.6	3.9%	22.2	14.60	11.1	7.29	7.30	16.61	12.06	Moderate
H70H	401.7	6426	456.3	7.86	19.6	4.3%	25.9	10.42	13.2	5.31	5.11	19.58	15.60	Moderate
H70J	553.1	8843	448.8	10.07	18.2	4.1%	24.3	13.40	12.2	6.74	6.66	18.23	15.49	Moderate
H70K	208.0	3221	549.0	5.85	29.1	5.3%	38.2	7.68	20.0	4.03	3.65	29.08	38.26	Moderate
H80A	149.5	2442	733.2	8.29	54.3	7.4%	68.8	10.49	39.9	6.09	4.40	54.34	68.06	High
H80B	123.4	1994	953.9	12.78	102.6	10.8%	123.5	15.39	81.7	10.18	5.20	102.58	98.86	High
H80C	285.8	4614	562.2	8.38	29.1	5.2%	37.9	10.93	20.2	5.82	5.11	29.06	59.94	Moderate
H80D	231.5	3738	478.3	4.86	20.8	4.3%	27.5	6.43	14.1	3.29	3.14	20.79	13.47	Moderate
H80E	374.6	5985	501.7	9.22	24.7	4.9%	32.5	12.15	16.8	6.30	5.85	24.66	43.18	Moderate
H80F	204.2	3224	613.1	7.59	37.6	6.1%	48.9	9.84	26.4	5.33	4.52	37.64	72.34	Moderate
H90A	179.6	2897	736.2	10.43	57.6	7.8%	72.3	13.09	42.9	7.77	5.32	57.60	59.75	High
H90B	118.5	1929	760.1	7.09	58.8	7.7%	74.3	8.95	43.3	5.22	3.73	58.79	68.66	High
H90C	218.2	3521	535.6	5.83	26.5	4.9%	34.7	7.63	18.3	4.02	3.61	26.49	59.96	Moderate
H90D	603.8	9684	499.5	14.28	23.6	4.7%	31.1	18.80	16.1	9.76	9.04	23.59	26.29	Moderate
H90E	496.9	7932	560.2	15.66	31.6	5.6%	41.3	20.47	21.9	10.87	9.60	31.58	70.63	Moderate
J11F	345.7	5594	277.8	2.62	7.5	2.7%	10.2	3.57	4.8	1.67	1.90	7.49	6.07	Moderate
J11H	653.6	10458	310.6	6.17	9.4	3.0%	12.8	8.37	6.1	3.97	4.40	9.44	13.63	Moderate
J11J	451.3	7333	384.2	7.37	16.1	4.2%	21.4	9.81	10.8	4.93	4.88	16.08	19.12	Moderate
J11K	517.4	8278	271.4	3.88	7.5	2.8%	10.2	5.26	4.8	2.49	2.77	7.50	10.88	Moderate
J12A	181.9	2955	552.3	7.19	38.9	7.0%	48.5	8.96	29.3	5.41	3.54	38.90	46.33	High
J12B	252.4	4037	331.2	2.64	10.5	3.2%	14.2	3.57	6.8	1.71	1.86	10.47	22.59	High
J12C	367.9	5912	363.6	4.73	12.8	3.5%	17.3	6.38	8.3	3.08	3.30	12.79	9.05	High
J12D	835.1	13362	346.5	9.89	11.8	3.4%	15.9	13.29	7.8	6.49	6.80	11.84	14.76	High
J12E	357.3	5701	389.1	5.21	14.6	3.8%	19.7	7.02	9.6	3.41	3.60	14.63	8.92	High
J12F	713.1	11429	305.4	7.57	10.6	3.5%	14.2	10.14	7.0	5.00	5.14	10.60	16.09	Moderate
J12G	764.0	12247	358.0	9.93	13.0	3.6%	17.4	13.34	8.5	6.51	6.83	12.97	12.20	Moderate

Catch-ment No.	Area (km^2)	Cells	CCWR Map (mm/yr)	Mean Recharge ($x10^6$ m^3/yr)	Mean Recharge (mm/yr)	Recharge Factor (%)	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ m^3/a/km^2)	Harvest Potential ($x10^3$ m^3/a/km^2)	Groundwater Development Potential Rating
J12H	551.5	8851	335.0	7.26	13.1	3.9%	17.4	9.63	8.8	4.89	4.74	13.13	20.81	Moderate
J12J	551.3	8816	313.7	5.45	9.9	3.2%	13.4	7.37	6.4	3.54	3.82	9.90	9.05	Moderate
J12K	518.6	8287	250.2	3.33	6.4	2.6%	8.8	4.53	4.1	2.13	2.40	6.43	8.40	Moderate
J12L	760.3	12200	384.5	12.98	17.0	4.4%	22.3	16.99	11.8	8.98	8.01	17.03	12.39	Moderate
J12M	484.6	7769	350.9	6.88	14.2	4.0%	18.6	9.04	9.7	4.73	4.31	14.18	18.75	High
J13A	519.5	8360	369.4	7.72	14.8	4.0%	19.6	10.24	9.9	5.19	5.05	14.77	15.77	Moderate
J13B	402.9	6560	368.9	5.76	14.1	3.8%	18.7	7.68	9.4	3.84	3.84	14.05	18.12	Moderate
J13C	436.2	6975	421.6	7.61	17.5	4.1%	23.2	10.10	11.8	5.12	4.97	17.45	15.65	Moderate
J23E	225.5	3616	389.8	3.79	16.8	4.3%	22.2	5.02	11.4	2.57	2.46	16.79	21.93	Low
J23F	478.5	7652	237.6	3.88	8.1	3.4%	10.7	5.13	5.5	2.62	2.51	8.10	10.13	Low
J23H	264.7	4256	253.5	2.50	9.4	3.7%	12.4	3.31	6.4	1.70	1.61	9.41	13.84	Low
J23J	229.1	3675	394.5	4.27	18.6	4.7%	24.4	5.61	12.8	2.93	2.68	18.60	29.84	Low
J24F	283.1	4532	287.6	2.37	8.4	2.9%	11.4	3.21	5.4	1.52	1.69	8.37	9.81	Low
J25A	354.5	5691	365.6	5.06	14.2	3.9%	19.0	6.77	9.4	3.35	3.42	14.24	37.32	Low
J25B	397.9	6381	398.9	7.00	17.5	4.4%	23.4	9.32	11.7	4.68	4.64	17.54	33.79	Moderate
J25C	181.0	2961	355.0	2.42	13.1	3.7%	17.6	3.26	8.5	1.58	1.68	13.06	40.15	Moderate
J25D	210.9	3381	448.1	4.84	22.9	5.1%	30.0	6.34	15.8	3.34	3.01	22.91	33.90	Moderate
J25E	287.2	4644	301.4	2.63	9.1	3.0%	12.3	3.57	5.9	1.70	1.88	9.08	40.16	Moderate
J31A	447.0	7180	550.0	15.63	34.8	6.3%	44.9	20.14	24.8	11.13	9.01	34.84	45.90	High
J31B	200.6	3213	426.8	3.89	19.4	4.5%	25.7	5.15	13.1	2.62	2.53	19.36	38.44	High
J31C	168.0	2696	450.1	3.38	20.1	4.5%	26.7	4.50	13.5	2.27	2.23	20.07	39.20	Moderate
J31D	303.8	4871	366.0	4.07	13.4	3.7%	17.9	5.44	8.8	2.69	2.75	13.36	25.22	Moderate
J32E	971.7	15523	297.0	8.67	8.9	3.0%	12.1	11.75	5.8	5.59	6.15	8.94	11.18	Moderate
J33A	449.8	7225	472.5	10.72	23.7	5.0%	31.1	14.06	16.3	7.37	6.69	23.73	36.32	Moderate
J33B	591.4	9493	549.9	19.07	32.1	5.8%	41.7	24.71	22.6	13.43	11.28	32.14	40.42	Moderate
J33C	428.7	6832	360.7	5.64	13.2	3.7%	17.7	7.56	8.7	3.72	3.84	13.21	18.83	Low
J33D	259.2	4149	518.4	7.65	29.5	5.7%	38.3	9.94	20.7	5.36	4.58	29.50	26.55	Moderate

Catch-ment No.	Area (km^2)	Cells	CCWR Map (mm/yr)	Mean Recharge ($x10^6$ m^3/yr)	Mean Recharge (mm/yr)	Recharge Factor (%)	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ $m^3/a/km^2$)	Harvest Potential ($x10^3$ $m^3/a/km^2$)	Groundwater Development Potential Rating
J33E	329.2	5294	557.2	11.06	33.4	6.0%	43.3	14.33	23.5	7.78	6.55	33.42	39.37	Moderate
J33F	366.3	5904	434.4	7.15	19.4	4.5%	25.5	9.42	13.2	4.88	4.54	19.39	41.33	Moderate
J34A	252.3	4055	552.2	8.72	34.4	6.2%	44.6	11.29	24.2	6.14	5.15	34.39	51.29	High
J34B	341.8	5533	669.8	17.05	49.3	7.4%	62.2	21.50	36.4	12.60	8.90	49.30	48.39	High
J34C	319.3	5126	790.0	21.43	66.9	8.5%	83.4	26.71	50.4	16.14	10.57	66.88	61.76	High
J34D	354.7	5691	578.6	12.47	35.1	6.1%	45.3	16.11	24.8	8.83	7.28	35.05	42.74	High
J34E	258.4	4194	543.9	7.87	30.0	5.5%	39.0	10.22	21.0	5.51	4.71	30.02	39.27	High
J34F	320.6	5131	498.9	8.65	27.0	5.4%	35.0	11.21	19.0	6.08	5.14	26.96	37.11	Moderate
J35A	428.2	6861	515.5	12.46	29.1	5.6%	37.6	16.11	20.5	8.81	7.30	29.05	38.16	Moderate
J35B	652.5	10455	488.0	17.67	27.0	5.5%	35.0	22.87	19.1	12.46	10.41	27.04	38.18	Moderate
J35C	265.1	4257	454.8	5.88	22.1	4.9%	29.1	7.74	15.1	4.01	3.73	22.09	43.63	Moderate
J35D	508.2	8124	495.5	13.10	25.8	5.2%	33.6	17.05	18.0	9.15	7.90	25.80	32.07	Moderate
J35E	215.7	3472	349.4	2.68	12.4	3.5%	16.6	3.60	8.1	1.77	1.84	12.37	36.85	Moderate
J35F	501.4	8070	432.1	10.47	20.8	4.8%	27.2	13.74	14.3	7.20	6.54	20.75	37.17	Moderate
J40A	454.6	7383	508.6	12.02	26.0	5.1%	34.2	15.79	17.9	8.25	7.55	26.04	29.74	Moderate
J40B	222.5	3582	517.7	6.08	27.2	5.2%	35.8	8.01	18.6	4.16	3.85	27.16	58.02	High
J40C	437.3	7009	622.2	16.97	38.7	6.2%	50.0	21.89	27.5	12.05	9.85	38.74	40.92	High
J40D	656.5	10528	516.9	16.36	24.9	4.8%	32.6	21.45	17.1	11.26	10.19	24.86	14.00	High
J40E	555.4	8890	526.1	14.90	26.8	5.1%	35.2	19.58	18.4	10.21	9.37	26.81	35.20	High
K10A	177.8	2670	530.5	4.61	27.6	5.2%	36.4	6.07	18.9	3.15	2.91	27.62	18.09	Very High
K10B	171.5	2799	532.6	4.71	26.9	5.1%	35.4	6.20	18.4	3.22	2.97	26.92	16.74	High
K10C	159.4	2588	591.4	6.01	37.2	6.3%	48.3	7.81	26.0	4.21	3.60	37.15	59.30	Very High
K10D	164.3	2632	532.9	4.43	26.9	5.1%	35.4	5.82	18.5	3.04	2.78	26.93	24.06	High
K10E	132.8	2155	822.8	9.75	72.4	8.8%	90.9	12.24	54.0	7.27	4.97	72.41	59.54	Very High
K10F	106.0	1698	574.8	3.40	32.1	5.6%	41.7	4.43	22.5	2.38	2.04	32.07	23.90	High
K20A	168.8	2682	833.6	12.30	73.4	8.8%	90.9	15.23	55.9	9.37	5.86	73.40	52.44	Very High
K30A	196.3	3121	886.4	16.49	84.5	9.5%	102.6	20.00	66.5	12.97	7.03	84.52	58.14	Very High

Catch-ment No.	Area (km^2)	Cells	CCWR Map (mm/yr)	Mean Recharge	Recharge (mm/yr)	Recharge Factor (%)	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ $m^3/a/km^2$)	Harvest Potential ($x10^3$ $m^3/a/km^2$)	Groundwater Development Potential Rating
K30B	138.8	2187	894.0	11.52	84.3	9.4%	102.5	14.02	66.0	9.02	5.00	84.27	52.14	Very High
K30C	190.4	3034	917.3	16.34	86.2	9.4%	105.6	20.03	66.8	12.66	7.37	86.17	55.28	Very High
K30D	178.1	2825	825.2	11.96	67.8	8.2%	84.9	14.98	50.7	8.96	6.03	67.77	58.94	Very High
K40A	87.6	1399	802.6	5.84	66.8	8.3%	84.0	7.35	49.6	4.33	3.01	66.79	93.14	Very High
K40B	111.7	1795	970.3	10.62	94.7	9.8%	115.3	12.93	74.0	8.30	4.63	94.65	74.08	Very High
K40C	99.7	1639	1053.6	11.30	110.4	10.5%	131.7	13.49	89.0	9.12	4.38	110.36	62.53	Very High
K40D	130.0	2001	859.5	8.61	68.9	8.0%	85.8	10.72	52.0	6.50	4.23	68.85	31.66	Very High
K40E	267.9	4255	975.3	26.21	98.5	10.1%	119.7	31.83	77.4	20.59	11.24	98.54	87.56	Very High
K50A	235.6	3817	967.0	23.28	97.6	10.1%	119.1	28.41	76.1	18.15	10.26	97.57	102.80	Very High
K50B	203.0	2960	995.5	19.18	103.7	10.4%	125.8	23.28	81.5	15.07	8.20	103.65	104.69	Very High
K60A	161.6	2663	786.8	10.59	63.6	8.1%	80.0	13.32	47.2	7.85	5.47	63.60	73.00	Very High
K60B	143.3	2289	888.8	12.00	83.9	9.4%	104.0	14.88	63.8	9.12	5.75	83.89	84.59	Very High
K60C	160.9	2577	847.0	11.82	73.4	8.7%	91.7	14.77	55.1	8.88	5.89	73.41	104.75	Very High
K60D	292.6	4695	938.2	27.77	94.6	10.1%	116.2	34.11	73.0	21.43	12.68	94.64	98.56	Very High
K60E	100.2	1603	882.3	8.30	82.9	9.4%	102.5	10.27	63.2	6.33	3.93	82.85	103.97	Very High
K60F	242.2	3880	915.2	20.67	85.3	9.3%	104.8	25.40	65.8	15.94	9.46	85.25	86.21	Very High
K60G	166.7	2575	965.8	15.75	97.9	10.1%	119.1	19.16	76.7	12.34	6.83	97.86	84.61	Very High
K70A	170.4	2703	1047.5	20.05	118.7	11.3%	142.9	24.13	95.1	16.07	8.06	118.68	111.51	Very High
K70B	106.5	1688	1143.5	14.68	139.1	12.2%	165.9	17.50	112.3	11.85	5.66	139.11	112.03	Very High
K80A	145.9	2333	1190.1	22.22	152.4	12.8%	180.2	26.27	124.7	18.18	8.09	152.41	114.15	Very High
K80B	208.3	3340	1190.4	31.76	152.2	12.8%	179.7	37.52	124.7	26.04	11.48	152.16	115.51	Very High
K80C	188.8	3001	1155.3	26.98	143.9	12.5%	170.5	31.97	117.3	22.00	9.97	143.87	115.86	Very High
K80D	173.0	2771	1090.2	22.50	129.9	11.9%	156.0	27.01	103.9	17.99	9.02	129.93	111.67	Very High
K80E	265.8	4260	1032.0	30.76	115.5	11.2%	140.0	37.29	91.1	24.24	13.05	115.54	104.60	High
K80F	220.9	3483	886.8	18.11	83.2	9.4%	103.4	22.50	63.1	13.73	8.77	83.20	102.73	High
K90A	213.6	3418	857.4	16.88	79.0	9.2%	98.5	21.04	59.5	12.72	8.32	79.01	86.03	High
K90B	149.6	2431	903.1	13.15	86.6	9.6%	107.2	16.29	65.9	10.01	6.29	86.55	83.74	High

Catch-ment No.	Area (km^2)	Cells	CCWR Map (mm/yr)	Mean Recharge ($x10^6$ m^3/yr)	Mean Recharge (mm/yr)	Recharge Factor	Upper recharge (mm/yr)	Upper Recharge ($x10^6$ m^3/yr)	Lower recharge (mm/yr)	Lower Recharge ($x10^6$ m^3/yr)	Hi-Low ($x10^6$ m^3/yr)	Mean Recharge ($x10^3$ m^3/a/km^2)	Harvest Potential ($x10^3$ m^3/a/km^2)	Groundwater Development Potential Rating
K90C	267.0	4292	703.0	14.32	53.4	7.6%	68.3	18.32	38.5	10.33	7.99	53.39	75.64	Moderate
K90D	215.3	3460	808.7	14.36	66.4	8.2%	83.4	18.04	49.4	10.68	7.36	66.42	55.13	Very High
K90E	176.4	2743	774.5	9.85	57.5	7.4%	72.7	12.46	42.3	7.25	5.20	57.48	42.43	Very High
K90F	250.3	4004	818.8	17.16	68.6	8.4%	85.8	21.46	51.4	12.86	8.60	68.57	55.49	High
K90G	286.5	4556	769.2	16.94	59.5	7.7%	75.4	21.48	43.6	12.41	9.07	59.50	45.07	High
L30A	360.9	5787	356.1	4.33	12.0	3.4%	16.1	5.84	7.8	2.82	3.02	11.97	8.07	Moderate
L30D	551.9	8803	318.8	5.34	9.7	3.0%	13.2	7.25	6.2	3.43	3.82	9.70	8.00	Low
L50A	466.6	7472	381.1	6.76	14.5	3.8%	19.4	9.03	9.6	4.49	4.55	14.48	12.33	Moderate
L50B	557.0	8884	335.8	6.13	11.1	3.3%	14.9	8.29	7.2	3.98	4.32	11.05	7.84	Low
L70A	581.7	9306	317.8	5.99	10.3	3.2%	13.9	8.06	6.8	3.93	4.13	10.30	12.61	Low
L70B	440.6	7017	268.5	3.05	6.9	2.6%	9.5	4.16	4.4	1.93	2.23	6.94	8.32	Low
L70C	661.9	10614	292.0	6.01	9.1	3.1%	12.2	8.07	6.0	3.95	4.13	9.06	15.68	Low
L70D	535.8	8577	311.1	4.99	9.3	3.0%	12.6	6.77	6.0	3.21	3.55	9.31	11.52	Low
L70E	701.7	11239	343.9	7.32	10.4	3.0%	14.1	9.90	6.7	4.73	5.16	10.41	10.70	Low
L70F	306.4	4926	397.6	4.90	15.9	4.0%	21.2	6.53	10.7	3.28	3.25	15.93	26.70	Low
L70G	469.7	7524	601.5	17.98	38.2	6.4%	49.6	23.32	26.9	12.64	10.68	38.23	56.17	Moderate
L81A	332.2	5361	676.2	18.25	54.5	8.1%	68.6	22.99	40.3	13.51	9.48	54.47	60.35	High
L81B	261.2	4177	525.5	8.10	31.0	5.9%	40.4	10.54	21.7	5.66	4.88	31.02	60.43	Moderate
L81C	332.1	5406	539.0	11.06	32.7	6.1%	42.5	14.37	22.9	7.75	6.62	32.74	61.97	Moderate
L81D	307.7	4973	485.1	7.90	25.4	5.2%	33.5	10.42	17.3	5.39	5.03	25.42	60.68	Moderate
L82A	269.3	4354	705.2	14.99	55.1	7.8%	70.1	19.06	40.1	10.91	8.15	55.08	68.89	High
L82B	404.9	6519	809.9	30.69	75.3	9.3%	93.6	38.12	57.1	23.26	14.86	75.32	70.77	High
L82C	362.2	5825	802.6	26.03	71.5	8.9%	89.6	32.62	53.4	19.45	13.18	71.51	75.53	Very High
L82D	591.0	9477	745.2	36.69	61.9	8.3%	77.9	46.14	46.0	27.24	18.90	61.94	75.53	High
L82E	365.1	5878	710.2	19.95	54.3	7.6%	69.3	25.45	39.4	14.46	11.00	54.32	67.30	High
L82F	168.6	2714	624.7	7.20	42.5	6.8%	55.1	9.35	29.8	5.05	4.30	42.45	61.02	Moderate
L82G	265.3	4248	564.8	9.12	34.3	6.1%	44.9	11.92	23.8	6.31	5.61	34.34	66.62	Moderate

Catch-ment No.	Area (km²)	Cells	CCWR Map (mm/yr)	Mean Recharge (x10⁶ m³/yr)	Mean Recharge (mm/yr)	Recharge Factor (%)	Upper recharge (mm/yr)	Recharge (x10⁶ m³/yr)	Lower recharge (mm/yr)	Lower Recharge (x10⁶ m³/yr)	Hi-Low (x10⁶ m³/yr)	Mean Recharge (x10³ m³/a/km²)	Harvest Potential (x10³ m³/a/km²)	Groundwater Development Potential Rating
L82H	229.9	3691	536.5	6.98	30.3	5.6%	39.8	9.19	20.7	4.78	4.41	30.28	62.12	Moderate
L82J	164.0	2652	578.9	6.02	36.3	6.3%	47.4	7.86	25.2	4.18	3.68	36.31	67.54	Moderate
L90A	515.9	8258	642.4	21.66	42.0	6.5%	54.2	27.96	29.8	15.36	12.60	41.97	43.28	High
L90B	365.8	5860	706.7	18.05	49.3	7.0%	62.9	23.05	35.6	13.05	10.00	49.29	30.20	High
L90C	318.9	5114	717.9	17.00	53.2	7.4%	67.4	21.54	39.0	12.47	9.06	53.20	38.26	High
M10A	264.3	4251	662.6	12.78	48.1	7.3%	62.1	16.50	34.1	9.06	7.45	48.10	57.32	High
M10B	392.9	6284	673.3	17.80	45.3	6.7%	58.2	22.87	32.4	12.74	10.13	45.33	47.34	Moderate
M10C	429.9	6883	675.2	19.55	45.5	6.7%	58.3	25.08	32.6	14.02	11.06	45.45	42.54	High
M10D	306.5	4850	555.8	8.69	28.7	5.2%	37.4	11.33	20.0	6.06	5.27	28.68	26.04	Moderate
M20A	361.5	5707	809.7	24.28	68.1	8.4%	85.3	30.42	50.9	18.15	12.27	68.07	70.70	Very High
M20B	307.5	4933	844.9	21.95	71.2	8.4%	89.0	27.45	53.3	16.44	11.01	71.19	47.31	High
M30A	257.8	4123	542.0	7.05	27.4	5.1%	35.9	9.24	18.9	4.87	4.37	27.38	24.58	Low
M30B	306.6	4858	521.8	6.68	22.0	4.2%	29.0	8.81	15.0	4.55	4.27	22.00	16.11	Low
N40B	1209.7	19312	398.1	17.81	14.8	3.7%	19.7	23.81	9.8	11.82	11.99	14.76	16.47	Low
N40C	580.0	9307	619.7	20.34	35.0	5.6%	45.3	26.34	24.7	14.35	12.00	34.97	13.14	Low
N40D	668.8	10703	576.8	19.37	29.0	5.0%	37.8	25.30	20.1	13.44	11.86	28.96	13.44	Low
N40E	510.1	8160	446.5	8.79	17.2	3.9%	23.0	11.72	11.5	5.86	5.86	17.23	18.07	Low
TOTAL	**116,686.7**	**1,867,419**	**612.3**	**3,770.30**		**6.4%**		**4,746.66**		**2,794.14**				

*Coincidence of Ecological Importance and Groundwater Development Potential

APPENDIX IV

SUMMARY OF THE BOREHOLE YIELD, DEPTH AND ELECTRICAL CONDUCTIVITY OF THE DRAINAGE REGIONS

Catchment No.	No. DWAF NGDB of boreholes	Average Yield (l/s)	Minimum Yield (l/s)	Maximum Yield (l/s)	Standard Deviation	No. of boreholes for yield statistics	Average Borehole Depth (m)	Minimum Borehole Depth (m)	Maximum Borehole Depth (m)	Standard Deviation	No. of boreholes for depth statistics	No. of WSM Boreholes	Average Ec (mS/m)	Minimum Ec (mS/m)	Maximum Ec (mS/m)	Standard Deviation	No. of boreholes for yield statistics
E10A	32	10.26	2.00	20.00	4.99	24.00	94.75	0.00	145.00	38.44	32	2	20.20	18.70	21.70	2.12	2
E10B	11	13.50	4.29	22.71	13.02	2.00	68.63	35.00	110.00	31.51	11	12	24.60	0.00	177.00	51.59	12
E10C	3	6.08	2.00	8.75	3.59	3.00	100.00	0.00	170.00	88.88	3	1	8.40	8.40	8.40	0.00	1
E10D	66	5.56	0.02	29.16	8.62	21.00	823.44	0.00	-999.99	2647.75	66	81	6.90	0.00	35.30	7.34	81
E10E	192	4.06	0.13	22.73	5.04	71.00	2739.81	0.00	-999.99	4379.60	192	124	24.33	0.00	1138.00	108.51	124
E10F	114	5.12	0.01	22.70	6.44	26.00	707.91	12.00	-999.99	2388.42	114	71	15.44	0.00	190.00	28.31	71
E10G	110	5.86	0.04	30.12	8.02	37.00	73.99	0.00	220.00	43.99	110	76	26.04	0.00	603.00	77.77	76
E10H	4	22.75	22.75	22.75	0.00	1.00	50.00	40.00	80.00	20.00	4						
E10J	143	6.26	0.01	37.50	9.19	48.00	997.54	0.00	-999.99	2862.48	143	59	53.81	0.00	648.00	95.85	59
E10K	66	1.28	0.01	6.67	1.76	28.00	990.46	0.00	-999.99	2873.62	66	9	116.00	0.00	403.00	134.67	9
E21A	80	7.96	0.10	18.80	6.50	13.00	49.62	30.00	150.00	28.91	80	94	30.14	0.00	533.00	70.72	94
E21B	65	7.88	0.05	26.52	7.03	15.00	68.29	0.00	180.00	38.05	65	26	75.05	0.00	315.00	90.02	26
E21C	14	9.38	6.25	12.50	4.42	2.00	93.73	12.20	145.00	38.01	14	15	13.94	0.00	76.70	19.85	15
E21D	50	7.89	3.15	12.50	4.57	7.00	47.87	30.00	120.00	21.12	50	65	17.26	0.00	117.30	27.00	65
E21E	10	3.96	0.51	6.31	3.05	3.00	48.65	30.00	95.00	18.31	10	11	17.70	0.00	128.70	37.32	11
E21F	13	1.34	0.04	5.00	2.06	5.00	81.45	21.34	180.00	46.80	13	2	15.40	13.00	17.80	3.39	2
E21G	33	5.77	2.39	10.09	3.34	5.00	50.85	2.00	120.00	29.02	33	53	26.96	0.00	190.00	41.17	53
E21H	22	3.04	1.05	5.55	1.74	11.00	648.99	0.00	-999.99	2123.98	22	9	2.49	0.00	7.00	2.74	9
E21J	24	1.08	0.21	3.30	0.98	8.00	487.28	0.00	-999.99	2026.67	24	23	47.21	0.00	270.00	79.73	23
E21K	24	6.05	0.01	22.76	8.83	11.00	61.83	27.00	184.00	43.22	24	10	9.39	0.00	20.30	9.27	10
E21L	6	0.21	0.09	0.29	0.11	3.00	88.26	46.60	134.00	36.60	6						
E22C	23	8.91	0.38	22.50	7.61	16.00	74.01	0.00	200.00	52.13	23	13	97.94	17.70	489.00	123.88	13
E22D	6	0.35	0.25	0.63	0.19	4.00	54.23	12.20	80.00	29.60	6	6	871.22	249.00	2183.10	778.64	6
E22E	15	2.39	1.00	4.42	1.45	6.00	44.94	0.00	100.58	35.12	15	8	358.05	18.30	1165.00	387.02	8
E22G	40	0.68	0.14	1.90	0.82	4.00	71.27	7.92	206.65	39.71	40	2	49.55	0.00	99.10	70.07	2
E24A	10	3.80	3.80	3.80	0.00	1.00	33.33	18.28	35.00	5.29	10						
E24B	24	2.03	0.22	10.00	2.73	13.00	899.65	18.00	-999.99	2803.03	24						
E24D	54	1.47	0.36	2.86	1.30	4.00	69.22	10.36	146.00	29.07	54						
E24E	100	1.17	0.01	25.30	3.14	71.00	61.00	0.00	207.00	47.03	100	8	359.36	106.00	996.00	307.25	8
E24F	85	1.78	0.01	18.90	3.21	51.00	64.42	2.00	215.00	39.27	85	3	269.20	250.20	282.20	16.82	3
E24G	87	1.57	0.01	8.00	1.84	35.00	85.06	0.00	330.00	55.10	87	5	314.60	151.00	494.00	122.48	5
E24H	30	2.35	0.23	5.15	2.25	6.00	59.90	15.20	165.20	35.28	30	2	202.00	0.00	404.00	285.67	2
E24J	218	8.74	0.02	68.10	12.24	80.00	1439.50	0.00	-999.99	3427.80	218	67	167.42	0.00	801.40	222.74	67
E24K	146	1.39	0.01	16.67	2.71	63.00	79.76	0.00	204.21	53.18	146	6	406.80	140.00	1045.00	335.56	6

Catchment No.	No. DWAF NGDB of boreholes	Average Yield (l/s)	Minimum Yield (l/s)	Maximum Yield (l/s)	Standard Deviation	No. of boreholes for yield statistics	Average Borehole Depth (m)	Minimum Borehole Depth (m)	Maximum Borehole Depth (m)	Standard Deviation	No. of boreholes for depth statistics	No. of WSM Boreholes	Average Ec (mS/m)	Minimum Ec (mS/m)	Maximum Ec (mS/m)	Standard Deviation	No. of boreholes for yield statistics
E24L	172	12.28	0.01	62.50	18.55	78.00	1454.31	0.00	-999.99	3452.29	172	64	46.93	0.00	646.00	109.73	64
E24M	160	1.11	0.02	10.00	1.47	60.00	1075.60	0.00	-999.99	2985.35	160	39	113.69	0.00	562.00	137.11	39
E31H	51	1.30	0.01	20.50	4.32	22.00	62.48	0.00	116.00	29.10	51	8	475.83	144.00	879.00	244.96	8
E32E	208	1.11	0.01	12.60	1.99	112.00	69.18	0.00	401.00	54.24	208	14	394.36	35.20	1440.00	379.48	14
E33A	154	0.64	0.01	4.84	0.93	68.00	84.34	3.66	174.00	37.61	154	11	510.45	178.00	1253.00	292.74	11
E33B	36	2.23	0.03	16.60	4.35	14.00	76.37	0.00	158.00	39.17	36	6	1151.90	505.00	2070.00	584.26	6
E33C	76	0.94	0.01	9.00	1.62	32.00	73.38	0.00	183.20	45.50	76	11	487.25	143.00	988.00	287.58	11
E33D	290	1.78	0.01	33.10	5.05	185.00	81.74	0.00	169.50	38.28	290	119	531.07	0.00	1541.40	247.04	119
E33E	183	1.00	0.01	12.50	1.73	76.00	120.94	0.00	-999.99	735.56	183	31	623.51	126.60	1142.00	246.15	31
E33F	539	7.18	0.04	804.41	48.38	277.00	88.31	0.00	-999.99	606.49	539	220	193.63	0.00	1996.80	188.30	220
E33G	161	4.96	0.01	40.20	9.17	88.00	84.34	0.00	202.69	49.16	161	16	298.14	53.40	600.00	154.01	16
E33H	96	0.82	0.01	9.50	1.53	64.00	76.20	0.00	195.07	45.03	96	12	520.48	0.00	1430.00	426.71	12
E40C	186	2.17	0.01	32.50	4.18	118.00	55.93	0.00	198.70	38.38	186	6	331.73	12.90	1216.20	476.15	6
E40D	36	3.01	0.13	10.10	3.27	17.00	60.45	0.00	252.00	61.56	36	6	125.52	8.60	400.00	151.98	6
F60B	114	0.85	0.02	5.00	1.08	61.00	58.68	0.00	130.45	32.84	114	144	719.42	0.00	6900.00	692.98	144
F60D	99	0.35	0.01	2.18	0.41	70.00	62.14	0.00	170.69	40.41	99	5	1189.60	709.00	1460.00	285.30	5
F60E	126	0.74	0.01	8.20	1.14	92.00	72.75	0.00	156.67	44.34	126	10	980.80	88.00	2770.00	771.70	10
G10A	58	3.15	0.08	16.30	3.93	26.00	47.77	0.00	185.00	46.90	58	7	14.99	8.30	42.00	12.09	7
G10B	20	2.78	2.52	3.03	0.36	2.00	13.70	0.00	70.41	23.32	20						
G10C	156	1.63	0.01	10.09	1.56	112.00	58.56	0.00	359.70	40.04	156	31	37.17	3.00	600.00	109.44	31
G10D	219	1.30	0.01	11.36	1.56	124.00	50.99	0.00	180.00	32.44	219	61	257.26	9.40	1031.50	227.23	61
G10E	36	3.61	0.16	8.83	2.80	20.00	66.43	0.00	152.00	35.67	36	2	189.80	9.60	370.00	254.84	2
G10F	94	1.97	0.06	17.07	2.66	56.00	67.18	0.00	305.00	40.98	94	24	444.85	23.00	2264.90	624.02	24
G10G	3	4.81	0.51	12.50	6.67	3.00	81.33	23.00	158.00	69.34	3						
G10H	107	2.62	0.19	9.40	2.74	13.00	4328.60	0.00	-999.99	4948.26	107	57	213.61	0.00	2000.00	320.99	57
G10J	198	1.13	0.01	7.57	1.67	69.00	47.44	0.00	420.00	43.54	198	63	487.59	42.10	2200.00	354.53	63
G10K	140	1.43	0.01	5.60	1.34	44.00	699.96	0.00	-999.99	2446.73	140	82	254.52	0.00	1500.00	377.99	82
G10L	896	1.72	0.01	37.80	4.16	413.00	112.24	0.00	-999.99	813.18	896	134	333.59	0.00	2188.80	371.81	134
G10M	950	2.10	0.01	54.00	5.79	241.00	948.91	0.00	-999.99	2875.52	950	634	423.98	0.00	10444.00	758.99	634
G21A	322	1.46	0.02	25.25	2.78	138.00	99.24	0.00	-999.99	784.54	322	198	162.42	17.00	1048.00	124.91	198
G21B	347	5.53	0.06	25.10	8.19	33.00	35.96	0.00	130.00	22.43	347	144	174.49	0.00	1122.70	248.42	144
G21C	69	0.69	0.01	5.00	0.99	42.00	198.36	0.00	-999.99	1197.99	69	54	142.62	0.00	1610.00	235.72	54
G21D	263	4.20	0.01	83.10	9.29	146.00	132.38	0.00	-999.99	866.75	263	272	195.30	0.00	2070.00	387.72	272
G21E	154	3.15	0.04	50.00	6.00	119.00	141.37	0.00	-999.99	800.48	154	128	237.41	0.00	2110.00	370.63	128

Catchment No.	No. DWAF NGDB of boreholes	Average Yield (l/s)	Minimum Yield (l/s)	Yield (l/s)	Standard Deviation	No. of boreholes for yield statistics	Average Borehole Depth (m)	Minimum Borehole Depth (m)	Maximum Borehole Depth (m)	Standard Deviation	No. of boreholes for depth statistics	No. of WSM Boreholes	Average Ec (mS/m)	Minimum Ec (mS/m)	Maximum Ec (mS/m)	Standard Deviation	No. of boreholes for yield statistics
G21F	38	3.29	0.40	15.00	3.91	27.00	48.91	0.00	110.00	30.76	38	74	181.78	0.00	1640.00	260.29	74
G22A	15	0.98	0.01	5.00	1.34	12.00	14.54	0.00	72.00	21.64	15	15	79.67	0.00	120.90	33.48	15
G22B	12	1.10	0.20	3.15	1.04	7.00	37.75	0.00	150.00	39.75	12	5	38.68	16.50	82.00	25.92	5
G22C	50	2.26	0.01	8.00	2.50	39.00	47.09	0.00	106.68	33.40	50	38	63.18	0.00	332.00	72.27	38
G22D	359	13.47	0.05	110.30	23.46	41.00	10.26	0.00	228.00	22.10	359	635	88.46	14.50	221.80	22.08	635
G22E	136	1.67	-0.29	14.20	2.00	104.00	63.21	2.40	138.00	31.81	136	19	208.76	33.80	659.00	182.87	19
G22F	14	5.39	0.83	15.78	6.98	7.00	68.65	0.00	127.00	36.22	14	1	57.80	57.80	57.80	0.00	1
G22G	93	1.59	0.06	8.25	1.44	72.00	60.41	0.00	146.00	27.40	93	5	41.08	18.80	65.10	20.64	5
G22H	99	0.95	0.04	2.78	0.81	60.00	48.83	4.00	125.00	26.34	99	16	86.79	19.50	284.00	83.67	16
G22J	17	1.04	0.05	2.27	0.89	9.00	32.31	0.00	69.19	23.57	17	8	176.93	17.60	745.00	241.81	8
G22K	23	1.40	0.01	3.00	1.23	7.00	1336.66	0.00	-999.99	3430.85	23	14	180.28	18.90	885.00	234.02	14
G30A	177	4.55	0.01	28.00	7.33	75.00	1064.51	0.00	-999.99	3015.21	177	88	417.81	0.00	6830.00	870.49	88
G30B	173	3.95	0.17	21.47	5.50	14.00	7014.34	0.00	-999.99	4567.67	173	162	112.42	0.00	953.00	196.98	162
G30C	66	2.48	0.07	15.00	3.55	18.00	2047.86	0.00	-999.99	3968.89	66	46	27.01	0.00	121.90	35.10	46
G30D	99	4.61	0.10	38.89	10.36	13.00	4586.18	0.00	-999.99	4967.37	99	113	80.98	0.00	421.00	109.42	113
G30E	123	2.85	0.01	23.00	4.65	52.00	1354.64	0.00	-999.99	3357.18	123	161	1403.79	0.00	6200.00	2073.45	161
G30F	477	5.66	0.01	82.00	8.67	235.00	722.64	0.00	-999.99	2490.91	477	158	94.21	0.00	1161.70	144.23	158
G30G	473	2.54	0.01	51.60	5.14	248.00	100.55	0.00	-999.99	459.47	473	134	157.24	0.00	1530.00	248.05	134
G30H	431	1.32	0.01	38.40	3.25	228.00	77.95	0.00	351.00	47.28	431	108	315.04	0.00	1570.00	355.24	108
G40A																	
G40B	3	0.00	0.00	0.00	0.00	0.00	84.00	80.00	90.00	5.29	3	3	44.47	23.30	57.00	18.43	3
G40C	28	4.39	0.02	18.29	4.98	16.00	44.58	0.00	128.00	27.83	28						
G40D	108	3.10	0.01	24.38	3.91	54.00	60.51	0.00	165.00	37.24	108						
G40E	97	8.62	0.01	22.71	7.37	38.00	114.99	0.00	457.50	87.31	97						
G40F	66	4.25	0.01	25.25	6.46	49.00	84.18	0.00	275.00	50.50	66	26	27.10	18.00	103.10	16.24	26
G40G	12	2.00	0.07	7.06	2.74	8.00	86.45	30.00	190.50	65.01	12						
G40H	9	1.34	0.50	2.27	0.89	3.00	62.23	0.00	150.00	65.92	9	3	40.00	27.80	48.90	10.93	3
G40J	17	7.09	0.12	22.73	9.44	11.00	113.95	10.00	244.00	56.73	17	2	25.70	23.50	27.90	3.11	2
G40K	37	4.65	0.01	20.84	7.00	26.00	83.74	0.00	142.34	35.24	37						
G40L	148	5.30	0.18	29.30	7.12	54.00	1674.56	0.00	-999.99	3675.39	148	14	185.29	77.80	300.00	65.88	14
G40M	6	8.80	8.80	8.80	0.00	1.00	95.15	12.19	149.35	52.96	6						
G50A	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	1	154.00	154.00	154.00	0.00	1
G50B	1	3.70	3.70	3.70	0.00	1.00	39.30	39.30	39.30	0.00	1						
G50C	26	0.71	0.32	1.26	0.39	4.00	8087.58	18.00	-999.99	3996.91	26	4	373.50	218.00	657.00	204.18	4

Catchment No.	No. DWAF NGDB of boreholes	Average Yield (l/s)	Minimum Yield (l/s)	Maximum Yield (l/s)	Standard Deviation	No. of boreholes for yield statistics	Borehole Depth (m)	Minimum Borehole Depth (m)	Maximum Borehole Depth (m)	Standard Deviation	No. of boreholes for depth statistics	No. of WSM Boreholes	Average Ec (mS/m)	Ec (mS/m)	Maximum Ec (mS/m)	Standard Deviation	No. of boreholes for yield statistics
G50D	30	4.68	0.10	37.49	10.49	12.00	2052.74	0.00	-999.99	4041.74	30	1	5740.00	5740.00	5740.00	0.00	1
G50E	50	7.80	0.54	20.00	5.49	11.00	1839.76	0.00	-999.99	3862.71	50	17	57.94	0.00	85.20	16.71	17
G50F	70	10.14	1.51	32.00	7.74	15.00	3884.03	0.00	-999.99	4881.55	70	19	98.83	0.00	206.10	40.34	19
G50G	1	0.00	0.00	0.00	0.00	0.00	81.00	81.00	81.00	0.00	1	1	0.00	0.00	0.00	0.00	1
G50H	74	0.29	0.01	2.57	0.53	47.00	185.53	0.00	-999.99	1157.03	74	21	1702.60	89.20	6820.00	1721.13	21
G50J	46	0.35	0.10	1.72	0.60	7.00	1961.52	0.00	-999.99	4008.42	46	10	258.59	0.00	615.00	226.44	10
G50K	10	3.00	1.00	5.00	2.83	2.00	5000.00	0.00	-999.99	5270.46	10						
H10A	14	9.34	0.16	31.25	8.47	11.00	64.49	0.00	160.00	46.61	14	33	189.40	16.00	396.00	103.17	33
H10B	17	7.45	0.05	20.00	5.86	14.00	642.83	0.00	-999.99	2411.48	17	46	88.75	4.70	591.70	132.59	46
H10C	135	11.49	0.01	35.00	6.67	110.00	81.81	0.00	287.00	49.14	135	64	62.90	0.00	240.00	58.55	64
H10D	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2						
H10E																	
H10F	20	1.95	0.79	4.17	1.32	6.00	72.75	20.00	127.00	31.51	20	15	54.97	9.10	425.00	103.55	15
H10G	47	8.39	0.62	40.00	11.78	12.00	245.89	0.00	-999.99	1454.43	47	93	24.34	3.60	73.90	17.46	93
H10H	22	10.35	0.75	40.00	12.54	11.00	52.53	0.00	135.00	35.05	22	54	251.65	9.90	1314.00	307.84	54
H10J	5	8.24	4.54	15.14	5.98	3.00	21.88	0.00	43.28	21.65	5	3	10.13	7.00	15.70	4.83	3
H10K	8	4.12	0.03	10.09	3.86	5.00	28.16	0.00	64.62	22.16	8	1	15.50	15.50	15.50	0.00	1
H10L	21	2.37	0.05	10.00	3.03	10.00	48.32	0.00	150.00	40.89	21	51	43.29	5.00	484.30	95.82	51
H20A	29	7.60	0.01	22.00	7.33	20.00	92.42	0.00	270.00	70.09	29	85	73.42	0.80	686.70	91.60	85
H20B	88	5.30	0.01	100.00	13.22	58.00	192.61	0.00	-999.99	1059.63	88	344	76.09	0.60	975.20	112.83	344
H20C	2	8.15	3.80	12.50	6.15	2.00	102.50	80.00	125.00	31.82	2	2	14.55	9.70	19.40	6.86	2
H20D	2	0.90	0.01	1.79	1.26	2.00	53.34	35.36	71.32	25.43	2	12	37.34	2.80	197.90	57.89	12
H20E	2	2.00	2.00	2.00	0.00	1.00	54.00	48.00	60.00	8.49	2	15	8.39	0.80	49.50	14.50	15
H20F	57	3.97	0.09	13.00	3.46	20.00	74.36	0.00	270.00	69.21	57	302	37.52	0.80	167.10	28.69	302
H20G	6	6.11	0.25	20.00	8.17	5.00	34.50	14.00	56.00	15.62	6	3	10.60	5.40	18.70	7.11	3
H20H	17	3.97	0.08	18.93	6.60	15.00	85.78	12.95	153.00	43.25	17	2	135.15	17.00	253.30	167.09	2
H30A	27	6.44	0.20	15.00	3.92	17.00	36.67	0.00	137.00	36.41	27	9	144.14	71.20	247.00	60.82	9
H30B	14	11.05	0.15	68.00	17.85	13.00	60.17	0.00	148.00	42.25	14	6	230.30	41.80	346.00	112.87	6
H30C	18	4.28	0.12	13.75	3.43	17.00	61.92	0.00	137.16	34.98	18	21	82.74	7.20	327.00	91.85	21
H30D	4	3.10	3.10	3.10	0.00	2.00	2574.25	40.00	-999.99	4950.70	4	19	29.96	15.80	151.00	31.68	19
H30E	3	4.40	4.40	4.40	0.00	1.00	11.68	0.00	19.50	10.31	3	1	77.80	77.80	77.80	0.00	1
H40A	9	6.82	0.10	16.66	6.67	8.00	93.37	25.00	155.00	37.90	9	28	95.46	55.90	177.00	39.03	28
H40B	5	6.90	1.25	16.00	5.85	5.00	128.30	91.50	183.00	34.91	5	4	105.75	84.40	138.00	24.00	4
H40C	29	4.52	0.06	23.90	5.68	24.00	74.09	0.00	200.00	47.27	29	3	12.27	5.00	19.80	7.40	3

Catchment No.	No. DWAF NGDB of boreholes	Average Yield (l/s)	Minimum Yield (l/s)	Maximum Yield (l/s)	Standard Deviation	No. of boreholes for yield statistics	Average Borehole Depth (m)	Minimum Borehole Depth (m)	Borehole Depth (m)	Standard Deviation	No. of boreholes for depth statistics	No. of WSM Boreholes	Average Ec (mS/m)	Minimum Ec (mS/m)	Maximum Ec (mS/m)	Standard Deviation	No. of boreholes for yield statistics
H40D	19	9.30	0.63	37.80	10.22	15.00	61.39	0.00	163.00	41.78	19						
H40E	53	8.01	0.27	25.00	5.16	45.00	74.54	0.00	210.00	42.18	53						
H40F	3	9.49	0.08	18.90	13.31	2.00	58.67	0.00	116.00	58.01	3	17	67.69	3.10	514.00	119.44	17
H40G	69	6.04	0.20	18.90	4.36	67.00	69.98	0.00	183.00	42.49	69	3	139.87	13.60	242.00	116.10	3
H40H	45	8.42	0.10	30.00	9.14	40.00	60.57	3.00	244.00	42.78	45	2	244.10	63.20	425.00	255.83	2
H40J	22	5.72	0.60	22.70	6.28	21.00	83.93	0.00	232.00	56.79	22	5	200.38	19.70	619.00	247.28	5
H40K	34	11.15	0.75	26.50	7.23	31.00	70.48	0.00	122.00	39.96	34	4	210.83	18.40	781.00	380.12	4
H40L	50	1.09	0.10	7.60	1.98	27.00	56.46	10.00	100.00	28.97	50	6	575.67	352.00	803.00	173.13	6
H50A	1	0.00	0.00	0.00	0.00	0.00	91.50	91.50	91.50	0.00	1	1	550.00	550.00	550.00	0.00	1
H50B	8	4.75	0.10	18.22	6.05	8.00	57.31	0.00	120.00	43.34	8	3	394.90	21.70	800.00	390.13	3
H60A	46	11.21	1.24	22.70	5.33	25.00	107.72	0.00	305.00	65.31	46	5	23.24	11.40	33.10	7.79	5
H60B	53	8.98	1.00	17.68	4.36	31.00	129.83	0.00	503.00	80.02	53	2	30.30	23.20	37.40	10.04	2
H60C	35	6.49	0.46	18.94	5.90	25.00	66.91	0.00	255.00	45.12	35						
H60D	28	1.48	0.01	5.55	1.52	19.00	72.98	0.01	241.00	58.20	28						
H60E	13	1.57	0.03	6.49	2.51	6.00	57.79	0.00	120.00	46.41	13						
H60F												7	88.79	80.90	96.00	5.93	7
H60G	20	1.73	0.07	6.31	1.76	17.00	59.83	12.49	90.22	18.11	20						
H60H	19	1.17	0.06	5.04	1.47	19.00	62.56	18.29	121.92	31.76	19						
H60J												2	0.00	0.00	0.00	0.00	2
H60K	19	0.16	0.01	0.42	0.14	11.00	58.41	0.00	99.06	30.40	19	1	796.00	796.00	796.00	0.00	1
H60L	30	2.88	0.01	53.35	11.88	20.00	53.70	0.00	97.53	24.54	30	3	602.33	443.00	899.00	257.16	3
H70A	5	0.24	0.05	0.45	0.16	5.00	38.39	0.00	71.01	25.95	5	2	1061.50	925.00	1198.00	193.04	2
H70B	1	3.30	3.30	3.30	0.00	1.00	110.00	110.00	110.00	0.00	1	1	27.90	27.90	27.90	0.00	1
H70C	126	9.50	0.10	22.50	4.97	56.00	71.53	0.00	213.00	43.80	126						
H70D																	
H70E	1	0.00	0.00	0.00	0.00	0.00	68.58	68.58	68.58	0.00	1						
H70F																	
H70G	28	0.14	0.01	0.50	0.14	23.00	50.03	0.00	91.50	26.26	28	6	1094.67	454.00	1780.00	477.22	6
H70H	23	0.11	0.01	0.38	0.13	7.00	40.95	0.00	107.00	35.73	23	3	1119.67	120.00	2480.00	1220.64	3
H70J	28	0.14	0.01	0.50	0.14	17.00	56.38	0.00	139.90	33.31	28	5	835.00	361.00	1091.00	290.74	5
H70K	7	0.05	0.04	0.06	0.01	2.00	8.58	0.00	33.53	14.79	7	18	137.52	102.00	390.40	63.91	18
H80A	1	0.00	0.00	0.00	0.00	0.00	40.00	40.00	40.00	0.00	1						
H80B																	
H80C	10	1.98	0.15	6.67	3.13	4.00	78.80	18.29	136.00	41.58	10	1	809.00	809.00	809.00	0.00	1

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H80D	22	0.10	0.03	0.38	0.10	15.00	46.66	0.00	107.29	27.89	22	1	1470.00	1470.00	1470.00	0.00	1
H80E	11	0.69	0.03	2.84	0.89	10.00	37.75	12.00	65.00	21.34	11	1	89.00	89.00	89.00	0.00	1
H80F	4	0.30	0.30	0.30	0.00	1.00	53.25	0.01	97.00	41.36	4	7	153.74	74.70	561.00	179.72	7
H90A	3	0.00	0.00	0.00	0.00	0.00	77.22	68.58	91.44	12.41	3						
H90B																	
H90C	22	0.30	0.05	0.47	0.22	3.00	74.13	31.39	160.63	31.95	22						
H90D	92	0.34	0.02	2.08	0.64	10.00	21.90	0.01	142.00	28.95	92	11	257.64	71.00	638.00	165.88	11
H90E	136	1.72	0.01	7.00	2.02	15.00	116.23	0.01	-999.99	855.31	136	42	208.01	64.50	450.00	109.49	42
J11F	28	3.86	0.20	30.48	6.49	23.00	60.88	0.00	136.85	29.89	28	4	258.75	147.00	435.00	132.56	4
J11H	46	2.18	0.02	11.11	2.77	24.00	54.87	0.00	120.00	42.15	46	59	96.41	0.00	624.00	108.74	59
J11J	58	2.66	0.07	7.50	2.06	30.00	60.80	0.01	154.40	35.79	58	22	272.36	0.00	754.00	206.75	22
J11K	25	2.33	0.05	12.50	3.46	16.00	56.50	0.00	121.00	39.95	25	15	409.64	0.00	1059.30	345.68	15
J12A	3	6.55	0.25	15.00	7.61	3.00	97.00	80.00	107.00	14.80	3	3	94.83	31.50	211.00	100.74	3
J12B	41	4.87	0.25	21.21	5.31	30.00	88.90	0.00	250.00	47.32	41	11	415.53	109.90	900.60	246.71	11
J12C	76	5.02	0.08	20.20	5.60	46.00	115.03	6.00	296.00	79.35	76	9	152.57	18.20	649.20	194.22	9
J12D	51	4.76	0.01	20.25	5.71	44.00	74.30	0.00	240.00	50.07	51	14	244.91	16.10	779.20	192.48	14
J12E	19	5.52	0.25	24.22	6.07	18.00	81.46	9.00	137.00	31.78	19	6	137.70	14.40	437.00	175.21	6
J12F	26	2.08	0.06	13.75	3.50	16.00	72.73	0.00	213.50	59.93	26	10	306.52	70.20	640.00	190.51	10
J12G	25	1.67	0.25	12.50	2.93	19.00	68.69	30.00	122.00	26.88	25	11	296.05	30.20	603.00	188.28	11
J12H	40	4.27	0.01	17.68	5.41	33.00	321.81	9.14	-999.99	1569.84	40	13	225.03	22.90	537.00	185.60	13
J12J	60	4.27	0.05	15.00	3.44	35.00	57.57	0.00	180.00	40.86	60	7	285.63	35.30	803.00	269.11	7
J12K	11	1.28	0.15	5.00	1.96	11.00	33.55	0.00	78.00	34.19	11	10	507.66	66.60	1117.00	288.82	10
J12L	32	6.17	0.03	20.00	6.53	25.00	68.87	0.00	288.00	63.53	32	36	255.79	0.00	3000.00	520.83	36
J12M	8	18.46	5.00	37.88	17.23	3.00	19.19	0.00	62.00	28.15	8	2	187.00	146.00	228.00	57.98	2
J13A	52	4.78	0.06	30.28	6.19	30.00	36.57	0.00	91.00	23.26	52	13	221.21	0.00	919.70	285.01	13
J13B	31	2.55	0.10	10.00	2.52	18.00	39.36	0.00	114.00	27.52	31	24	425.47	20.50	1018.30	250.24	24
J13C	8	1.79	0.20	3.80	1.84	3.00	43.88	0.01	100.00	40.85	8	8	638.31	49.90	1411.30	472.10	8
J23E	1	13.00	13.00	13.00	0.00	1.00	110.00	110.00	110.00	0.00	1	2	189.45	151.90	227.00	53.10	2
J23F	39	2.76	0.01	12.60	3.00	27.00	62.05	0.00	136.00	37.25	39	36	175.23	2.80	439.00	102.20	36
J23H	7	1.85	0.10	3.28	1.38	4.00	52.59	36.88	75.29	13.98	7						
J23J																	
J24F	4	1.08	1.08	1.08	0.00	1.00	124.29	0.00	318.00	135.89	4	6	41.17	0.00	80.90	33.39	6
J25A	3	1.25	0.91	1.59	0.48	2.00	42.25	30.48	62.78	17.84	3						
J25B	96	6.29	0.01	27.78	8.22	40.00	72.36	0.00	307.00	59.44	96	7	52.73	0.00	80.10	28.60	7

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J25C	47	12.33	0.10	37.00	12.63	15.00	758.85	0.00	-999.99	2440.09	47	43	20.10	0.00	62.60	24.30	43
J25D	11	0.79	0.01	2.80	1.09	6.00	968.73	3.00	-999.99	2995.57	11	7	320.86	0.00	795.00	351.17	7
J25E	32	5.01	0.01	20.20	8.31	9.00	41.08	0.00	110.03	32.39	32	2	391.25	334.50	448.00	80.26	2
J31A	61	2.94	0.01	19.00	4.01	27.00	98.81	0.00	253.00	59.53	61	1	57.80	57.80	57.80	0.00	1
J31B	12	4.30	0.01	14.00	5.77	8.00	88.00	30.00	156.00	39.72	12	1	687.00	687.00	687.00	0.00	1
J31C	38	3.42	0.13	22.00	4.67	22.00	103.72	0.00	274.50	71.48	38						
J31D	33	2.65	0.06	9.09	3.01	23.00	83.81	10.00	181.00	50.76	33	21	54.54	0.00	568.00	127.12	21
J32E	69	1.42	0.01	10.00	2.40	42.00	203.20	0.00	-999.99	1197.85	69	15	56.74	0.00	333.00	108.95	15
J33A	62	2.52	0.06	24.00	4.20	44.00	77.35	0.00	222.00	53.44	62	7	372.79	0.00	1350.00	513.65	7
J33B	83	6.20	0.06	20.20	6.21	35.00	64.91	0.00	292.60	55.19	83	11	92.58	0.00	557.00	166.05	11
J33C	26	1.82	0.01	10.00	2.41	19.00	80.19	0.00	210.00	43.02	26	1	110.00	110.00	110.00	0.00	1
J33D	5	0.70	0.12	1.28	0.82	2.00	51.20	23.77	83.82	22.39	5						
J33E	347	12.33	0.01	400.00	41.65	194.00	221.99	0.00	-999.99	1186.37	347	180	16.80	0.00	221.00	36.61	180
J33F	304	11.88	0.01	600.00	52.53	164.00	301.07	0.00	-999.99	1493.39	304	96	58.32	0.00	715.00	120.86	96
J34A	18	1.25	0.25	2.58	0.84	8.00	656.93	30.00	-999.99	2332.05	18	28	36.91	0.00	257.00	49.72	28
J34B	23	1.48	0.01	6.66	2.00	12.00	110.75	0.00	210.00	63.38	23	14	97.89	0.00	249.00	87.88	14
J34C	43	1.81	0.01	17.67	3.93	24.00	86.60	0.00	200.00	57.50	43	4	11.98	0.00	26.40	13.97	4
J34D	95	3.40	0.01	22.71	4.51	65.00	503.43	0.00	-999.99	2002.14	95	32	19.55	0.00	155.00	34.95	32
J34E	28	3.00	0.01	25.24	6.00	17.00	56.17	12.19	173.43	42.44	28	2	25.40	0.00	50.80	35.92	2
J34F	59	7.28	0.03	22.22	7.54	39.00	53.02	0.00	142.34	34.89	59	8	121.95	0.00	341.00	150.28	8
J35A	112	8.45	0.01	27.80	7.84	49.00	72.13	0.00	359.70	59.64	112	21	43.25	0.00	224.00	48.91	21
J35B	243	11.41	0.05	25.00	8.22	138.00	221.84	0.00	-999.99	1268.11	243	27	135.12	0.00	666.00	181.33	27
J35C	72	12.06	0.05	25.00	9.00	37.00	186.15	0.00	-999.99	1173.49	72	2	66.00	0.00	132.00	93.34	2
J35D	128	4.29	0.12	18.70	5.03	33.00	63.12	0.00	289.60	49.46	128	45	250.62	2.60	2500.00	383.56	45
J35E	54	3.20	0.20	12.50	3.73	22.00	45.00	0.00	146.30	28.23	54	1	828.00	828.00	828.00	0.00	1
J35F	153	5.54	0.01	51.00	10.06	72.00	72.69	0.00	275.00	56.93	153	7	113.79	0.00	568.00	204.64	7
J40A	19	3.73	0.01	45.72	11.25	16.00	47.57	7.01	115.21	28.89	19						
J40B	8	1.64	0.28	4.26	1.74	5.00	86.00	0.01	309.00	97.27	8	3	214.93	128.80	357.00	123.96	3
J40C	29	6.50	0.03	23.00	8.44	11.00	73.38	0.01	182.88	47.11	29	4	673.00	191.00	1275.00	450.97	4
J40D	65	1.08	0.03	4.27	1.35	14.00	42.85	0.00	180.00	50.25	65	14	287.19	56.50	1202.00	340.46	14
J40E	157	1.83	0.01	8.30	2.25	60.00	50.75	0.00	193.00	51.17	157	23	289.14	53.60	1075.00	261.01	23
K10A	27	3.11	0.01	18.17	4.51	20.00	86.35	0.01	138.00	38.19	27	7	485.59	149.00	899.00	313.91	7
K10B	28	3.15	0.01	18.75	5.23	15.00	81.23	0.00	143.00	38.87	28	12	228.72	47.20	492.00	152.46	12
K10C	1	0.00	0.00	0.00	0.00	0.00	80.00	80.00	80.00	0.00	1						

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K10D	13	1.50	0.01	3.78	1.59	9.00	80.72	0.00	168.00	45.74	13	3	489.27	323.50	747.50	226.62	3
K10E	8	1.73	0.01	4.59	2.18	4.00	103.50	61.00	183.00	40.39	8	1	166.00	166.00	166.00	0.00	1
K10F	6	0.69	0.01	2.70	1.15	5.00	105.38	49.00	161.00	46.29	6						
K20A	9	1.93	0.60	4.15	1.53	5.00	59.06	0.00	122.53	51.54	9	2	507.00	484.00	530.00	32.53	2
K30A	19	0.55	0.01	1.25	0.45	15.00	102.92	0.00	392.05	98.62	19	4	311.75	79.00	740.00	296.19	4
K30B	13	0.72	0.20	1.08	0.35	7.00	80.45	0.00	161.00	50.65	13	20	39.37	10.00	93.30	19.13	20
K30C	6	0.66	0.03	1.25	0.50	6.00	109.83	71.32	138.68	29.63	6	2	252.50	199.00	306.00	75.66	2
K30D	5	0.65	0.02	1.40	0.59	5.00	84.60	0.00	161.00	71.88	5	2	128.50	11.00	246.00	166.17	2
K40A	1	1.25	1.25	1.25	0.00	1.00	30.00	30.00	30.00	0.00	1						
K40B	3	0.55	0.55	0.55	0.00	1.00	158.67	100.00	204.00	53.27	3						
K40C	1	1.40	1.40	1.40	0.00	1.00	150.00	150.00	150.00	0.00	1						
K40D	6	2.03	1.75	2.50	0.41	3.00	120.33	70.00	180.00	51.22	6	3	82.53	69.80	90.10	11.09	3
K40E	11	12.82	1.01	45.00	18.60	5.00	79.27	34.00	120.00	27.70	11						
K50A	2	0.00	0.00	0.00	0.00	0.00	145.00	140.00	150.00	7.07	2	1	26.90	26.90	26.90	0.00	1
K50B	3	0.31	0.28	0.33	0.04	2.00	40.73	29.87	60.96	17.54	3	4	35.83	21.50	48.50	13.92	4
K60A	10	1.95	0.64	3.65	1.14	6.00	85.37	40.08	137.46	25.16	10						
K60B	1	0.00	0.00	0.00	0.00	0.00	54.00	54.00	54.00	0.00	1	4	21.98	7.30	48.40	18.10	4
K60C	7	2.58	1.00	4.04	1.52	3.00	135.29	48.00	200.00	59.15	7	7	29.94	0.00	74.00	23.32	7
K60D																	
K60E	3	0.29	0.29	0.29	0.00	1.00	136.42	88.00	210.00	64.78	3	3	201.50	130.00	314.90	99.32	3
K60F	8	1.41	0.10	2.52	1.07	4.00	128.00	66.00	200.00	46.43	8	1	11.20	11.20	11.20	0.00	1
K60G	29	3.52	0.08	22.70	5.27	26.00	99.23	41.06	170.00	37.60	29	2	20.45	0.00	40.90	28.92	2
K70A	2	0.00	0.00	0.00	0.00	0.00	120.79	61.57	180.00	83.74	2	3	170.53	91.80	209.90	68.19	3
K70B																	
K80A																	
K80B												4	28.55	19.70	44.20	11.27	4
K80C	6	2.15	0.21	4.04	1.62	5.00	78.58	55.50	119.00	25.71	6						
K80D	15	0.00	0.00	0.00	0.00	0.00	79.87	10.06	192.00	45.05	15	1	0.00	0.00	0.00	0.00	1
K80E	33	0.94	0.04	3.16	0.99	12.00	71.47	30.50	130.00	27.98	33	30	81.44	0.00	861.00	152.11	30
K80F	38	1.52	0.04	5.37	1.61	16.00	90.29	46.00	196.00	34.21	38						
K90A	10	1.92	0.08	7.01	2.56	6.00	98.22	26.82	145.00	39.40	10	2	35.45	19.70	51.20	22.27	2
K90B	20	30.18	0.35	60.00	42.18	2.00	69.24	27.00	154.00	35.98	20	35	76.10	0.00	751.00	124.09	35
K90C	35	1.04	0.05	4.08	1.03	24.00	107.47	0.00	600.00	95.54	35	12	40.70	0.00	136.00	40.49	12
K90D	24	2.32	0.06	6.18	1.99	11.00	87.33	18.00	200.00	51.72	24						

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K90E	42	1.36	0.04	12.60	2.59	28.00	75.25	17.68	181.00	37.19	42	20	129.54	42.00	787.00	157.93	20
K90F	83	1.23	0.05	4.26	1.27	40.00	425.19	0.00	-999.99	1865.78	83	37	150.89	28.60	970.00	221.27	37
K90G	115	6.94	0.04	88.00	12.59	65.00	426.31	12.19	-999.99	1825.71	115	15	264.52	63.50	910.00	303.62	15
L30A	34	1.64	0.01	9.00	2.50	25.00	58.26	14.78	121.92	25.40	34	25	348.11	3.80	728.00	152.57	25
L30D	58	4.47	0.01	60.00	10.93	34.00	50.19	0.00	163.00	31.67	58	8	442.91	89.30	884.00	280.00	8
L50A	32	1.73	0.03	6.69	1.91	17.00	52.94	0.00	228.75	42.96	32	6	327.92	116.50	563.00	157.58	6
L50B	80	1.08	0.01	10.00	2.05	31.00	85.27	0.00	300.00	40.44	80	32	260.37	84.30	561.00	113.94	32
L70A	83	1.95	0.01	34.10	6.34	33.00	65.53	0.00	150.00	31.32	83						
L70B	90	2.53	0.01	13.00	3.81	35.00	185.93	18.00	-999.99	1046.59	90	263	466.66	14.00	2054.40	338.69	263
L70C	124	2.60	0.08	10.10	3.17	32.00	630.60	0.00	-999.99	2301.34	124	131	382.74	0.00	1752.20	305.27	131
L70D	124	1.06	0.02	11.37	2.04	34.00	792.67	11.00	-999.99	2586.47	124	64	206.37	0.00	862.00	224.14	64
L70E	147	1.14	0.03	12.00	1.87	48.00	275.89	0.00	-999.99	1408.80	147	10	360.52	77.70	1020.00	286.51	10
L70F	44	2.12	0.01	8.00	2.36	22.00	293.04	16.00	-999.99	1497.72	44	1	235.30	235.30	235.30	0.00	1
L70G	14	1.01	0.10	2.80	0.96	8.00	78.56	32.00	150.00	32.40	14						
L81A	45	2.30	0.02	16.46	4.09	18.00	104.65	6.70	801.00	121.43	45	7	51.09	18.50	70.80	16.53	7
L81B	21	3.10	0.02	13.97	4.01	11.00	79.16	12.80	138.38	35.99	21						
L81C	7	0.00	0.00	0.00	0.00	0.00	82.37	0.01	274.00	102.71	7	1	0.00	0.00	0.00	0.00	1
L81D												4	0.00	0.00	0.00	0.00	4
L82A	1	10.00	10.00	10.00	0.00	1.00	201.00	201.00	201.00	0.00	1	40	6.96	3.80	53.90	8.51	40
L82B	5	1.73	0.45	3.00	1.80	2.00	146.20	106.00	190.00	30.66	5	1	28.00	28.00	28.00	0.00	1
L82C	2	3.46	1.80	5.11	2.34	2.00	100.50	81.00	120.00	27.58	2						
L82D	47	3.04	0.01	11.50	3.26	33.00	69.99	0.00	169.00	37.93	47	30	34.77	8.00	210.00	45.48	30
L82E	18	0.35	0.01	0.77	0.33	7.00	80.86	27.00	210.00	54.60	18						
L82F	14	1.18	0.28	2.08	1.27	2.00	116.32	46.94	222.00	53.48	14						
L82G	18	0.51	0.08	2.90	0.81	11.00	97.90	58.83	150.00	29.48	18	12	43.91	0.00	216.00	57.64	12
L82H												3	36.57	0.00	99.40	54.66	3
L82J	10	0.45	0.13	0.75	0.31	3.00	90.32	48.00	133.50	28.99	10						
L90A	53	0.70	0.04	2.50	0.86	14.00	114.05	23.16	214.00	45.58	53	3	102.07	27.50	198.00	87.24	3
L90B	33	1.76	0.08	21.34	4.78	19.00	73.70	22.86	180.00	40.98	33	17	255.62	12.30	1360.00	355.51	17
L90C	29	1.90	0.06	4.07	1.46	22.00	65.76	0.01	190.00	52.07	29	12	235.48	29.70	458.00	151.18	12
M10A																	
M10B	28	0.85	0.01	2.05	0.70	13.00	94.66	0.00	174.00	58.98	28	10	58.27	10.60	309.00	89.08	10
M10C	228	15.27	0.01	704.79	87.82	132.00	356.83	0.00	-999.99	1590.62	228	693	472.37	0.00	6970.00	1050.14	693
M10D	54	2.30	0.06	13.46	4.10	10.00	411.79	0.00	-999.99	1898.74	54	248	1021.24	0.00	17500.00	2176.09	248

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M20A	48	0.90	0.02	4.00	1.04	29.00	107.31	13.71	222.00	53.02	48	14	167.29	9.90	475.00	126.01	14
M20B	65	1.31	0.04	7.50	1.89	47.00	96.20	0.01	640.00	83.70	65	65	221.04	0.00	959.00	202.07	65
M30A	99	1.76	0.01	32.30	5.74	31.00	104.98	0.00	305.60	59.37	99	28	595.05	0.00	3620.00	829.38	28
M30B	88	0.94	0.06	9.69	2.23	18.00	245.08	0.00	-999.99	1056.52	88	38	646.98	23.50	1465.00	566.50	38
N40B	175	3.23	0.02	18.95	4.40	79.00	71.86	1.00	271.27	49.51	175	31	402.48	21.00	1571.70	437.74	31
N40C	301	5.65	0.03	60.96	7.74	270.00	56.59	0.00	-999.99	575.91	301	14	577.23	5.60	861.00	233.63	14
N40D	61	10.36	0.10	243.84	45.86	28.00	249.56	0.01	-999.99	1270.62	61	22	289.27	37.80	1122.00	207.00	22
N40E	49	0.58	0.01	3.19	0.66	26.00	95.45	0.00	213.36	50.71	49	6	676.05	0.00	1940.00	723.05	6