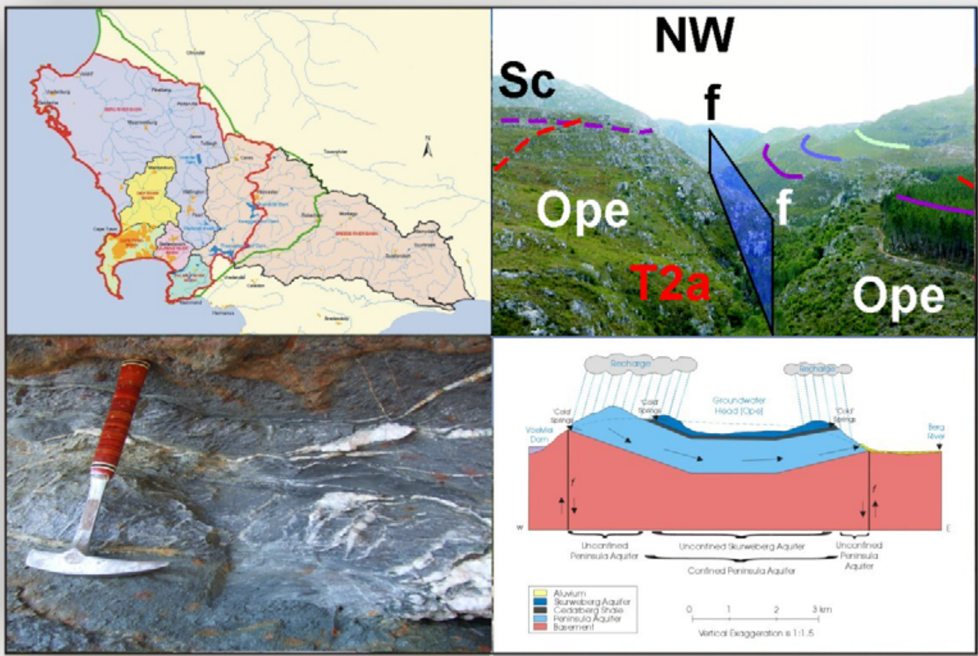
Ref No: P WMA19/000/00/0408

Department of Water Affairs and Forestry

Directorate: National Water Resource Planning

The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models

GROUNDWATER MODEL REPORT VOL. 3
REGIONAL CONCEPTUAL MODEL



FINAL **August 2008**

Submitted by
Umvoto Africa (Pty) Ltd
in Association with
Ninham Shand (Pty) Ltd

NINHAM SHAND CONSULTING SERVICES

UMVOTO

DEPARTMENT OF
WATER AFFAIRS AND FORESTRY

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS

GROUNDWATER MODEL REPORT VOLUME 3
REGIONAL CONCEPTUAL MODEL

Final

August 2008

Department of Water Affairs and Forestry
Directorate National Water Resource Planning

THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS

GROUNDWATER MODEL REPORT VOLUME 3
REGIONAL CONCEPTUAL MODEL

APPROVAL

TITLE	:	**The Assessment of Water Availability in the Berg Catchment (WMA 19) by Means of Water Resource Related Models :** **Groundwater Model Report Volume 3** **Regional Conceptual Model**
DWAF REPORT NO.	:	**P WMA 19/000/00/0408**
CONSULTANTS	:	**Umvoto Africa in association with Ninham Shand**
AUTHORS	:	**Chris Hartnady and Rowena Hay**
REPORT STATUS	:	**Final**
DATE	:	**August 2008**

STUDY TEAM: Approved for Umvoto and Ninham Shand

....
E.R HAY

....
A. Görgens

DEPARTMENT OF WATER AFFAIRS AND FORESTRY
Directorate National Water Resource Planning
Approved for Department of Water Affairs and Forestry

....
I THOMPSON
CE : NWRP (South)

....
J A VAN ROOYEN
Director : NWRP

REFERENCE

This report is to be referred to in bibliographies as :

Department of Water Affairs and Forestry, South Africa. 2008. *The Assessment of Water Availability in the Berg Catchment (WMA 19) by Means of Water Resource Related Models : Groundwater Model Report Volume 3 – Regional Conceptual Model*. Prepared by Umvoto Africa (Pty) Ltd in association with Ninham Shand (Pty) Ltd on behalf of the Directorate : National Water Resource Planning. DWAF Report No. P WMA 19/000/00/0408

REPORT No	REPORT TITLE	VOLUME No.	VOLUME TITLE
1	Final Summary Report		
2	Rainfall Data Preparation and MAP Surface		
3	The Assessment of Flow Gauging Stations		
4	Land Use and Water Requirements	Vol 1	Data in Support of Catchment Modelling
		Vol 2	Invasive Alien Plant Mapping
		Vol 3	Water Use and Water Requirements
5	Update of Catchment Hydrology	Vol 1	Berg River
		Vol 2	Upper Breede River
		Vol 3	Peripheral Rivers
6	Water Quality	Vol 1	A Literature Review of Water Quality Related Studies in the Berg WMA, 1994 - 2006
		Vol 2	Updating of the ACRU Salinity Model for the Berg River
		Vol 3	Update Monthly FLOSAL Model to WQT
7	(Report No Not Used)		
8	System Analysis Status Report		
9	Groundwater Model	Vol 1	Overview of Methodology and Results
		Vol 2	Data Availability and Evaluation
		Vol 3	Regional Conceptual Model
		Vol 4	Regional Water Balance Model
		Vol 5	Cape Flats Aquifer Model
		Vol 6	Langebaan Road and Elandsfontein Aquifer System Model
		Vol 7	TMG Aquifer, Piketberg Model
		Vol 8	TMG Aquifer, Witzenberg – Nuy Model
		Vol 9	Breede River Alluvium Aquifer Model
10	Berg and Mhlathuze Assessment Studies (Refer to Report No.1)		
11	Applicability of the Sami Groundwater Model to the Berg WAAS Area		

THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS

GROUNDWATER MODEL REPORT VOLUME 3
REGIONAL CONCEPTUAL MODEL

EXECUTIVE SUMMARY

INTRODUCTION

This Water Availability Assessment Study (WAAS) forms part of five studies commissioned nationally by DWAF to support, *inter alia*, allocable water quantification as a prerequisite for compulsory licensing. The main objectives of the Study are to (DWAF, 2005a):

- Reconfigure the existing Water Resources Yield Model (WRYM) configurations at a spatial resolution suitable for allocable water quantification to support compulsory licensing.
- Use reconfigured existing models or newly configured models for allocable water quantification for both surface water and groundwater, where applicable.

The Study comprises two phases: Phase 1 (Inception) and Phase 2 (Model configurations for assessment of current water availability and selected augmentation options). Phase 2 comprises several distinct components that can be grouped into:

- Surface water hydrology
- Groundwater hydrology
- Surface water quality
- Water resources analysis
- Reconciliation options analysis
- Study management and review

Based on the hydrogeological analysis and the requirements for modelling as well as the over-arching strategic management intent established for the Berg Catchment, a number of models are considered for evaluating the groundwater availability on a regional scale.

After finalizing all tasks, a combined modelling report will be prepared, comprising separate volumes for each task. Each report documents model development and model scenarios, as well as recommendations for implementation and model upgrade.

These volumes are:

Volume 1: Summary Groundwater Availability Assessment (due at end of project)

Volume 2: Data Availability and Evaluation

Volume 3: Regional Conceptual Model

Volume 4: Regional Water Balance Model

Volume 5: Cape Flats Aquifer

Volume 6: Langebaan Road Aquifer

Volume 7: Table Mountain Group Aquifers – Piketberg area

Volume 8: Table Mountain Group Aquifers – Witzenberg - Nuy area

Volume 9: Breede River Alluvium

This report is Volume 3 in the project series. Volume 2 and 3 are to be read in conjunction with each other as the available data has informed the conceptual model and the conceptual model has informed the selection of data for model input and calibration.

AQUIFER PRINCIPLES

This Conceptual Model Volume outlines a strategic aquifer-specific approach to groundwater resource assessment at a regional or a local scale and documents a methodology that can be applied in any other geographic region since it is based on first principles. It is necessary to adopt an aquifer-specific approach to support regulatory decisions (as compulsory licensing) about sustainable aquifer, wellfield or borehole yield as well as the impacts of abstraction.

The aquifers considered here include the regionally relevant Table Mountain Group (TMG) aquifers viz. the Skurweberg and the Peninsula Aquifers (“fractured rock aquifers”) and also the larger and more significant primary aquifers within the study domain which are the Sandveld (Langebaan and the Cape Flats) and the Breede Alluvium Aquifers (“Intergranular aquifers”). The “fractured-and-weathered” or regolith zones are largely disregarded in this study, except where they might interface laterally with, or grade into, the afore-mentioned aquifers.

STUDY DOMAIN

The study domain for the groundwater component extends beyond the boundary of the Berg WMA and includes the upper part of the Breede WMA as well as southern portions of the Olifants/Doorn WMA. About 17% of the total water requirements in the Breede WMA are estimated to be supplied from groundwater, while the estimation for the Berg WMA is about 6% (DWAF, 2003).

The topography, drainage, hydroclimate, land-use and even the agricultural crops are largely determined by the underlying rock type and its structural character. This strong geological control also exerts an influence on the local climate and land-use potential, through orographic control over precipitation and the widely variable geochemical composition of the different formations. The western half of the study area is host to predominantly Pre-Cape basement including rocks of the **Malmesbury Group** and the intrusive **Cape Granite Suite**, overlain by quaternary sediments of the **Sandveld Group**. The Cape Fold Belt comprising rocks of the **Table Mountain Group** (TMG) and the overlying Post-Cape **Bokkeveld** and **Witteberg Groups** as well as **Karoo Supergroup** dominate the eastern half of the study area.

REGIONAL CONCEPTUAL MODEL

The purpose of the present modelling study is to provide a sound quantitative basis for water resource assessment in the future. The process for calculating the aquifer-specific mass balance and or catchment mass balance is as follows: The recharge areas are defined based on physically measurable aquifer outcrop areas underlying rainfall isohyets. These are correlated to the known discharge sites (considering volume, water quality, isotopic character and temperature) with likely flow paths defined by 3D structural geology and hydrostratigraphic relationships. Cross checks as regards temperature, chemistry and isotopic character of discharge water allows qualitative evaluation of the conceptual flow model.

The TMG is well known for the occurrence of numerous spring systems, discharge points of groundwater flow. The study area is host to several hot springs, among them Brandvlei and Goudini. Water temperature measurements in springs, boreholes and streams provide a potentially important source of information about deep groundwater flow paths within the TMG aquifer system.

As part of the groundwater flow-path investigations, eleven definite structural zones of increased hydraulic conductivity (so-called “hydrotects”) were identified. The evidence for their existence takes the form of a definite spatial association between springs and high-yielding boreholes, on the one hand, and major geological fracture systems, on the other hand. These hydrotects are the preferred flow paths that link the major recharge zones to the discharge sites within any one aquifer.

Groundwater and surface water interact at many places throughout the landscape. These interactions can be highly dynamic as they respond to the variations and changes in the hydraulic gradients which drive the flows between them.

INTEGRATED WATER RESOURCE MANAGEMENT

During the Hydrogeological Reconnaissance Report for the City of Cape Town (CCT) Table Mountain Group Aquifer Feasibility Study and Pilot Project (CMC, 2004), the concept of an Integrated Water Resource Management (IWRM) domain was introduced. The purpose for establishing IWRM domains is to “initiate the planning for the groundwater modelling as well as the Water Resource Yield Model (WRYM) development and to promote the integration of surface water groundwater and ecological monitoring within a domain that conceivably responds differently in time but has the same boundary conditions”. Each of the fifteen IWRM domains are chosen such that they can effectively be considered isolated units. This was done with an understanding of the spatial and temporal distribution of both surface and groundwater flow, in addition to knowledge of the water recharge, storage and discharge areas.

DETAILED MODEL DOMAINS

Five detailed model domain areas were selected and delineated as part of the requirements of this study.

Small Model Domain	Aquifer of Interest
Cape Flats	Cape Flats “Intergranular” Aquifer
Langebaan Road and Geelbek	Langebaan Road and Geelbek “Intergranular” Aquifers
Piketberg	Peninsula “Fractured-Rock” Aquifer and Sandveld “Intergranular” Aquifer
Witzenberg-Nuy Valley	Peninsula and Skurweberg “Fractured-Rock” Aquifers
Breede River Alluvium	Breede River Alluvial “Intergranular” Aquifer and Peninsula and Skurweberg “Fractured-Rock” Aquifers

CONCLUSIONS

- Recharge to the TMG aquifers occurs in the high-lying mountainous ranges of the Cape Fold Belt.
- Recharge to the Sandveld aquifers occurs in the areas of aquifer exposure as well as through lateral and flood recharge.
- The groundwater from the different aquifers discharges either into rivers and streams via springs or along river reaches, or direct into the ocean. In some areas groundwater from the TMG discharges into the alluvium aquifers.
- Groundwater flow in the TMG aquifers follows structurally-controlled preferred flow paths, called hydrotects.

- Groundwater flow in the Sandveld aquifers is controlled by the current surface topography and the bedrock topography, forming palaeo channels.

RECOMMENDATIONS

The following data collection activities are recommended for verification of model assumptions and to increase the confidence of hydraulic parameters and hence model outputs.

- Spring hydrocensus
- Borehole hydrocensus
- Fracture mapping in TMG terrain
- Hydraulic testing in selected boreholes in both the Peninsula and Skurweberg aquifers
- Mapping of palaeo channels and bedrock topography in West Coast and alluvium aquifers
- Hydrochemical sampling at specific river reaches
- Review and revise geological mapping in selected areas
- Review and revise monitoring network.

The following recommendations are made for the subsequent water balance model and the detailed groundwater flow models:

a) Extend the study area for the groundwater component at the northern boundary to reflect the results of the structural analysis and conceptual flow modelling in these areas.
b) Undertake the water balance modelling for the extended study area on an aquifer-specific basis.
c) Combine the proposed detailed models of Task 15b (TMG Tulbagh – Ceres) and Task 15c (TMG Hex River Mountains) into one model domain, called TMG Witzenberg – Nuy Valley.
d) Restrict the detailed modelling of the West Coast aquifers (Task 14a) to the Langebaan Road and Geelbek aquifers.
e) Extend the model domain for the detailed model of Task 15d (TMG Piketberg) towards the coast to include the interaction with the primary aquifer in the Verlorenvlei palaeo channel.
f) Set-up, configure and run the detailed groundwater flow models for the revised model domains:
    - Cape Flats aquifer
    - Langebaan Road and Geelbek aquifers
    - Piketberg TMG and Verlorenvlei palaeo channel aquifers
    - TMG Witzenberg – Nuy Valley aquifers
    - Breede Alluvium

THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS

GROUNDWATER MODEL REPORT VOLUME 3
REGIONAL CONCEPTUAL MODEL

TABLE OF CONTENTS

Page No.

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

±	plus minus
~	approximately
<	Less than
>	Greater than
°	Degrees
°C	degrees Celsius
δ18O	Delta Oxygen 18
δD	Delta Deuterium
2D	Two dimensions
3D	Three dimensions
Alk	Alkaline
API	Aerial Photographic Interpretation
ASR	Aquifer storage and recovery
CAGE	Citrusdal Artesian Groundwater Exploration
CCT	City of Cape Town
CHF	Caledon-Hawston Fault Zone
CHSL	Cape Hot Springs Line
Cl	Chloride
cm^2	centimeters squared
CMC	Cape Metropolitan Council
CMWL	Cape Meteoric Water Line
DWAF	Department of Water Affairs and Forestry
EC	electrical conductivity
et. al.	and others
E-W	east west
GBAS	Geelbek Aquifer System
GBF	Groenhof-Bokke River Fault Zone
GIS	Geographical Information System
GMWL	Global Meteoric Water Line
GRA	Groundwater Resources Assessment
GVM	Gydo-Verlorenvlei Megafault Zone
ISP	Internal Strategic Perspective
IWRM	Integrated Water Resources Management
k	Intrinsic permeability
K	thousand
K	Hydraulic Conductivity
KDLF	Klein Drakenstein and La Motte Fault
km	kilometres
km^2	kilometers squared
LRAS	Langebaan Road Aquifer System

m	metres
m^2	metres squared
mamsl	metres above mean sea level
Ma	Million annums
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
m/day	metres per day
mm	millimetres
mm/a	millimetres per annum
mm/day	millimetres per day
m/s	metres per second
mS/m	milliSiemens per metre
N#	National road
Na	Sodium
N-S	north south
NWA	National Water Act
op.cit.	work previously cited
p.	Page
PAJA	Promotion of Administrative Justice Act
R#	Regional Road
RGF	Riviersonderend (Greyton) Fault
RQD	Resource Quality Development
RQO	Resource Quality Objectives
RRM	Robertson-Rooiels Megafault Zone
SACS	South African Committee for Stratigraphy
SAM	Saron-Aurora Megafault Zone
SBM	Steenbras-Brandvlei Megafault Zone
SDM	Source Directed Measures
SGD	Submarine groundwater discharge
TMG	Table Mountain Group
WAAS	Water Availability Assessment Study
WCWSS	Western Cape Water Supply System
WMA	Water Management Area
WPMZ	Worcester-Pletmos Megafault Zone
WRYM	Water Resources Yield Model

1. INTRODUCTION

1.1 THE WAAS PROJECT

1.1.1 Project Background

The Berg River Catchment forms the heart of the Western Cape Water Supply System (WCWSS), whose supply area constitutes the economic hub of the Western Cape and serves a primary export industry based on agricultural produce. The WCWSS serves the City of Cape Town, both urban water users and irrigators along the Berg, Eerste, Lourens, Steenbras and Palmiet Rivers, domestic and industrial users on the West Coast, as well as irrigators and urban users in the Riviersonderend catchment of the Breede WMA.

The Department of Water Affairs and Forestry (DWAF) have initiated two major water resource management and planning undertakings in the environment of the WCWSS:

a) Compulsory licensing in terms of the National Water Act (NWA) - Act 36 of 1998 - is due to be piloted in the Berg WMA, in response to concerns that growing water user demands, as well as stream flow salinity increases, might place parts of the WCWSS in a water-stress condition during the foreseeable future.

b) A Reconciliation Strategy Study has been completed, which reviewed the future water requirements and the options for meeting these demands. The Study identified the most favourable augmentation options and recommended a programme of feasibility studies and other investigations to improve the operation and planning of the system, and to ensure that the necessary infrastructure or other interventions are implemented timeously so as to reconcile the supplies with the future demands.

This Water Availability Assessment Study (WAAS) forms part of five studies commissioned nationally by DWAF to support, *inter alia*, allocable water quantification as a prerequisite for compulsory licensing. The objectives of the Study are to (DWAF, 2005):

- Reconfigure the existing Water Resources Yield Model (WRYM) configurations at a spatial resolution suitable for allocable water quantification to support compulsory licensing.
- Use reconfigured existing models or newly configured models for allocable water quantification for both surface water and groundwater, where applicable.
- Incorporate changes in concepts, models and approaches, as derived from pilot studies initiated by DWAF elsewhere, if these become available in time.
- Support the Reconciliation Study with model-based assessment of water resource augmentation options.

Ninham Shand (Pty) Ltd is the Lead Consultant for the Berg WAAS and is responsible for the surface water components of the Study, as well as study management, while Umvoto Africa (Pty) Ltd is responsible for the groundwater components. Both Consulting Firms contribute either conceptually or directly to certain shared tasks.

1.1.2 Study area delineation

The study area shown in **Figure 1-1** comprises the following drainage systems and bulk water infrastructure:

- The complete Berg River catchment from its source in the Groot Drakenstein Mountains to its estuary at Laaiplek on the Atlantic West Coast.
- The Cape Town Basin, which includes the Eerste, Lourens and Sir Lowry's Pass rivers – all of which drain into False Bay.

- The Diep River, which flows westerly from its source in the Riebeeck Kasteel Mountains to its mouth in the northern suburbs of Cape Town.
- The complete Palmiet and Steenbras catchments in the south of the Study Area, which flow in a southwesterly direction to the south of False Bay.
- The Breede River, which flows easterly to the Indian Ocean and of which the Upper and Middle Breede and the Upper Riviersonderend catchments are focus areas for this Study.

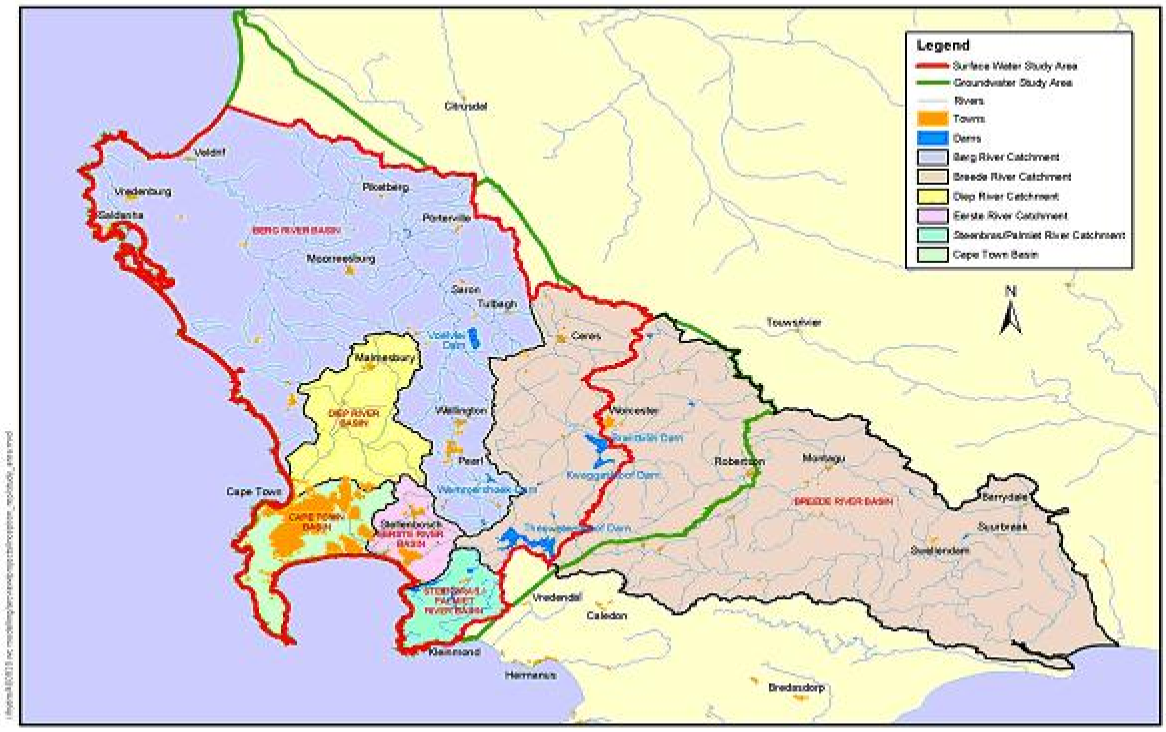


Figure 1-1: Study Area Locality

The Western Cape Water Supply System (WCWSS) is an integrated system of reservoirs, linked via a complex network of tunnels, pump stations and pipelines that stores and reticulates the runoff from rivers for use in the greater Cape Town Metropolitan area. Surface water inter-basin transfers take place between the Berg, Riviersonderend and Eerste catchments, while water from the existing Steenbras Scheme is supplied from the Lower Steenbras water treatment works into the Cape Town Water Undertaking network. The Palmiet Scheme is a dual hydroelectric pumped-storage and water transfer scheme (to the Steenbras pumped-storage scheme), of which the water transfer component has not yet been fully implemented.

The study domain for the groundwater component extends beyond the boundary of the Berg WMA and includes the upper part of the Breede WMA as well as southern portions of the Olifants/Doorn WMA. This extended area between Tulbagh-Ceres, Kleinmond and Robertson approximately coincides with the “syntaxis” zone of N-S and E-W cross- or interference folding in the Cape Fold Belt. The high mountain exposures of the Table Mountain Group (TMG) in the anticlinal folds, the confined TMG fractured-rock aquifers in the synclinal folds and the hydrotects are the main structural elements forming natural boundaries of groundwater flow. These structures would therefore build the conceptual basis of any sound groundwater models in the TMG terrain of the Berg WMA.

1.1.3 Project Components

The Study comprises two phases: Phase 1 (Inception) and Phase 2 (Model configurations for assessment of current water availability and selected augmentation options). Phase 2 comprises several distinct components that can be grouped into:

- Surface water hydrology
- Groundwater hydrology
- Surface water quality
- Water resources analysis
- Reconciliation options analysis
- Study management and review

1.1.4 Terms of Reference for Groundwater

In 2001 it was estimated that a minimum of 30 Mm^3/a of water was available to augment supply to the WCWSS from the confined Peninsula Aquifer alone (City of Cape Town, 2001). More recent evaluations of both the confined Peninsula and the Skurweberg aquifers suggest that between 20 and 400 Mm^3/a can be abstracted from the TMG within the Breede River basin area of the WCWSS domain (City of Cape Town, 2004a) if these aquifers are drawn down by 1 and 20 m respectively.

DWAF, as the custodian of the water resources in South Africa, has several tools available under the NWA for ensuring that the goals of IWRM are met within the boundaries of the WMAs, of which compulsory licensing is one. The aim of compulsory licensing is to equitably and sustainably distribute the available supply of water (i.e. current yield, not potential yield) within the catchment between all potential users, without compromising future needs or foreclosing on certain water resource development options.

Allocation of future surface water involves a 2D analysis of the hydrology and current use. Similarly the impact of future groundwater use on current users and therefore the sustainable utilisation of water in aquifer storage by both user groups can only be assessed if the potential yield rather than the current yield is analysed with appropriate spatial and time series detail. This is primarily a 3D problem in the study domain.

In order to achieve this, the regulatory authority needs to have knowledge of the following:

- total amount of water available within the catchment;
- temporal and spatial distribution of water availability;
- current and future water requirements;
- impact of water abstraction at any point and time on the environment and other users;
- scenario for optimal development of the aquifer and
- scenario for best possible aquifer development and management given the *status quo*.

The contrast between the two scenarios will indicate the extent to which *ad hoc* aquifer development and management impacts on the resource from a Source Directed (SDM) and a Water Quality (RQD) directed perspective.

The Promotion of Administrative Justice Act (PAJA) - Act 3 of 2000 – suggests that it is necessary that any water resource modelling undertaken to support administrative or regulatory decisions be based on all available data and uses the most appropriate models and methodologies available (and/or notes the limitations and uncertainties thereof). Water resource quantification or allocation models need to be configured, sequenced or linked in such a way that different scenarios may be assessed for aligning water supply and demand to best meet the Reserve and the Resource Quality Objectives (RQOs) in a given catchment (DWAF, 2003). Where limited data is available, it is good practise to establish an agreed-upon set of scenarios, which reflect a range of values for model input parameters. As improved data becomes available the range in value of model input variables or scenario testing is narrowed down.

The manner in which surface and groundwater model usage should be integrated will likely vary between catchments. Sound modelling outcomes would depend, not only on the impact of groundwater abstraction on baseflow and on the ecology, but also on the temporal relationship/operating rules for groundwater storage and surface water storage and the impact of surface water storage and reduced stream flows on groundwater levels and on the ecology.

Based on the hydrogeological analysis and the requirements for modelling as well as the over-arching strategic management intent established for the Berg Catchment, the following models are considered the *minimum* requirement to address the Terms of Reference and to evaluate the groundwater availability on a regional scale:

- Task 7a: GIS database for groundwater component
- Task 7b: Digitising geological maps
- Task 12: Regional model development
    - Conceptual model for study domain
    - GIS-based water balance model for study domain
- Task 13: Configuration of a numerical model for the Cape Flats Aquifer
    - Quantification of surface water – groundwater interaction
    - Calibration of recharge estimation and water balance
    - Scenario for augmentation of bulk water supply to the City of Cape Town (in support of Western Cape Reconciliation Study)
    - Scenario for flood management (in support of Western Cape Reconciliation Study)
- Task 14: Review and update conceptual model for West Coast aquifers
    - Review of conceptual model
    - Quantification of surface water – groundwater interaction
    - Review and revision of recharge estimation and water balance
- Task 14a: Configuration of a numerical groundwater model for Langebaan Road Aquifer
    - Refinement of surface water – groundwater interaction
    - Refinement of recharge and yield estimation
    - Scenario for artificial recharge schemes (in support of Western Cape Reconciliation Study)
- Task 15: Water balance and storage model for TMG Aquifer
    - Recharge estimation and water balance on regional scale
- Task 15a: Configuration of a numerical TMG groundwater model for Worcester
    - Quantification of surface water – groundwater interaction
    - Refinement of recharge and yield estimation

  - Scenario for Aquifer Storage Recovery (ASR) schemes (in support of Western Cape Reconciliation Study)
- Task 15b: Configuration of a numerical TMG groundwater model for Tulbagh – Ceres
  - Quantification of surface water – groundwater interaction
  - Refinement of recharge and yield estimation
- Task 15c: Configuration of a numerical TMG groundwater model for the Hex River Mountains
  - Quantification of surface water – groundwater interaction
  - Refinement of recharge and yield estimation
  - Scenario for Aquifer Storage Recovery (ASR) schemes (in support of Western Cape Reconciliation Study)
- Task 15d: Configuration of a numerical TMG groundwater model for Piketberg
  - Quantification of surface water – groundwater interaction
  - Refinement of recharge and yield estimation

After finalizing all tasks, a combined modelling report will be prepared, comprising separate volumes for each task. Each report documents model development and model scenarios, as well as recommendations for implementation and model upgrade. Volume 2 and 3 below are to be read in conjunction with each other as the available data has informed the conceptual model and the conceptual model has informed the selection of data for model input and calibration.

The complete set of volumes are:

Volume 1: Summary Groundwater Availability Assessment (due at end of project)

Volume 2: Data Availability and Evaluation

Volume 3: Regional Conceptual Model

Volume 4: Regional Water Balance Model

Volume 5: Cape Flats Aquifer

Volume 6: Langebaan Road and Geelbek Aquifer Systems

Volume 7: Table Mountain Group Aquifers – Piketberg area

Volume 8: Table Mountain Group Aquifers - Witzenberg-Nuy Valley area

Volume 9: Breede River Alluvium

This report is Volume 3 of the groundwater modelling report. A full bibliography of work known to the authors and containing data, information or insight pertinent to this project is contained in Volume 2 (DWAF, 2007). The reference list in this report is a subset of the bibliography and references only direct quotes. The bibliography is referred to when background information or supportive argument is mentioned in the text.

1.2 REGIONAL CONCEPTUAL MODEL DEVELOPMENT REPORT

1.2.1 Purpose of this Volume

The ultimate purpose of the present Berg WAAS is to provide a sound physical and quantitative basis for resource assessment into the future. The Groundwater Resource Assessment Phase II (GRA II) project (DWAF, 2004f) proposed a general methodology for groundwater resource evaluation in order to provide an estimate of groundwater potential on a national scale. For generic estimates and broad based planning it is possibly adequate.

However, separate aquifers are not adequately distinguished and data from different aquifers are conflated because the grid values in the GRA II model are calculated by interpolation and averaging across aquifer boundaries. It is common practice and strongly recommended that any one borehole or wellfield targets only one aquifer and it is therefore necessary to adopt an aquifer-specific approach to support regulatory decisions about sustainable aquifer, wellfield or borehole yield including evaluating the impacts of this abstraction. Furthermore, given the variable geography of the Western Cape where topography, hydroclimatology and geology and aquifer type and process are closely correlated, conflating aquifer data significantly increases the margin of error in results and therefore in regulatory decisions.

This report therefore outlines a strategic aquifer-specific approach to groundwater resource assessment at a regional or a local scale and documents a methodology that can be applied in any other geographic region since it is based on first principles. The focus in this volume is on the conceptual model development at the regional scale as well as in outline for the five local scale models to be reported on in Volumes 5 – 9 of the groundwater report.

1.2.2 Conceptual model development

The three critical steps in building a conceptual model (Anderson and Woesner, 1992) are:

- Defining the hydrostratigraphic units;
- Defining a flow system
- Preparing a water balance.

The first step is always to define the hydrostratigraphic units. This is based on the lithological characteristics of different stratigraphic units, the three dimensional (3D) spatial relationship of the hydrostratigraphic units to each other as well as the process history of their formation to the present day. There is however an iterative nature to the second and third steps because it is not possible to prepare a water balance without defining a flow system and it is not possible to define a flow system without understanding the process relationship between the different hydrostratigraphic units, the hydroclimatology, empirical and measured field evidence of groundwater movement and the surface water flow systems.

The different sections in this report consider the primary data sets and knowledge needed to propose and decide upon a conceptual flow model as well as to prepare a mass balance for the regionally relevant Table Mountain Group (TMG) aquifers viz. the Skurweberg and the Peninsula aquifers and also the larger and more significant primary aquifers within the study domain which are the Sandveld (Langebaan and the Cape Flats aquifers) and the Breede Alluvium aquifers. The “fractured-and-weathered” or regolith zones are largely disregarded in this study, except where they might interface laterally with, or grade into, TMG and/or Sandveld aquifer compartments and thus could provide a diffuse or channelised flowpath between the different aquifers.

Even though it is the lowest and locally can be, the deepest of the units, the Peninsula Aquifer takes precedence in the broad definition of the flow system, because it is the topographically dominant unit, building most of the high mountain ranges and summit ridges. Due to the strong orographic control on rain-and snowfall in the mountain ranges of the Western Cape province, the Peninsula therefore has the widest aerial extent in the areas of maximum precipitation and recharge potential, and provides the primary topographic control on both surface and groundwater flow systems at their common source.

Using the results of the regional conceptual model and the surface water flow patterns, the model domains for local scale-modelling are decided. During the Hydrogeological Reconnaissance Report for the City of Cape Town (CCT) Table Mountain Group Aquifer Feasibility Study and Pilot Project (CMC, 2004), the concept of an IWRM domain was introduced, comparable to what was previously termed a hydrogeological response unit (McKay 1999). This concept was further applied and developed during the ISP study in both the Western and Eastern Cape (DWAF, 2004a,b) and is used in this study to delineate the IWRM domains and the local-scale model domains (Task 13 – 15) as well as to map and as far as possible to quantify surface water and groundwater interaction.

The explicitly-stated purpose of establishing IWRM domains is to "initiate the planning for the groundwater modelling as well as the Water Resource Yield Model (WRYM) development and to promote the integration of surface water groundwater and ecological monitoring within a domain that conceivably responds differently in time but has the same boundary conditions".

1.2.3 Structure of this Volume of the Report

This volume of the report is structured into seven sections with sub-sections in each.

Section 1 describes the background to the project, determines the terms of reference for the groundwater component and gives the purpose of this specific report.

Section 2 provides a general description of the regional study domain and key non-geological data sets needed for conceptual modelling, viz. topography, drainage, geology (stratigraphy and structure), hydroclimatology and water use.

Section 3 describes the general geology of the different model domains and details the hydrostratigraphic subdivisions needed for aquifer definition and classification as well as the regional structural geology, occurrence of springs, groundwater and surface water quality variations and surface water flow paths or patterns needed for the definition of flow paths.

Section 4 describes the regional flow paths for the Peninsula and Skurweberg aquifers throughout the study domain as well as the relevant primary aquifers and the relationship with the key primary aquifers and surface water systems. The associated water balance will be presented in Volume 4.

Section 5 details the Integrated Water Resource Management (IWRM) domains and the delineation thereof, which establish the basis for determining the mass balance for the different aquifers.

Section 6 uses the principles and results described in the previous sections to outline the basic conceptual model for the more detailed local-scale modelling in smaller model domains. These will be presented in detail in volumes 5 (Cape Flats Aquifer), 6 (Langebaan Road and Geelbek Aquifers), 7 (Piketberg area TMG Aquifer), 8 (Witzenberg - Nuy Valley TMG Aquifers), and 9 (Breede River Alluvium).

Section 7 summaries the conclusions and recommendations.

2. GENERAL DESCRIPTION OF THE STUDY AREA

2.1 PHYSIOGRAPHY

2.1.1 Locality

The study domain for the groundwater component extends beyond the boundary of the Berg WMA and includes the upper part of the Breede WMA as well as southern portions of the Olifants/Doorn WMA. The northern boundary of the study area is located at 31° 18' S, just above Elands Bay on the West Coast. The boundary extends southeast from Elands Bay on the Atlantic coast, past the Piketberg, through the Warm Bokkeveld above the Hex River Mountains turning south just after the Matroosberg at approx. 19° 55' E, just beyond the town of Robertson. (See **Figure 1-1)**

The south-eastern boundary of the study area extends from Robertson to Kleinmond along the Klipberge, western Riviersonderendberge, Donkerhoekberge, Houwhoekberge and Palmietberge. The coastline is the extreme southern and western study boundary, thus including the Cape Peninsula in the southwest (see **Figure 2-1).**

The area falls within the following 1:250 000-scale geological and topographical map sheets:

- 3218 Clanwilliam;
- 3318 Cape Town; and
- 3319 Worcester.

2.1.2 Access

Three national roads link the greater metropolitan area of the City of Cape Town situated in the southwest with the rest of the country. These are the north-south N7 that transects the Swartland en route to the Northern Cape province and Namibia, the N1 that extends north-east through the Cape Fold Belt and spectacular scenery linking the Cape to the Great Karoo and beyond and the N2 which travels in an easterly direction and links the Cape to the Overberg and further the Garden Route.

In the west, smaller regional roads such as the R27 traverse northwards along the west coast through small coastal resorts and industrial towns, i.e., Atlantis, Yzerfontein, Langebaan, Saldanha, Vredenburg and northwards across the Sandveld. The R44 travels northwards from Kleimond along the base of the Hottentots Holland, Elandskloof, Groot Winterhoek, and Olifants Mountains and over the Swartland to Piketberg.

In the eastern area, the R62 branches off the N1 beyond Worcester, connecting to Robertson and extending through the Overberg into the Klein Karoo and Oudshoorn in the east, trending parallel to the Breede River itself. The R43 parallels the coastline beginning at Kleinmond and continuing to Hermanus and beyond to Cape Agulhas.

Numerous divisional roads join the smaller rural and agricultural villages and towns to the north and east. A comprehensive railway network parallels the major road networks.

2.1.3 Demography

While the large flat-lying areas in the western and northwestern area are relatively unpopulated and undeveloped except for predominantly stock farming and smaller coastal towns, the eastern area is more densely populated with small rural and agricultural towns that support a thriving agricultural sector and coastal tourism. This area is heavily cultivated with formal commercial agriculture along the river valleys. The high mountain land is either designated wilderness area or is under commercial forests. The coastline has numerous villages and small towns, which have both permanent inhabitants as well as high influxes of seasonal visitors.

2.1.4 Topography

The topography of the study area in the east varies greatly from that in the west. In the east the high and rugged mountains and valleys of the Cape Fold Belt and their footslopes dominate the area. These extend the full length of the study area in the east. They grade westwards into the flat rolling hills of the Swartland, which is underlain by the Malmesbury Shale bedrock. Between the Swartland and the Atlantic Ocean is the flat coastal plain known as the Sandveld. The Sandveld topography is that of shallow lying palaeo- and modern-dunes transacted by ephemeral streams. In the southwest, the study area is defined by the distinctive topography of the Cape Peninsula itself, an outlier of the Table Mountain Group (TMG), rocks of which also form the Cape Fold Belt.

Similarly, the Piketberg in the northeastern portion of the study area is also a TMG outlier that separates the Boland from the Sandveld.

2.2 HYDROLOGY

The study area falls within the Berg WMA (west and south) and overlaps in the east and southeast into the Breede WMA and in the northeast into the Olifants-Doorn WMA (see **Figure 2-2**).

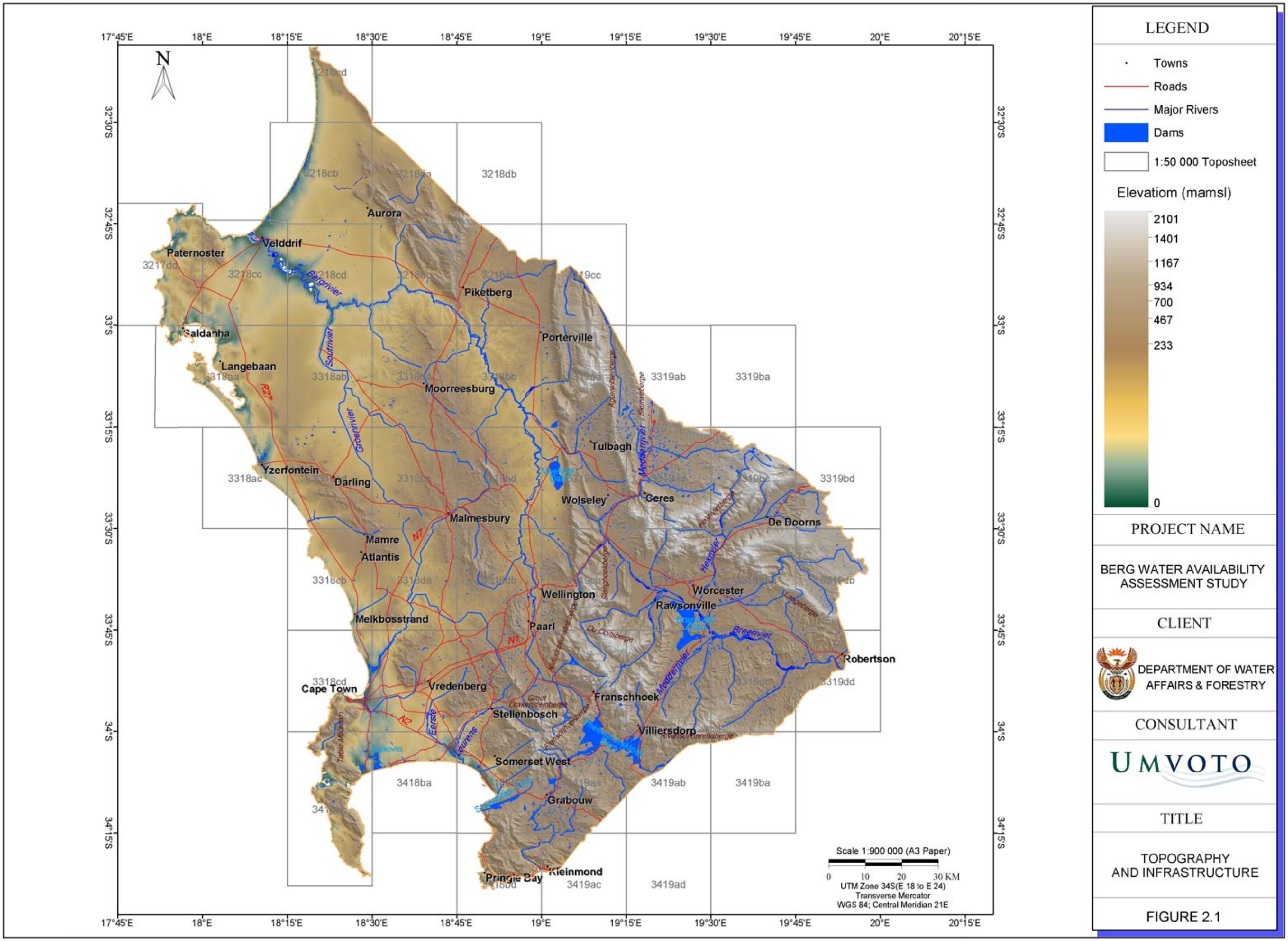
The Berg WMA comprises the G10, G21, G22 and G40 tertiary catchments. The parts of the study area in the Breede WMA fall within the H10, H20, H40 and H60 tertiary catchments.

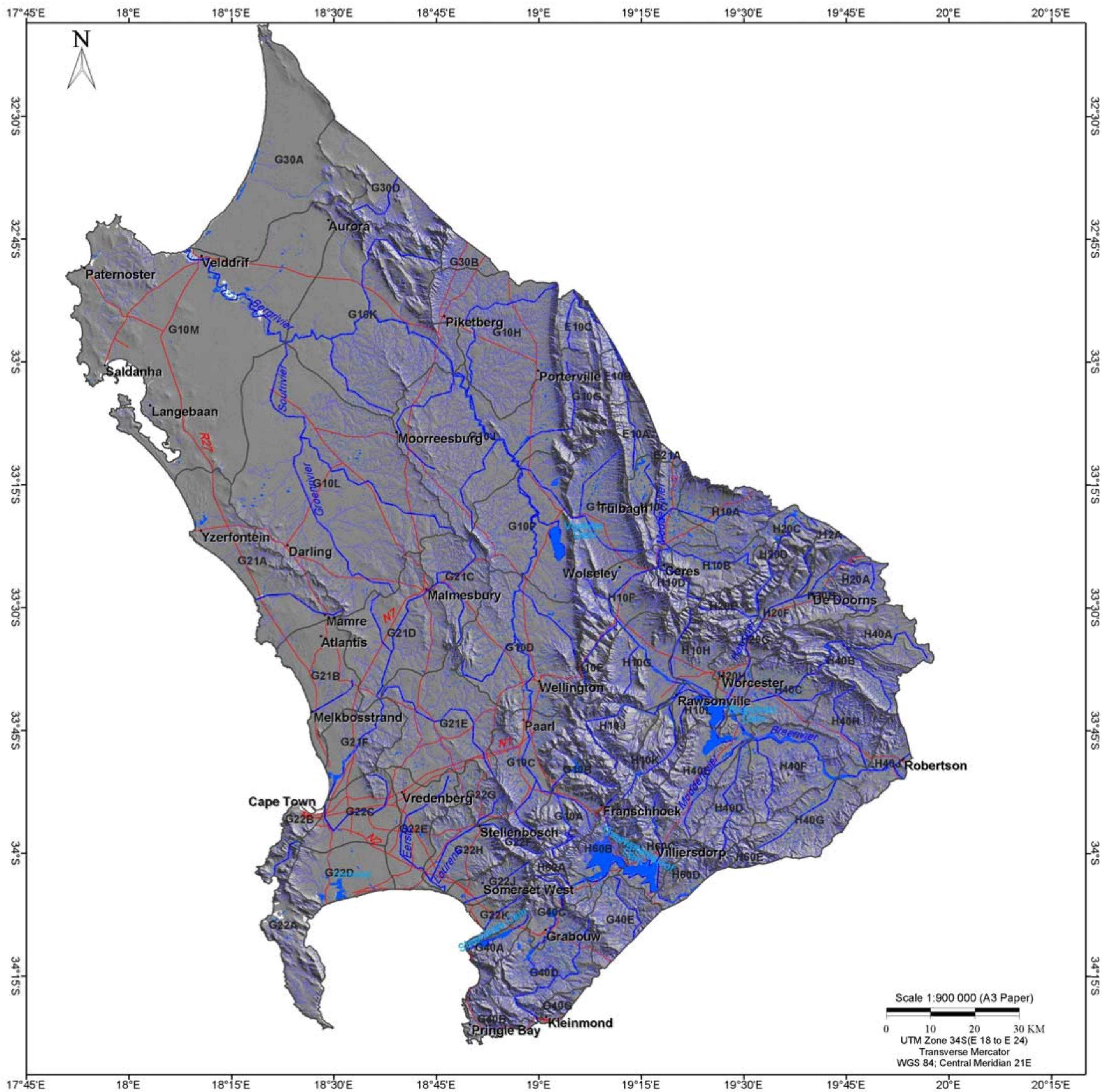
2.2.1 Rivers and Dams

The Great Berg River flows from the Groot Drakenstein Mountains in the central to southeastern part of the study area into St Helena Bay at a small town called Laaiplek in the northwest. The G10 tertiary catchment covers the Berg River catchment from its source in the Groot Drakenstein Mountains to the Berg River mouth at Laaiplek on the West Coast. Main storage reservoirs in the Berg River catchment include the Wemmershoek and off-channel Voëlvlei dams, while the construction of the new Berg River Dam near Franschhoek commenced late 2004 (DWAF, 2005) and was completed in November 2007.

The G21 catchments comprise the Diep River Basin and some small rivers flowing into the ocean at the West Coast between Cape Town and Saldanha.

The southern and south-western areas of the study are within the Berg WMA but the rivers drain primarily southwards into the Indian Ocean and comprise the G22 and G40 tertiary catchments. The larger rivers in G22, also known as the Cape Town Basin (DWAF, 2005) are the Eerste River, the Lourens River and Sir Lowry Pass River which drain into False Bay. The Eerste River has tributaries originating in the Jonkershoek Mountains and transects the Cape Flats west of Stellenbosch, while the latter two rivers have their headwaters in the Hottentots Holland Mountains and drain into False Bay east of the Strand. The Kleinplaas Dam, a balancing dam forming part of the Riviersonderend/Berg River Government Water Scheme, is situated in the Jonkershoek River catchment.


LEGEND
Towns
Roads
Major Rivers
Dams
1:50 000 Toposheet
Elevatiom (mamsl)
2101
1401
1167
934
700
467
233
0
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS & FORESTRY
CONSULTANT
UMVOTO
TITLE
TOPOGRAPHY AND INFRASTRUCTURE
17°45'E
18°E
18°15'E
18°30'E
18°45'E
19°E
19°15'E
19°30'E
19°45'E
20°E
20°15'E
32°30'S
32°45'S
33°S
33°15'S
33°30'S
33°45'S
34°S
34°15'S
N
Aurora
Velddrif
Paternoster
Piketberg
Porterville
Saldanha
Langebaan
Moorreesburg
Tulbagh
Yzerfontein
Darling
Wolseley
Ceres
Malmesbury
De Doorns
Mamre
Atlantis
Wellington
Worcester
Rawsonville
Melkbosstrand
Paarl
Robertson
Cape Town
Vredenberg
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
Kleinmond
Pringle Bay
Bergrivier
Soutrivier
Groenrivier
Breerivier
Hexrivier
Moddervier
Eerste
Lourens
Table Mountain
R27
N7
N1
N2
3218cd
3218cb
3218db
3217dd
3218cc
3219cc
3318aa
3318ab
3319ab
3319ba
3318ac
3319bd
3318cb
3318cd
3319dd
3418ba
3419ab
3419ba
3419ac
3419ad
Scale 1:900 000 (A3 Paper)
0
10
20
30 KM
UTM Zone 34S(E 18 to E 24)
Transverse Mercator
WGS 84; Central Meridian 21E
FIGURE 2.1



LEGEND

- Towns
- Roads
- Non-Perennial Rivers
- Major Rivers
- Dams

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

DRAINAGE NETWORK AND MAJOR RIVERS

FIGURE 2.2

The Steenbras River and the Palmiet River fall within the G40 tertiary catchment and flow in a westerly direction to the Indian Ocean. The Upper and Lower Steenbras dams are situated in the catchment.

The upper reaches of the Breede River and its main tributaries trend in a south-easterly direction and drain the eastern half of the study area. The Breede River is the largest river in the Western Cape. Its basin comprises the H10-H70 secondary catchments, of which the H10, H20, H40 and H60 tertiary basins fall within the study area. The Breede River originates in the Ceres Valley and flows in a south-easterly direction until its confluence with the Hex River near Worcester. (DWAF, 2005). Other large tributaries to the Breede River include the Slanghoek, Modder and Wit Rivers. The confluence of the Breede and the Riviersonderend is about 20 km west of Swellendam. The Riviersonderend however has its origins in the Groot Drakenstein and Franschhoek Mountains and flows eastward into Theewaterskloof Dam.

The major storage structures in the Breede River Basin include the Koekoedouw Dam in the Upper Breede River catchment, the Greater Brandvlei, Roode Elsberg and Lakenvallei dams in the Hex River catchment; Stettynskloof, Moordkuil, Keerom, Poortjieskloof and Pietersfontein dams in the middle Breede River catchment; Theewaterskloof Dam in the Riviersonderend River and Buffeljags Dam in the lower Breede River catchment, as well as farm dams.

The southern most tertiary catchments of the Olifants-Doring drainage basin (E10A, B, C) fall within the northeastern area of the study. The J12 tertiary drainage area is located on the eastern boundary of the study area on the northeastern extension of the Hex River Mountains.

2.2.2 Inter Basin Transfer

The Western Cape Water Supply System (WCWSS) is the integrated system of reservoirs, linked via a complex network of pump stations and pipelines that stores and reticulates the runoff from these rivers for use in the greater Cape Town Metropolitan area. Surface water inter-basin transfers take place between the Berg, Riviersonderend and Eerste catchments through these interventions.

Groundwater inter-basin and inter-catchment transfers take place naturally depending upon the aerial and depth distribution of aquifers and this relationship to the drainage and the storage of surface water. While it may be relatively simple to investigate the spatial distribution of both ground and surface water, it is the temporal and quantity patterns and differences as a result of interbasin transfers that informs the definition of IWRM domains and is addressed further in **Section 5.1**.

2.3 HYDROCLIMATOLOGY

The study area experiences a typical Mediterranean climate with moderate temperatures and winter rainfall. This means that in most areas there is a winter surplus and a summer demand for water. Perennial rivers are fed by springs that emerge from the TMG, which dominate the eastern sector of the study area and significant storage is required to ensure a reliable supply of water to both the urban and the agricultural sector. The relationship between the pattern of rainfall and the spatial distribution and fractured-rock nature of the TMG aquifers result in a simple spatial but a complex temporal relationship between surface and groundwater.

It is fortunate however that the major dams and aquifers are recharged in the same place and at the same time viz. by the rain in the high lying mountains. Thus it is relatively simple to conceptualise a “total catchment recharge, storage and yield” derived from the hydroclimatology, the surface water dam and particularly also "primary aquifer" information. Local scale recharge to smaller dams and aquifers generally happens at lower altitude, as does the interaction between surface and groundwater.

Hydroclimatology data is further addressed in Volume 2 of this report (DWAF, 2007) and in the area-specific modelling reports. Key hydroclimatology data and patterns used in the regional conceptual model are discussed and illustrated below.

2.3.1 Precipitation

The regional distribution of rain is illustrated in **Figure 2-3.** Summary details per quaternary catchment are contained in Volume 2 of this report (DWAF, 2007). As can be expected in an area where the rainfall is orographically controlled and the altitude range is from 0 mamsl in the west and the south to a maximum of 2249 mamsl on the Matroosberg Peak in the northeast, the Mean Annual Precipitation (MAP) varies significantly across the study area. It is highest in the high mountains in the east averaging greater than 1000 mm/a, and less than 200 mm/a along the flat lying coastal plain (Midgley et al., 1994). Rainfall on the Swartland west of the high mountain range can be between 300 and 600 mm/a decreasing westward. The Cape Peninsula, although in the extreme southwest, experiences MAP in the order of 800 mm/a, its particular topography creating a micro climate.

Within the eastern Cape Fold Belt area the rainfall distribution can vary across small distances with the far eastern area being in somewhat of a rain shadow (< 500 mm/a) while the high mountain range areas receive in excess of 1500 mm/a.

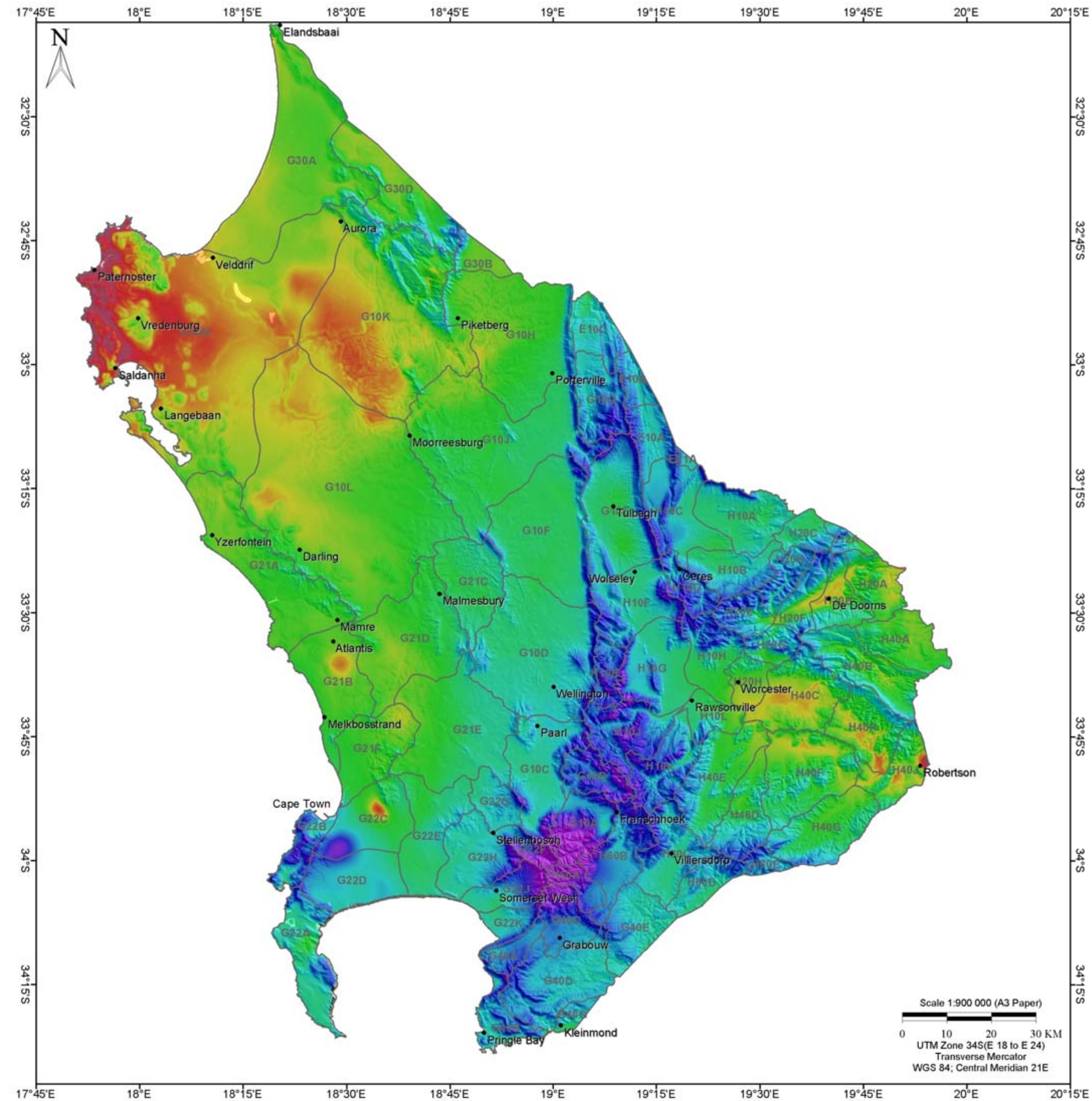
The seasonal pattern of rainfall is critical in the estimation of recharge since the aquifers are recharged in winter when the temperature and therefore evapotranspiration are also very low.

2.3.2 Run-off

The mean annual run-off parallels the trend of mean annual rainfall with most run-off occurring in the high-lying mountains. More than 200 mm of water is discharged as run-off in these Mountains every year. These values decrease toward the coast to less than 5 mm of run-off per annum (Midgley et al., 1994). The run-off is illustrated in **Figure 2-4**.

2.3.3 Evaporation

The mountain ranges and the ocean influence and moderate the Mean Annual Evaporation (MAE) resulting in increasing evaporation in the interior. The potential MAE increases from southwest to northeast across the study area but relative to rainfall the amount of evaporation decreases. Along the Cape Peninsula and South Coast the potential evaporation ranges between 1 300 and 1 400 mm/a, while the potential evaporation in northeast corner of the study area beyond Worcester ranges between 1 600 and 1 700 mm/a (Midgley et al., 1994, see **Figure 2-5**).



LEGEND

• Towns

Quaternary Catchments

Mean Annual Precipitation(mm)

3238
1495
1147
798
450
101

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

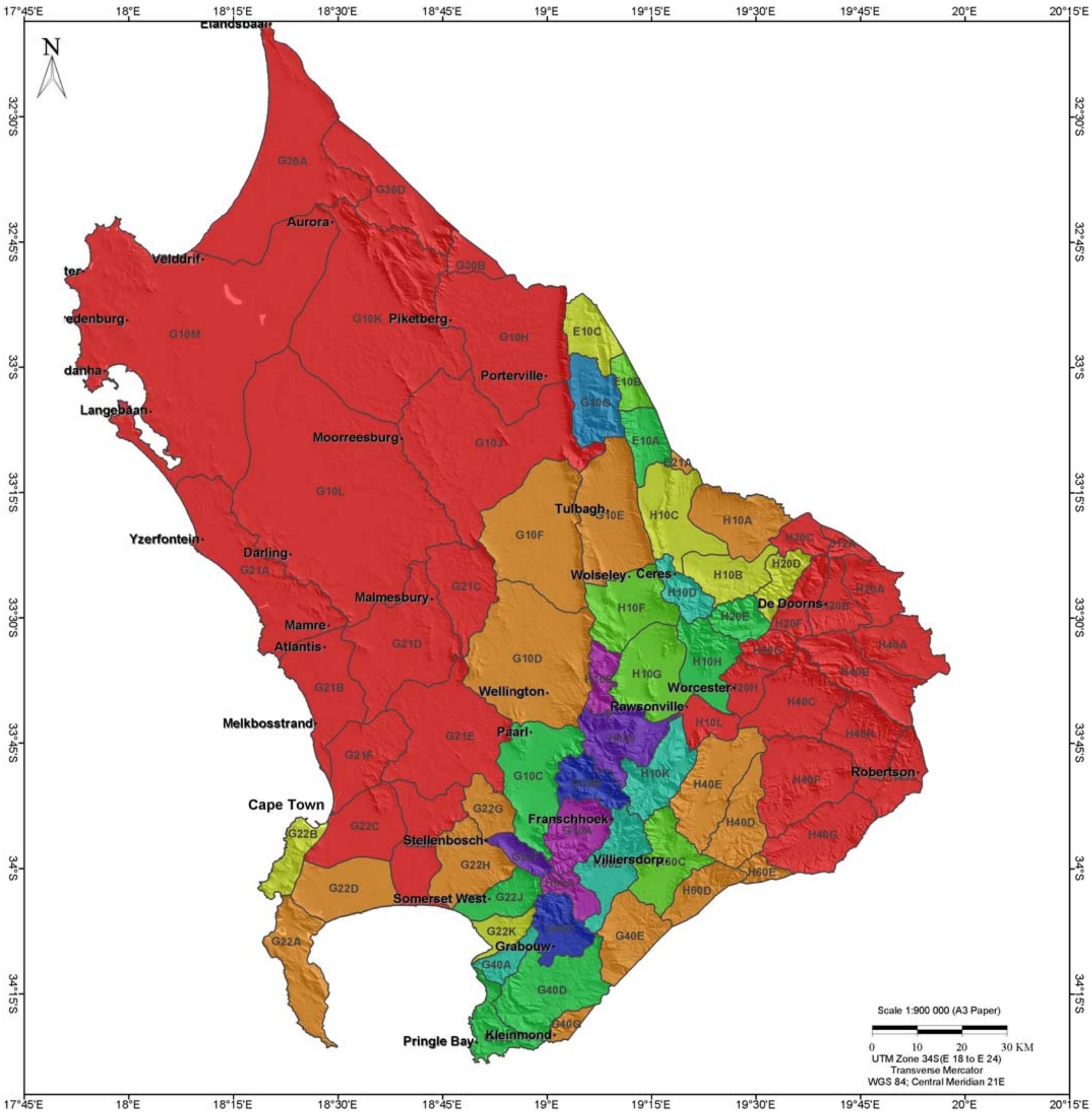
CONSULTANT

UMVOTO

TITLE

MEAN ANNUAL PRECIPITATION (after Ninham Shand)

FIGURE 2.3



LEGEND

· Towns

Quaternary Catchments

Mean Annual Runoff per Catchment

- 6.3 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1207

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

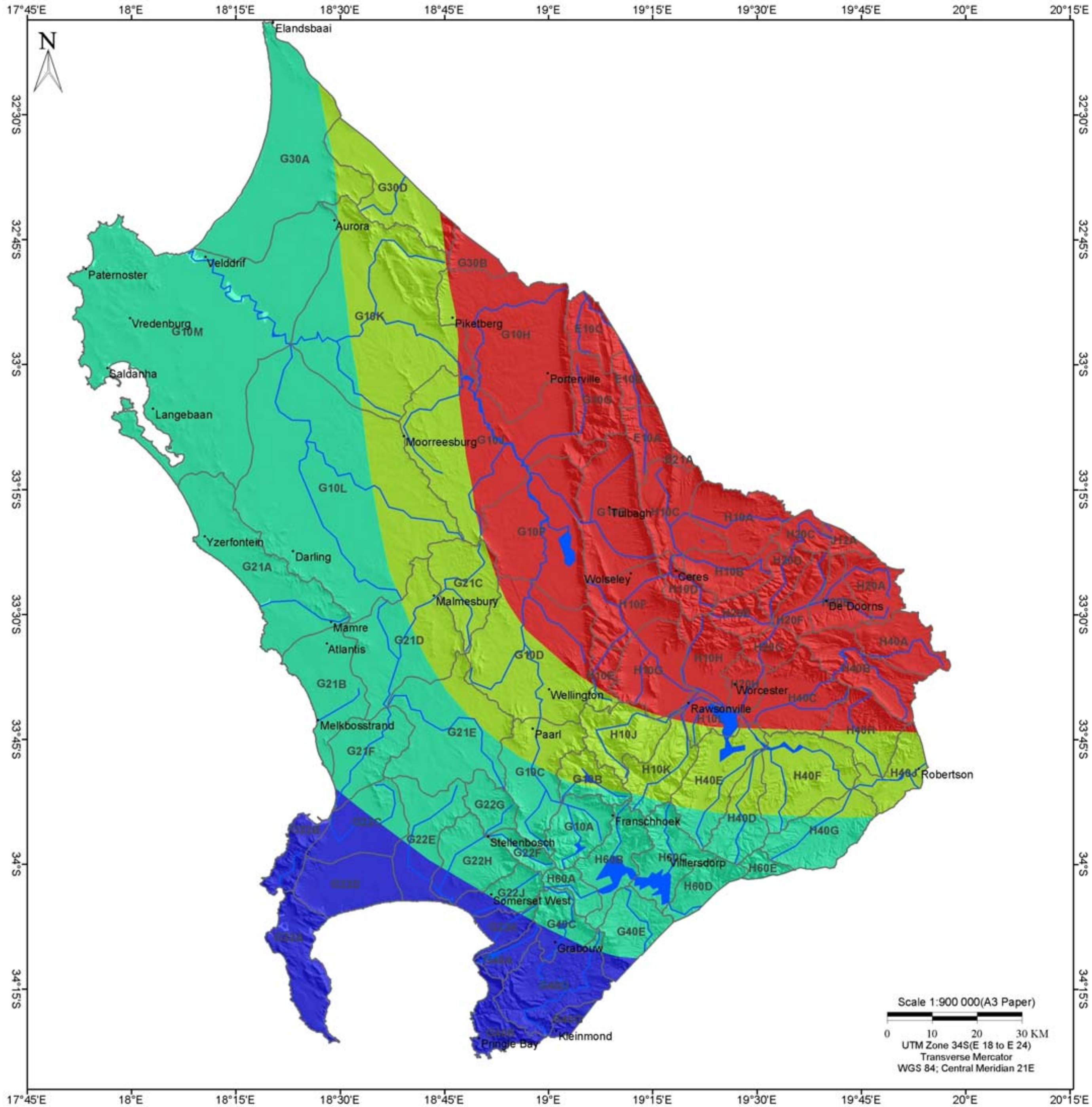
CONSULTANT

UMVOTO

TITLE

MAR PER CATCHMENT IN STUDY AREA (WR90)

FIGURE 2.4



LEGEND

- Towns
- Major Rivers
- Dams
- Quaternary Catchments

Mean Annual Evaporation (mm)

- 1200 - 1300
- 1300 - 1400
- 1400 - 1500
- 1500 - 1700

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

POTENTIAL EVAPORATION

FIGURE 2.5

2.4 WATER REQUIREMENTS

Since the Western Cape is largely a dry province receiving winter rainfall only in significant amounts in the eastern mountains, agriculture requires irrigation. Irrigation schemes therefore were usually initiated and remain near to a semi-permanent water source, be it a perennial river or a dam. The primary agricultural uses in the study area are discussed below relative to the river catchment wherein the area falls: (**Figure 2-6)**

- The pre-dominant land-use in the upper Berg River catchment is wine farming, with fruit farming taking place to a lesser extent, and small areas of lucerne, vegetables and other crops. Land-use in the middle and lower Berg River catchment changes to mainly dryland grain farming. Afforestation and invasive alien plants are distributed throughout the Berg catchment, but is concentrated in the upper reaches of the catchment (DWAF, 2005).
- The pre-dominant land-use in the eastern half of the Cape Town Basin catchment is vines and orchards with some vegetables and pastures. Afforestation is concentrated in the higher rainfall and mountainous areas of these catchments. In the upper Diep River catchments the pre-dominant land-use is viticulture, while fruit and vegetable farming comprise the rest of the irrigation demand and are found mainly in the middle and lower catchment areas, where wheat is also grown (DWAF, 2005). While there is little or no afforestation in the Diep River catchment, it is the most significant water user within the Steenbras catchment (DWAF, 2005).
- The pre-dominant land-use in the Breede River catchment is agriculture, mainly focussing on the production of fruit and wine. Afforestation occurs mainly in the upper Riviersonderend catchment, with small areas of afforestation scattered over the remainder of the catchment. Invasive alien plants are scattered throughout the catchment, with the highest level of infestation occurring in the Riviersonderend and Lower Breede catchments (DWAF, 2005).

There is a distinct difference in the water use patterns between the Berg WMA and the Breede WMA (DWAF, 2003c; -, 2003d).

- Close to 60% of the total water requirements in the Berg WMA are for urban and industrial use, and about 40% for irrigation;
- Geographically, 56% of the total water requirements in the Berg WMA occurs within the Greater Cape Town area and 31% in the Upper Berg area;
- Irrigation is by far the most dominant water use sector in the Breede WMA, representing more than 90% of the local requirements for water;
- Nearly 75% of the water use in the Breede WMA occurs in the Upper Breede area, followed by the Overberg West and then the Riviersonderend and Lower Breede;

The water requirements in the different sub-areas and for different sectors are listed in **Table 2-1**. It is noticeable that a huge quantity of interbasin water transfer is required to meet the water requirements. The study area comprises the three sub-areas of the Berg WMA, viz. Greater Cape Town, Upper Berg and Lower Berg, as well as parts of the Upper Breede, Riviersonderend and Overberg West sub-areas.

Table 2-1 Water requirements in Berg and Breede WMAS (million m^3/a), after DWAF, 2008

Sub-catchment	Irrigation	Urban	Forestry	Alien	Total[1)]
Berg Total	111.2	20.2	11.9	6.8	**150.1**
Diep	33.8		0.0	0.1	**33.9**
Eerste and Lourens	33.3	6.6	4.4	2.2	**46.5**
Palmiet and Steenbras	60.3		13.8	0.0	**74.1**
Riviersonderend	16.9		1.2	0.7	**18.8**
Upper Breede	20.6	26.6	0.1	1.3	**48.6**
Total	**276.1**	**360.2**[2)]	**31.4**	**11.1**	**372.0**

[1)]These figures are the local demand and do not include the transfers across catchment boundaries

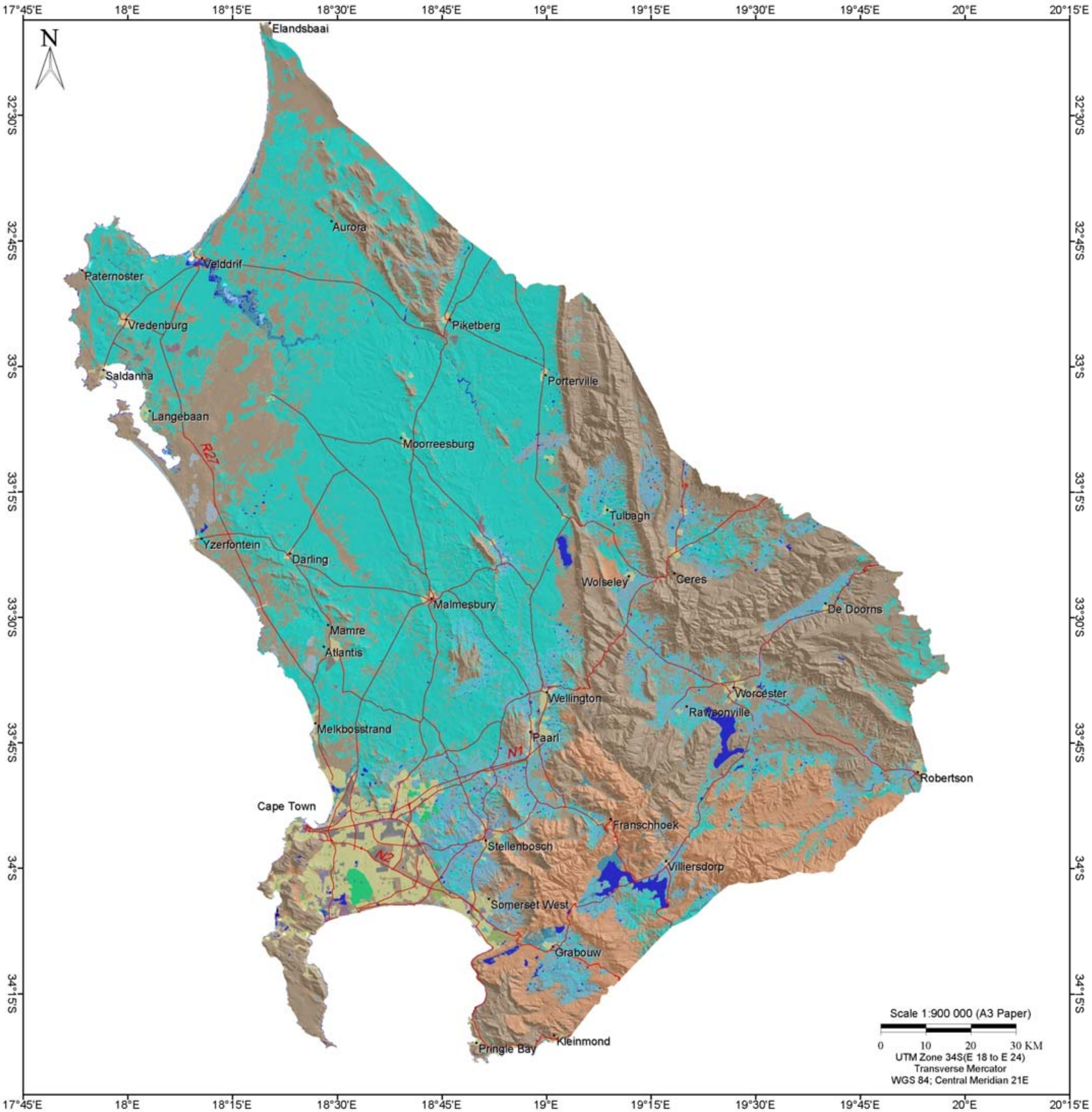
[2)]The sum of urban demand includes current water supply to the City of Cape Town.

Groundwater is an important component of the water resources in both the Berg and Breede WMAs. About 17% of the total water requirements in the Breede WMA are estimated to be supplied from groundwater, while the estimation for the Berg WMA is about 6. However, it is expected that the water supply from groundwater has increased in the last years and will increase further, due to limitations of the available surface water supply as well as increasing demand.

The recent Groundwater Resource Assessment Phase II (GRA II) project (DWAF, 2004d) estimated the groundwater use per quaternary catchment and per water use sector (see **Figure 2-7**) indicating an annual abstraction of 150.8 million m^3/a in the study domain.

- The highest groundwater demand is for irrigation with 107.5 million m^3/a, mainly in the G10E and H10C catchments (above 10 million m^3/a each, and in the E21A, E21D, G10K, H10F and H10G catchments (above 5 million m^3/a each).
- Urban domestic use accounts for 19 million m^3/a and is concentrated in the G21B catchment (Atlantis, 8.5 million m^3/a) and the G22D catchment (Cape Flats, 5.9 million m^3/a). Relevant abstraction for domestic use also occurs in the G22B and H10C catchments.

Neither of the afore-mentioned data sets are aquifer specific. A method to disaggregate and recalculate the distribution of groundwater abstraction per aquifer is further discussed and detailed in the Water Balance Report (Volume 4).



LEGEND

- Towns
- Roads

NLC 2000 Simplified Classification

- Thicket, Bushland, Shrubland, Bush Clumps & Fynbos
- Planted Grassland
- Forest Plantation
- Water
- Wetland
- Bare Rock & Soil
- Cultivated, permanent
- Cultivated, temporary
- Urban / Built-up, residential
- Urban / Built-up, smallholdings
- Urban / Built-up, commercial
- Urban / Built-up, industrial
- Mines & Quarries

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

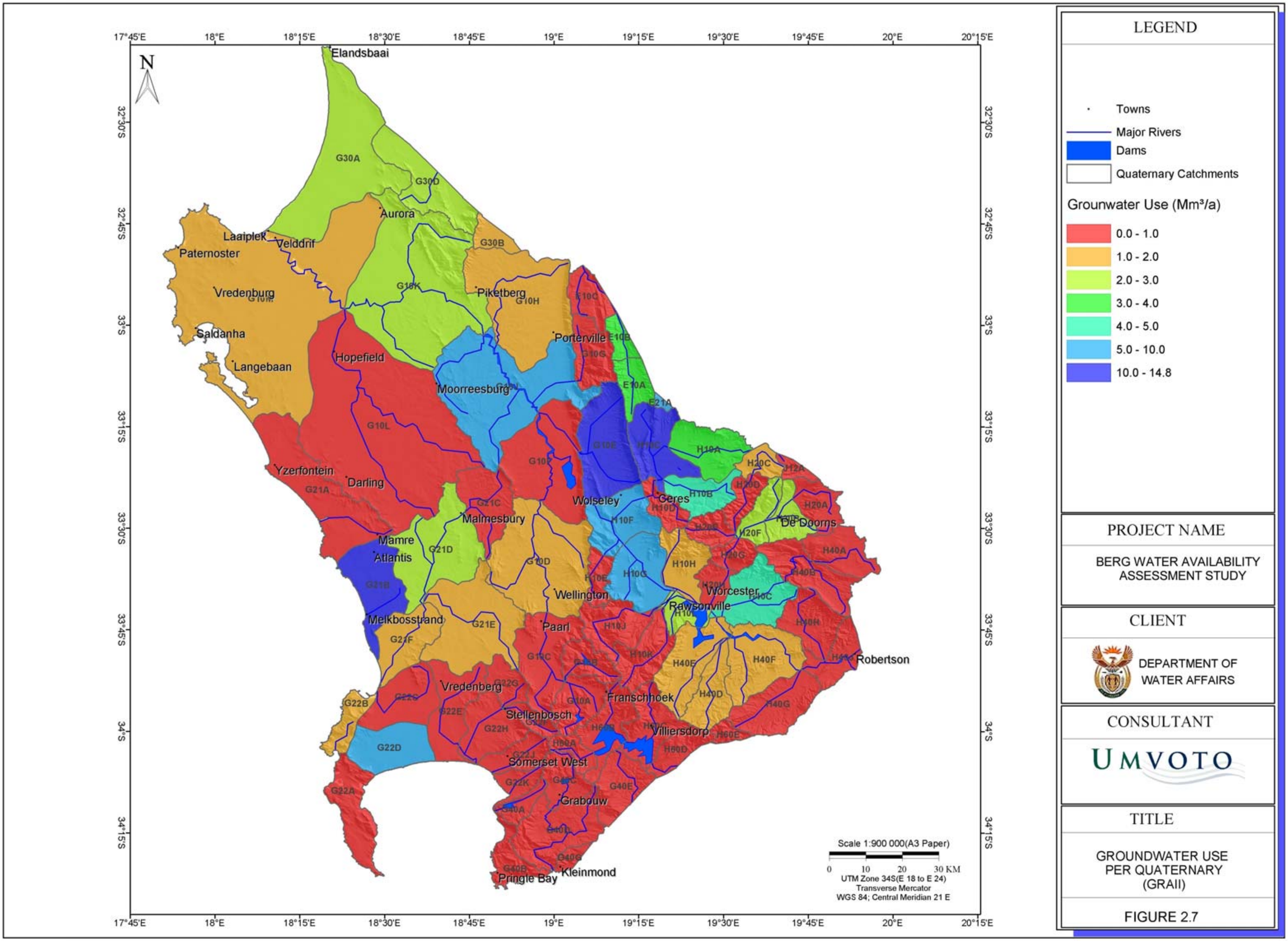
CONSULTANT

UMVOTO

TITLE

CURRENT LAND COVER (after NLC 2000)

FIGURE 2.6



LEGEND
Towns
Major Rivers
Dams
Quaternary Catchments
Grounwater Use (Mm³/a)
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 10.0
10.0 - 14.8
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS
CONSULTANT
UMVOTO
TITLE
GROUNDWATER USE PER QUATERNARY (GRAII)
FIGURE 2.7
N
Elandsbaai
Aurora
Laaiplek
Velddrif
Paternoster
Vredenburg
Piketberg
Saldanha
Porterville
Hopefield
Langebaan
Moorreesburg
Yzerfontein
Darling
Wolseley
Ceres
Malmesbury
De Doorns
Mamre
Atlantis
Wellington
Worcester
Rawsonville
Melkbosstrand
Paarl
Robertson
Vredenberg
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
Pringle Bay
Kleinmond
G30A
G30D
G30B
G10K
G10H
E10C
E10B
G10G
E10A
E21A
G10L
G10F
G10E
H10A
H20C
H12A
G21A
G21C
H10B
H20A
H10F
G21D
H20F
H40A
G10D
H10H
H10G
H40B
G21B
G21E
G21F
H10J
H40F
H40E
H40D
H40G
G22B
G22E
G22H
G22D
H60E
H60D
G22A
G40E
G40A
G40G
G40B
Scale 1:900 000(A3 Paper)
0 10 20 30 KM
UTM Zone 34S(E 18 to E 24)
Transverse Mercator
WGS 84; Central Meridian 21 E
17°45'E
18°E
18°15'E
18°30'E
18°45'E
19°E
19°15'E
19°30'E
19°45'E
20°E
20°15'E
32°30'S
32°45'S
33°S
33°15'S
33°30'S
33°45'S
34°S
34°15'S

3. GEOLOGY – HYDROGEOLOGY

3.1 BROAD STRATIGRAPHY OF THE STUDY AREA

The landscape of the study area is the product of a variety of geological processes acting over a long period of time; of the order of 500 million years (Ma) (see **Appendix A**).

The topography, drainage, hydroclimate, land-use and even the agricultural crops are largely determined by the underlying rock type and its structural character. The strong correlation between geology and terrain, illustrated on the DEM topographic base (**Figure 3-1)** implies a strong geological control also of local climate and land-use potential, through orographic control over precipitation and the widely variable geochemical composition of the different formations.

Underlying the younger cover strata along the West Coast, on the Sandveld and the Cape Flats in the western part of the study are, the oldest rocks, namely the **Malmesbury Group** (>555 Ma) and the **Cape Granite Suite** (555-510 Ma), are also exposed as rolling hills in the geographic region known as the Swartland. Locally pre-Cape **dolerite dyke** swarms, identified in the Tulbagh and Franschhoek area as well as on the Swartland plains, intrude the Malmesbury and Cape Granite basement.

The mountainous character of the eastern part of the study area is determined by the extremely resistant and fractured rocks that constitute the TMG (the lower part of the **Cape Supergroup; Tsble 3-1**) which are, in terms of Western Cape geological history, middle-aged (~400 Ma). The valleys in this region are infilled by slightly younger (~350 Ma) and more easily erodable rocks of the **Bokkeveld Group,** which consist largely of shales with a few relatively thin sandstone strata. The **Witteberg Group** and the lower parts of the **Karoo Supergroup** (**Table 3-1**) appear centrally in the eastern half of the study area between the towns of Worcester and Robertson, and extend southwest to just north of Villiersdorp.

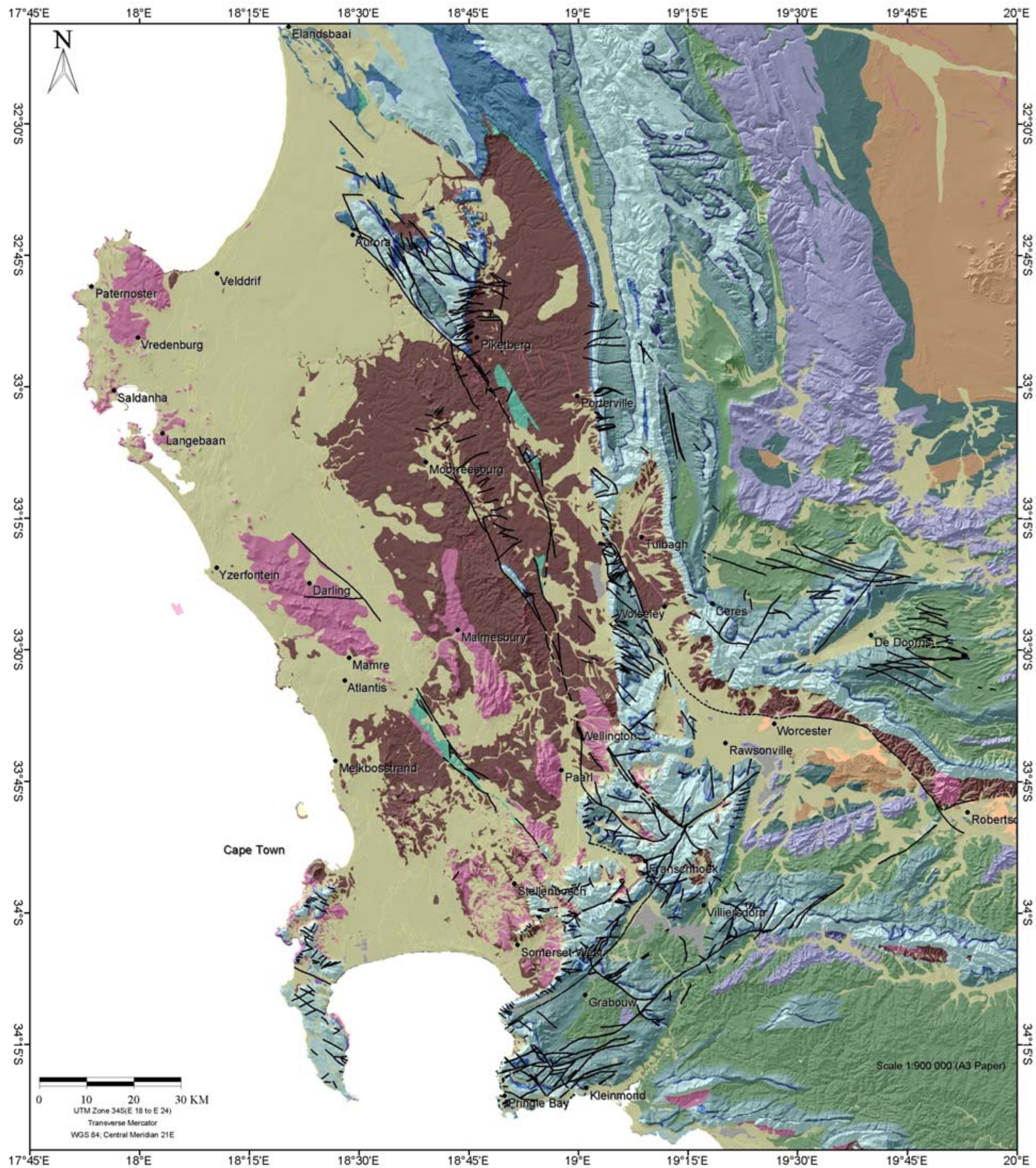
The Jurassic-Cretaceous **Uitenhage Group** is exposed in a downfaulted syncline to the south of the Worcester Fault, while the pene-contemporaneous **False Bay Suite** of ~136 Ma-old dolerite dykes are confined to the extreme south-western part of the study area, between the Cape Peninsula and the Kogelberg range.

The flat-lying and younger semi- to unconsolidated sediments of the fluvial-marine **Sandveld Group** (~2.5-25 Ma) and the largely aeolian **Bredasdorp Group** (0 – 2.5 Ma) widely in the western part of the study area. The young fluvial counterparts of these groups occur along stretches of the Berg and Breede Rivers and their main tributaries. Along the Berg River they are mapped in the region of Riebeek Kasteel and at the Berg River mouth, and between Wolseley and Robertson along the Breede River.

These major lithostratigraphic groups are summarised in **Table 3-1** below.

Table 3-1 Stratigraphy of the Study Area

Age range (Ma)	Supergroup	Group	Formation
0 – 2.5		Bredasdorp	Witzand
			Langebaan
			Velddrif
			Springfontyn
2.5 - 25		Sandveld	Varswater
			Saldanha
			Elandsfontyn
~~ Major unconformity ~~~~~			
65 - 144		Uitenhage	
			Enon
		False Bay Suite	(dolerite swarm)
~~ Major unconformity ~~~~~			
248 - 290	Karoo	Ecca	
		Dwyka	
290 - 354	Cape	Witteberg	(various)
354 - 417		Bokkeveld	(various)
		Table Mountain	Rietvlei
417 - 443			Skurweberg
			Goudini
			Cedarberg
			Pakhuis
			Peninsula
443 - 495			Graafwater
			Piekenierskloof
~~ Major unconformity ~~~~~			
495 - 545	(Saldanian)	Klipheuwel	
		Cape Granite Suite	
545 – >750		Malmesbury	



LEGEND

- • Towns
- — Faults

SIMPLIFIED LITHOLOGY

- Quaternary
- Uitenhage
- Ecca
- Dwyka
- Witteberg Group
- Bokkeveld Group
- Nardouw Group
- Cedarberg Formation
- Pakhuis Formation
- Peninsula Formation
- Graafwater Formation
- Piekenierskloof Formation
- Klipheuwel Group
- Cape Granite Suite
- Malmesbury Group
- Dam

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

1 : 250 000 GEOLOGY MAP (After CGS)

FIGURE 3.1

3.2 GEOLOGICAL STRUCTURES

The study area is dominated in the eastern half by the Cape Fold Belt, so named for the folded character of the mountains comprising the Table Mountain Group Formation. In addition to having been folded, the mountainous region is transected by a succession of strike-slip and normal faults that extend into the western half of the study area and beyond.

Since the groundwater flow in fractured rock aquifers mostly follows structurally controlled preferred flow paths, the 3 dimensional mapping of these structures (i.e. folds, faults, major fractures) becomes important to develop the conceptual understanding of the aquifer behaviour in these areas. The preferred flow paths as well as the 3D shape and aerial extent, surface and exposure, of the aquifer are relevant input parameters for the detailed groundwater flow modelling as well as the definition of model domains.

The palaeotopography of the coastal plain can also be controlled by the regional structural geology as well as changes in the base level of erosion due to sea level changes during previous times and the temporal relationship between these geological processes is important for understand the regional flow paths in the primary aquifers in these areas.

3.2.1 Major Fold Systems

A thorough structural analysis of folding in the mountains separating the eastern and western halves of the Berg WAAS area was conducted in a study of the feasibility of the TMG Aquifer as a water supply to the City of Cape Town done by the Table Mountain Group Aquifer Alliance (CMC, 2004). The study made use of previous and present conventional Aerial Photographic Interpretation (API) and selective follow-up field mapping of the main anticlinal and synclinal fold axial traces (CMC, 2004, fig. 3.4).

Two main trends of the anticline – syncline – fold axes dominate in the study area (**Table 3-2**). The fold axes in the northern and northeastern parts of the study area are predominantly orientated north south. The southeastern and central parts of the study area have fold axes orientated northeast southwest that accommodate the bending in the syntaxis of the Cape Fold Orogeny. A minor occurrence of fold axes orthogonal to the previous mentioned occurs in the southern Mountains around Franschhoek, in Piketberg and in the eastern extension of the study area. These fold axes are orientated northwest southeast.

The folded topography largely reflects the folded geology (See **Figure 3-2**), the topography being strongly governed by the lithological competence of the comprising units. As a result, the drainage of the main river streams follow the fold valleys that coincide with the lithological synclinal axes while the tributaries largely trend parallel to the fracture and fault patterns. The channelled flow of surface water from the recharge areas in the high mountain reaches is of particular importance when it drains over aquifer outcrop, realizing the potential for surface water – groundwater interaction and localized recharge to the aquifer (or river depending on elevations).

Table 3-2 Major Fold Structures in the Study Area

Fold	Fold Type	Orientation	Comment
Olifants River	Syncline	N - S	Related to the Olifants River
Koue Bokkeveld	Anticline	N - S	Watershed between Olifants River- and Agter Witzenberg Valleys
Agter Witzenberg	Syncline	N - S	Related to the Upper Olifants-, Koekedou- and Modder Rivers
Hansiesberg	Anticline	N - S	Accomodation fold between 2 large fault structures
Waterkloof	Syncline	N - S	Extension of Olifants River Syncline, related to the Watervals River
Slanghoek	Anticline	N - S	Related to the Slanghoek River
Hexriver Anticline	Anticline	NE - SW	Watershed bounding Warm Bokkeveld and Hex River Valley
Hexriver Syncline	Syncline	NE - SW	Related to the Hex River
Warm Bokkeveld	Syncline	NE - SW	Related to tributaries of the Upper Breede River
Zachariashoek	Syncline	N - S	Related to Paarl Rock
Wemmershoek	Anticline	NW - SE	Watershed bounding Wemmershoek Dam
Franschhoek	Syncline	NE - SW	Related to tributaries of the Upper Berg River
Steenbras	Syncline	NE - SW	Extension of Franschhoek Syncline, related to the Steenbras Dam
Stettynskloof	Anticline	NE - SW	Related to the Holsloot- and Elands- Rivers
Koegelberg	Anticline	NE - SW	Extension of Stettynskloof
Villiersdorp	Syncline	NE - SW	Related to the Modder-, Ratel-, Doring- and Poesjenels Rivers
Klipberg	Anticline	NE - SW	Related to the Konings River
Riviersonderend	Anticline	NE - SW	Related to the Riviersonderend River
Highlands	Syncline	NE - SW	Related to the Palmiet River
Botriver	Syncline	NE - SW	Related to the Bot River
Piketberg	Syncline	NW - SE	Related to the Boesmans- and Platkloof Rivers
Koo	Syncline	NW - SE	Related to the Nuy River

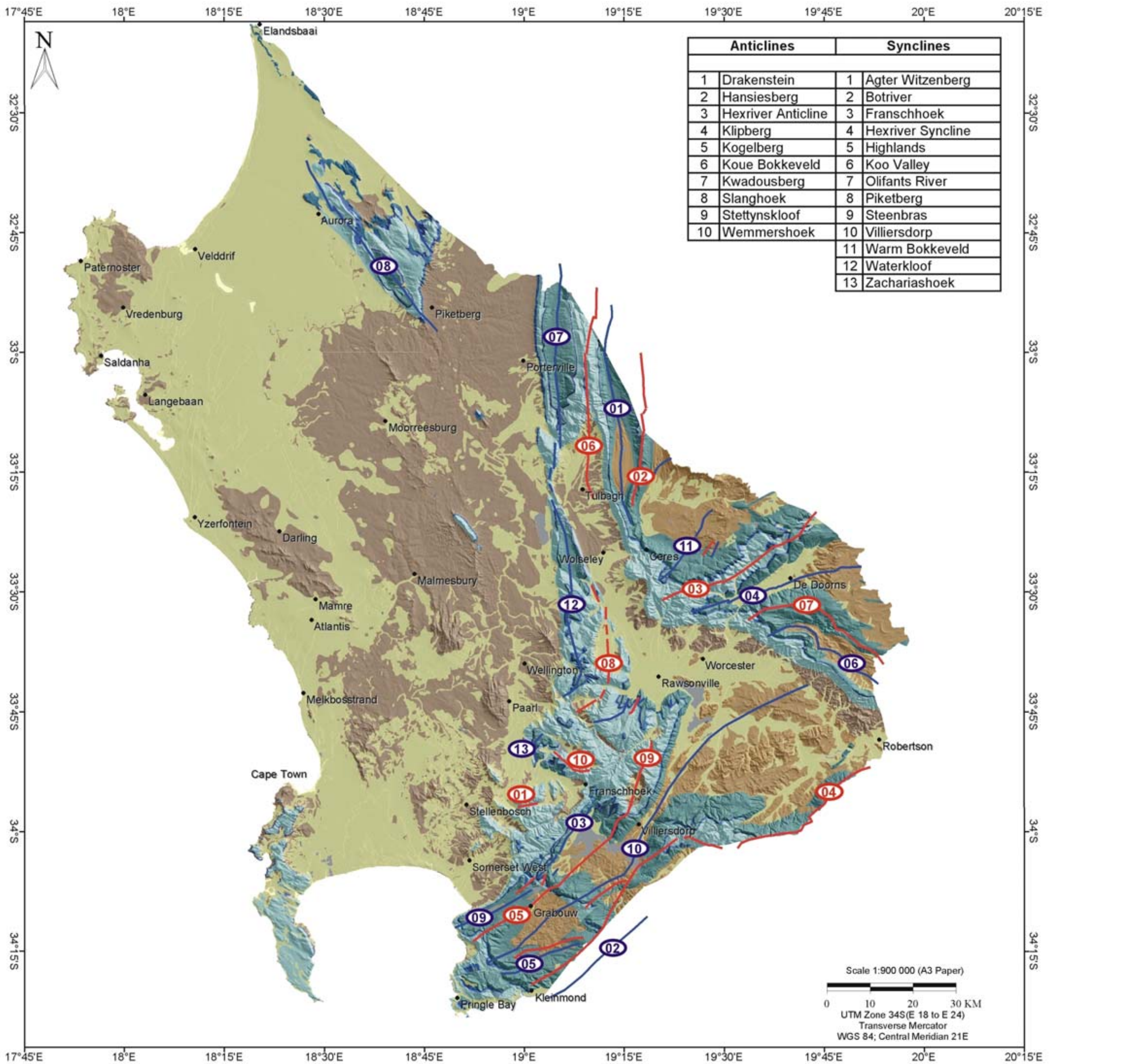
3.2.2 Major fault systems

Reverse, normal and strike-slip faults, many of which are of pre-Cape age, displace formations in the Malmesbury Group (Hartnady et al., 1974). These occurred before the deposition of the TMG and, except insofar as post-Cape faulting has reactivated them, these older structures within the basement aquiclude formations are not of relevance to this study.

Numerous post-Cape faults, generally with normal downthrow to the south, are present (**Table 3-3** and **Figure 3-3**). The largest of these is the well-known Worcester Fault, located south of the Hex River and Langeberg ranges, orientated west-to-east though the eastern part of the study area. The footwall is downthrown to the south by up to 6 km in the Worcester area where the southern Cretaceous sediments have been faulted against northern pre-Cape rocks. The fault is largely concealed under younger deposits of the Breede River valley (Gresse, 1992). Movement was presumably largely Jurassic-Cretaceous in age, though local post-Tertiary rejuvenation has been observed elsewhere in the Southern Cape (Toerien, 1979; Hill, 1988).

Table 3-3 Fault Systems

Fault	Fault type	Orientation	Comments
Colenso	Concealed	NW - SE	Greater than 100km in extent
Du Toit	Normal, downthrown to the S	NW - SE	Downthrow of ~100m, complicated to the N
Elandskloof	Normal, downthrown to the N	NW - SE	Offsplay of the western extension of the Worcester Fault
Groenlandberg	Normal, downthrown to the S	E - W	Downthrow of greater than 1km
Klein Drakenstein	Normal, downthrown to the S	NW - SE	Downthrows Skurweberg against Peninsula
La Motte	Normal, downthrown to the N	WNW - ESE	Concealed in the Franschhoek Valley, exception to S-downthrow in the western half of the study area
Milnerton	Concealed	NW - SE	Transects the Cape Flats
Piketberg-Aurora	Normal, downthrown to the N	NW - SE	Greater than 50km in extent
Riviersonderend	Normal, downthrown to the S	E - W	Complicated in the W at fault bend
Rooiels	Normal, downthrown to the S	NE - SW	Downthrow of ~300m
Steenbras-Brandvlei	Right lateral, strike-slip	NE - SW	Near vertical, complicated to the S
Tulbagh Road	Left lateral, strike-slip	NW - SE	Near vertical, western extension of the Worcester Fault
Worcester	Normal, downthrown to the S	E - W	Downthrow between 1.5km at the ends to 6km in the center



Anticlines		Synclines	
1	Drakenstein	1	Agter Witzenberg
2	Hansiesberg	2	Botriver
3	Hexriver Anticline	3	Franschhoek
4	Klipberg	4	Hexriver Syncline
5	Kogelberg	5	Highlands
6	Koue Bokkeveld	6	Koo Valley
7	Kwadousberg	7	Olifants River
8	Slanghoek	8	Piketberg
9	Stettynskloof	9	Steenbras
10	Wemmershoek	10	Villiersdorp
		11	Warm Bokkeveld
		12	Waterkloof
		13	Zachariashoek

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

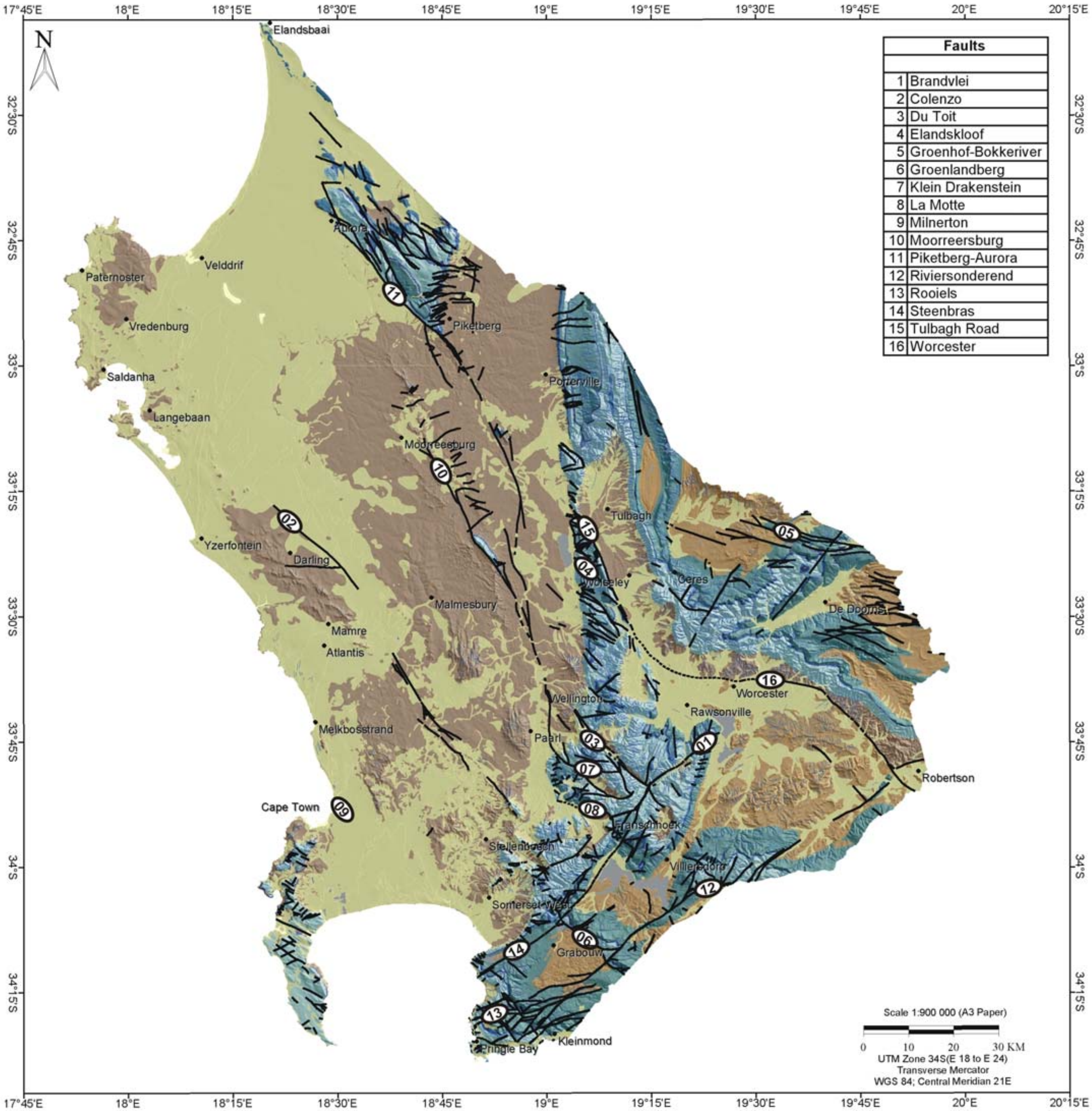
CONSULTANT

UMVOTO

TITLE

MAJOR TMG FOLD STRUCTURES

FIGURE 3.2



LEGEND

- Towns
- Regional Fractures
- Faults
- Quaternary Sediments
- Post_TMG
- Nardouw Group
- Cedarberg Formation
- Pakhuis Formation
- Graafwater Formation
- Peninsula Formation
- Piekenierskloof Formation
- Pre-Cape
- Dams
- 01 Faults

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

GEOLOGICAL STRUCTURES (FAULTS & REGIONAL FRACTURES)

FIGURE 3.3

3.3 AQUIFER CLASSIFICATION

In order to better understand the hydrostratigraphy adopted for this study, clear definitions of different aquifer types are useful, as in the existing 1: 500 000 hydrogeological mapping of the study domain. These maps present spatial distribution of aquifer types based on surface outcrop of lithology and further subdivided based on borehole yield.

The Cape Town hydrogeological map (DWAF, 2000) distinguishes three types of aquifer (see **Figure 3-4**) namely,

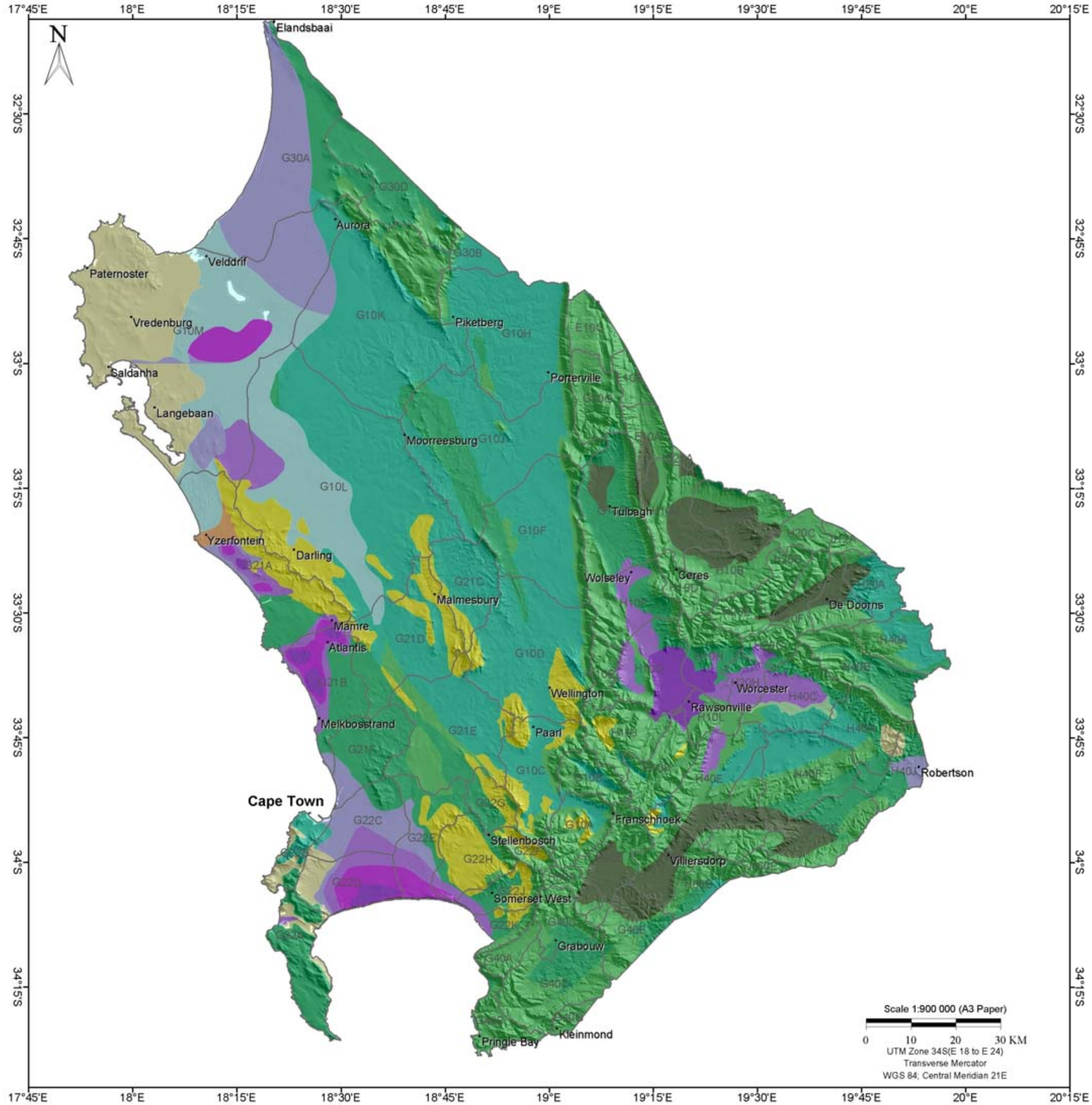
- type a - intergranular ("primary" or porous sandy aquifers),
- type b - fractured ("secondary" aquifers), and
- type d - intergranular-and-fractured (also termed "regolith" aquifers, in which porosity and permeability is related to a combination of near-surface fracturing and chemical weathering).

In addition, these aquifer types are further subdivided into yield classes, e.g., "b1" through "b5" from lowest yielding (0.0 – 0.1 l/s) to highest-yielding (>5.0 l/s) (cf. legend to **Figure 3-4**).

The aquifer classification used in this study differs in selected areas of the study relative to the different previous study areas in which they were defined. The summary reasons for the differences in aquifer classification in the past have been discussed in the Inception Report (DWAF, 2005) and the Internal Strategic Perspective Study (DWAF, 2004a and 2004b). The aquifer classification impacts on the hydrostratigraphic classification as well as the flow-path definition, the mass balance and on the definition of boundary conditions within local-scale model domains. For this reason the authors consider it important to work from first principles and observations that are measurable in the field in the study area, rather than conform to classification prepared for use at a national scale.

The key difference between the different aquifer classifications lies in the use of the term "Fractured or Secondary" Aquifer for the area underlain by the Malmesbury Group (the Swartland). In the authors' opinion, these areas consist dominantly of geomechanically weak slates and phyllites, which (in contrast to the TMG aquifers) are incapable of supporting open fractures below the near-surface weathered zone. Therefore, in this study, the terrain is classified as a regolith aquifer type (see below; DWAF, 2005).

A similar consideration applies to the high-yielding "b5" areas (**Figure 3-4**), which – except for a restricted patch near Tulbagh in the G10E quaternary catchment, which is underlain by Malmesbury shales on the slopes beneath the Saron and Winterhoek Mountains – covers areas underlain by the dominantly shale-bearing Bokkeveld Group. These b5 zones are usually surrounded by high quartzite mountains and ridges, which provide substantial lateral recharge, both through surface-channel seepage and through subsurface percolation, to the shallow regolith aquifers of the Bokkeveld (DWAF, 2005). It is mainly this circumstance that accounts for the high-yielding characteristic.



LEGEND

- Towns
- Quaternary Catchments

AQUIFER YIELD (l/s)

Intergranular Aquifer

a1	0.0 - 0.1
a2	0.1 - 0.5
a3	0.5 - 2.0
a4	2.0 - 5.0
a5	> 5.0

Fractured Aquifer

b1	0.0 - 0.1
b2	0.1 - 0.5
b3	0.5 - 2.0
b4	2.0 - 5.0
b5	> 5.0

Intergranular and Fractured

d1	0.0 - 0.1
d2	0.1 - 0.5
d3	0.5 - 2.0

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

AQUIFER YIELD
(After DWAF1:500 000 Hydrogeology Series)

FIGURE 3.4

3.3.1 Intergranular aquifers

Aquifers in which the porosity is interstitial to sedimentary grains in generally sandy formations (type a) occur in extensive areas along the coastal plain of the Berg WMA, between the Cape Flats in the south and Elands Bay in the north (DWAF, 2005). These deposits constitute the Sandveld Group and vary in origin from shallow-marine or littoral, fluvial to aeolian (dune-sand) sediments. These details, which determine their spatial distribution in the present day (see **Section 4.3.4**, for the impact on model domain analysis), are reflected in the stratigraphic details of the Sandveld Group.

In general, the coastal Sandveld aquifers consist of an upper unconfined semi- to unconsolidated unit, separated by relatively less permeable aquitard units from a deeper semi-confined to confined unit. The deeper confined-aquifer zones, which arguably have the greater resource potential, are controlled by the structure of palaeo-valleys incised in the coastal plain during periods of low sea-level stand (DWAF, 2005).

Just beyond the eastern border of the Berg WMA, there is an extensive area underlain by Tertiary-Recent alluvial aquifers in the valley of the middle Breede River, referred to as the Breede Alluvium in this study.

3.3.2 Fractured aquifers

In the current hydrogeological mapping most of the central Berg WMA underlain by Malmesbury Group strata is represented in the “fractured” aquifer yield classes. As stated above, these rocks are redefined to fall into the “fractured and weathered” aquifer class (see below).

The “b4” yield areas generally coincide with the outcrops of the Table Mountain Group and the Witteberg Group. These units are composed of thick quartzite successions of high compressive and tensile strength, and are therefore capable of supporting open, permeable fractures to depths of several kilometers, as the presence of several hot springs indicates. Accordingly these b4 areas alone are the true fractured-rock aquifer systems of the Berg WMA and its surroundings (DWAF, 2005).

The **Table Mountain Superaquifer**, which is composed of the larger **Peninsula Aquifer** (apparent thickness approximately 1,5 km in this area) and the lesser **Nardouw Aquifer** (with its component subaquifers), is the principal focus of the present study.

3.3.3 Fractured and weathered (regolith) aquifers

The type d (or “intergranular and fractured”) aquifers as currently mapped (DWAF, 2000) coincide with exposures of the Cape Granite Suite. In this case, the regolith aquifer is usually concentrated in the gravelly, leached, “gruss” zone within sub-horizontal exfoliation joints, between the fractured-and-weathered surface layer above and the fresh, unweathered bedrock below (DWAF, 2005).

At some depth (>50-100 m below surface) the Bokkeveld Group as a whole is a mega-aquitard; not only is the permeability low, but also the groundwater quality – even in the cleaner quartzitic zones - is (sometimes exceedingly) poor in terms of Total Dissolved Solids. Thus the only part of the Bokkeveld worth hydrogeological consideration is the “weathered and fractured” zone (categorically distinguished from true fractured-rock aquifers on the 1 : 500 000 DWAF hydrogeological map series), which may also be termed a “regolith” aquifer.

The quaternary catchment is chosen as the base scale for regulatory decisions as regards groundwater assessment and licensing. While it is possible to simplify data to a coarser scale, and impossible to disaggregate numbers into a finer scale if the physical principles and process scale are not applicable, it is necessary to ensure that the hydrostratigraphy and aquifer classification are coherent at the quaternary level. Similarly, the structural relationships between the different rock groups and formations, as well as surface water drainage are considered at this scale. This allows for the physically realistic mapping of flow paths within and between the different groundwater and surface water conduits. In instances where fractured aquifers and their defining features transect quaternary, secondary and basin-scale catchments, the recharge zone and the discharge zones of the flow paths are determined in domains where they can reasonably be considered to be contained. This principle is similar to the process definition of a surface water catchment.

3.4 HYDROSTRATIGRAPHY AND DETAILED AQUIFER CLASSIFICATION

The nature and composition (lithology) of particular stratigraphic units in the study domain is here considered from a purely hydrogeological viewpoint, with regard to the relative hydraulic conductivity or permeability of the unit, and its corresponding classification either as aquifer[1], aquitard[2], or aquiclude[3] (**Table 3-4**).

The TMG and its components are officially defined lithostratigraphic units in terms of South African Committee for Stratigraphy (SACS) protocols. Accordingly they are not susceptible to arbitrary redefinition, dictated by a specifically hydrogeological perspective. Based on information from the geological map at a scale of 1 : 250 000 (Theron et al., 1992; Gresse, 1997), the DWAF hydrogeological map at a scale of 1 : 500 000 (Meyer, 1999), and work conducted by Umvoto elsewhere in the TMG terrains, a general nomenclature for relating geological (stratigraphic) units to hydrogeological units (aquifers and aquitards) was provisionally proposed (DWAF, 2000). This is now upgraded and presented in **Table 3-4** below using new information obtained from drilling throughout the TMG terrain as well as revised desk top mapping and field work within the Breede Basin during the TMG Aquifer Feasibility Study and Pilot Project conducted by the City of Cape Town in 2004 (CMC, 2004).

Other than in the shallow weathered regolith zone overlying fresh bedrock, the pre-Cape aquicludes in the Berg WMA and surroundings are considered as major barriers to groundwater movement, whether they underlie the younger Sandveld aquifers (upper part of **Table 3-4**) or the older Table Mountain Group (TMG) aquifers (lower part of **Table 3-4**). Regional groundwater movements are controlled by the presence of these and other aquitard units.

---

1 "An aquifer is a layer or layered sequence of rock or sediment comprising one or more geological formations that contains water and is able to transmit significant quantities of water under an ordinary hydraulic gradient. Aquifers therefore have sufficient permeability to transmit groundwater that can be exploited economically from wells or springs. Good aquifers are usually developed in sands, gravels, solutionally weathered limestones and fractured sandstones".

2 "An aquitard is a unit of lower permeability that may transmit quantities of water that are significant in terms of regional groundwater flow, but from which negligible supplies of groundwater can be obtained".

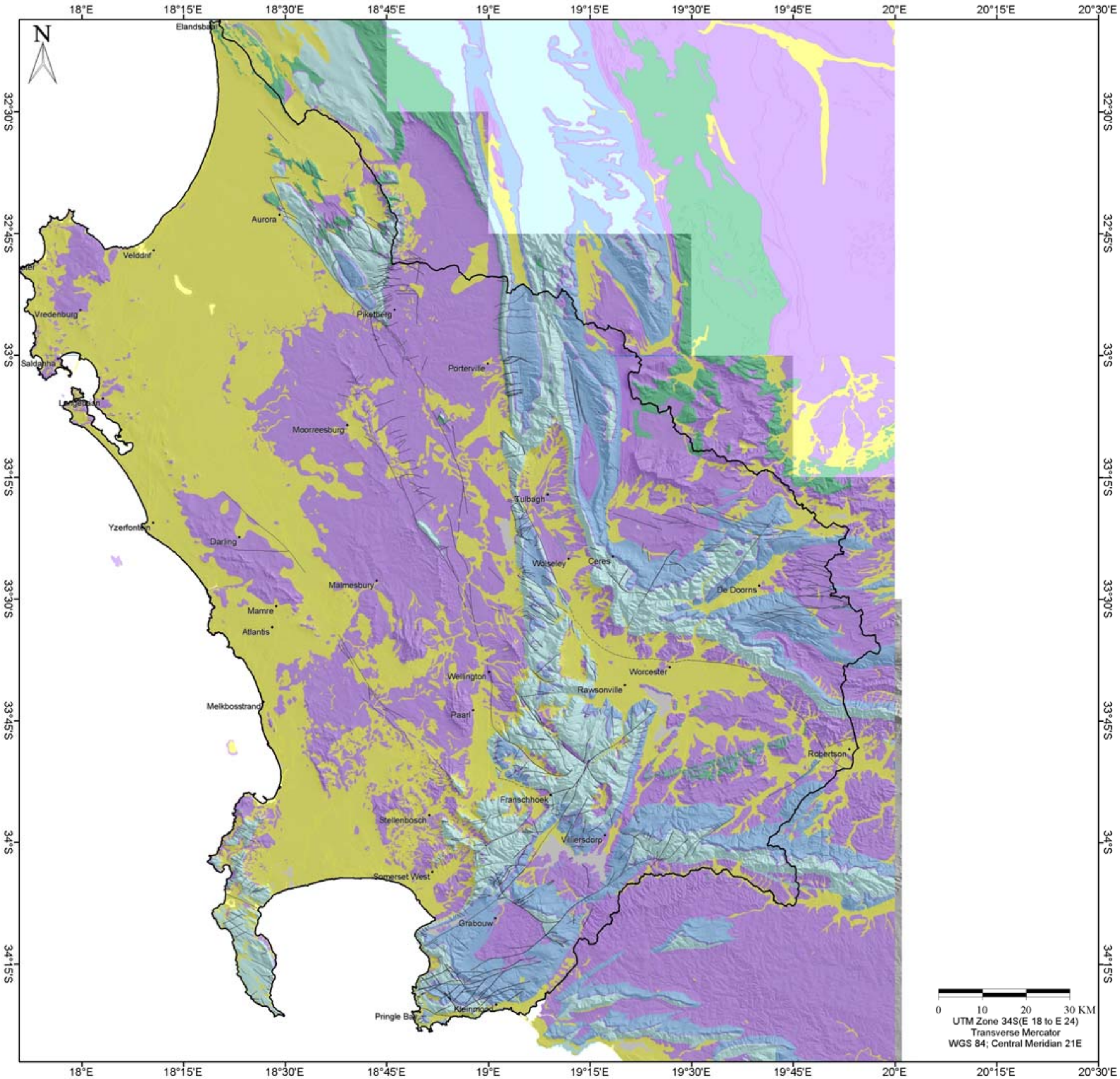
3 "An aquiclude is a saturated geological unit of such low permeability that it is incapable of transmitting significant quantities of water under ordinary hydraulic gradients and can act as a barrier to regional groundwater flow. Aquiclude rocks include clays, shales and metamorphic rocks". (Hiscock, 2005)

3.4.1 Hydrostratigraphy

The division and sub-division of the stratigraphic units into aquifer and aquitard units is shown in **Table 3-4**. More detailed lithostratigraphic descriptions can be obtained from previous works (e.g., Visser, 1967; Broquet, 1992; Theron et al., 1992; Gresse, 1997; Gresse and Theron, 1992). These are summarized in **Appendix B**. A definition of hydrostratigraphy and the proposed subdivision between mini-, meso- and mega-aquifers is documented in **Appendix C**.

Table 3-4 Coincident hydrostratigraphic units of the study area

Superunits	Units	Subunits
	Bredasdorp Aquifer	Various discrete alluvial aquifers
		Springfontyn Subaquifer
		Local (unnamed) aquitards(s)
	Sandveld Aquifer	Varswater Subaquifer
		Local (unnamed) aquitards(s)
		Elandsfontyn Subaquifer
	Mainly underlain by aquicludes of Malmesbury Group and or Cape Granite Suite in western part of Berg WMA; alluvial Sandveld is locally underlain by TMG and higher units in eastern part	
	Gydo Mega-aquitard	
Table Mountain Superaquifer	Nardouw Aquifer	Rietvlei Subaquifer
		Verlorenvalley Mini-aquitard
		Skurweberg Subaquifer
	Winterhoek Mega-aquitard	Goudini Meso-aquitard
		Cedarberg Meso-aquitard
		Pakhuis Mini-aquitard
	Peninsula Aquifer	Platteklip Subaquifer ? (not yet separately mapped throughout Berg WMA)
		Leeukop Subaquifer ? (not yet separately mapped throughout Berg WMA)
		Graafwater Meso-aquitard
		Piekenierskloof Subaquifer (localized)
	Aquicludes	[Klipheuwel Group] [Cape Granite Suite] [Malmesbury Group]



LEGEND

Faults
Dam

AQUIFER OUTCROPS

Intergranular
Intergranular Fractured

Fractured
Other
Nardouw
Peninsula

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS

CONSULTANT

UMVOTO

TITLE

AQUIFER OUTCROPS CLASSIFICATION

FIGURE 3.5

3.4.2 Aquifer Mapping in this Study

The spatial distribution of the different aquifer types is illustrated in **Figure 3-5**. The detailed vertical distribution within each aquifer type can best be illustrated using local-scale cross sections on which it is possible to highlight the hydrostratigraphic units and relationships which are not necessarily easy to conceptualise in plan view. This aspect is addressed in the Water Balance Volume of the report (Volume 4).

The hydrostratigraphic scheme adopted for the present study is based on **Table 3-4**, and focuses on the three main “coincident” or stratabound aquifer units; namely, the Peninsula, Nardouw and Sandveld aquifers. The non-coincident aquifer units, which correspond to the intervening “fractured-and-weathered” or regolith zones, are largely disregarded in this approach, except where they might interface laterally with, or grade into, TMG and/or Sandveld aquifer compartments. In these cases, the near-surface regolith zone may provide a diffuse or channelised flowpath between the different aquifers.

Of interest to this study are the “Fractured” Aquifer class, specifically the Peninsula and Nardouw (Skurweberg) aquifers in the Table Mountain Group, and the Sandveld Group in the “Intergranular” Aquifer class. The Peninsula and Skurweberg aquifers have large recharge potential in the high-lying mountains forming the escarpment separating the eastern and western halves of the study area. The aquifer dimensions are such that these aquifers are a significant supply of groundwater to the study. The Sandveld Aquifer is of particular importance in the northern part of the West Coast where natural water suitable for drinking is in short supply.

Intergranular aquifers

As discussed above the intergranular aquifers are confined to the coastal Sandveld aquifers along the West Coast and on the Cape Flats, the limited alluvial aquifer along reaches of the Berg River in the G10 catchment and the aquifer known as the Breede River Alluvium in the Worcester region of the Breede Valley.

The Sandveld Aquifers consist of an upper unconfined semi- to unconsolidated unit (mapped as the Varswater and the Springfontyn units by Rogers (1980) and herein classified as sub aquifers), separated by relatively less permeable and unnamed aquitard units from a deeper semi-confined to confined unit (the Elandsfontyn Subaquifer). The deeper confined-aquifer zones have the greater resource potential, and are controlled by the structure of palaeo-valleys incised in the coastal plain during periods of low sea-level stand (DWAF, 2005).

There is widespread evidence (Birch, 1968; Theron *et al.*, 1992, Pl. 5.7, p. 56; Hay, 1981; Rogers, 1980) for erosional platforms at ~20 m elevation along the entire coastal plain of the study area. The platforms formed by the abrasive action of the ocean waves on the beachfront. This suggests that the Malmesbury bedrock occurs as a flat platform of generally constant altitude. Varying facies of the Sandveld Group immediately overlies the bedrock. From a hydrogeological perspective, the cleaner sandy facies of the Springfontyn Formation (see **Table 3-4**) is the principal primary aquifer in the majority of the Sandveld Group outcrop.

It is possible that sub-outcrops of the Varswater Formation or older Miocene units (Saldanha and Elandsfontyn formations) occur at much lower elevations beneath the younger superficial sands in the area south of Elands Bay and around Saldanha Bay. If these are confined within channelized palaeo-drainage systems including coarser-grained fluviatile sedimentary components, they could - as the formation name (“Freshwater’) implies - be important aquifers.

In the further hydrogeological characterisation and modelling of the confined-aquifer zones within the Sandveld, there is a particular requirement to establish the bottom-boundary conditions, particularly with regard to possible lateral recharge from adjoining fractured-rock and/or regolith aquifer terrains. A similar requirement for the modelling of subsurface, lateral recharge holds also for the fluvial aquifers of the Breede valley, as these have extensive, gravel-rich, alluvial-fan elements at the mouths of major canyons draining the high mountain terrains.

Fractured-rock aquifers

The discussion is confined to the hydrostratigraphy of the TMG or the **Table Mountain Superaquifer** because, in this study, we do not classify the Malmesbury bedrock or the Bokkeveld Group as an aquifer unit. The true fractured-rock systems of the Berg WMA and its surroundings are the “b4” yield areas (**Figure 3-4**), generally coincident with the TMG outcrops or the Witteberg Group. They comprise a thick quartzite successions of high compressive and tensile strength, and are capable of supporting open, permeable fractures to depths of several kilometers (DWAF, 2005). Areas underlain by the dominantly shale-bearing Malmesbury and Bokkeveld groups are usually bordered or surrounded by high TMG ridges, from which substantial lateral recharge into the shallow regolith aquifers accounts for locally high-yielding characteristics.

The TMG quartzites are stratabound aquifers (i.e. having significant fracture porosity and a permeability greater than $10^{-16}\,m^2$), and therefore constitute “coincident” hydrostratigraphic units, as defined by Al-Aswad and Al-Bassam (1997), in that the hydrostratigraphic boundaries generally coincide with those of the lithostratigraphic units. The **Table Mountain Superaquifer**, which is composed of the larger **Peninsula Aquifer** (apparent thickness approximately 1.1 km in this area) and the lesser **Nardouw Aquifer** (with its component subaquifers), are the principal focus of the present study.

The **Peninsula Formation (Aquifer)** consists of predominantly planar-bedded, light-grey, coarse-grained quartzitic sandstone, with occasional thin layers of vein quartz pebbles. The succession contains isolated bioturbated zones, biogenic trails and rare anthropod traces (Gresse and Theron, 1992). The Peninsula Aquifer, approximately 550 m thick in the Cape Peninsula area but reaching ~1300 m in the Citrusdal region, wedges out beyond Clanwilliam in a northerly or northeasterly direction. Eastwards within the Cape Fold Belt, however, it thickens to >2000 m in the Oudtshoorn area.

In the Cape Peninsula, the formation is subdivided into a lower Leeukop Member, distinguished by repeated upward fining and thinning sedimentary cyclicity, and an upper Platteklip Member, which is generally thick bedded and lacks this cyclicity (Broquet, 1992). It has not yet been proven that the Leeukop-Platteklip boundary can be mapped distinctly in areas other than the Cape Peninsula. In the Hottentots-Holland and Hawequas Mountain ranges, however, there is some indication that the Peninsula Formation may be divisible between two members, the upper more massively bedded one of which may be an excellent fractured-rock aquifer.

The overlying unit that confines the Peninsula Aquifer in the subsurface, and separates it from the overlying Nardouw Aquifer, consists of a conformable package of three aquitard units (**Table 3-4**). These are grouped as the **Winterhoek Mega-aquitard**, following terminology originally used by Rust (1967) to describe the glaciation event recorded by the Pakhuis tillite. Hydrogeologically, the entire Pakhuis – Goudini sequence is an effective aquitard.

Although the Goudini Formation is considered part of the Nardouw Subgroup, it is not part of the Nardouw Aquifer. The provisional hydrostratigraphic nomenclature proposed above also recognizes that the Rietvlei Formation in the Nardouw Subgroup may have an upper, water-bearing zone (**Rietvlei Subaquifer**), separated from the larger Skurweberg Aquifer by the Verlorenvalley Mini-aquitard.

Structural complications such as faulting may, however, introduce some ambiguities in the hydrostratigraphical classification. For example, where a highly fractured and thus sufficiently permeable fault zone has a sufficiently large stratigraphic throw, it may juxtapose and thus create a leakage junction between two otherwise separate aquifers, e.g. between the Peninsula and the Piekenierskloof aquifers.

Fractured and weathered (regolith) aquifers

The type d (or “intergranular and fractured”) aquifers as currently mapped (DWAF, 2000) coincide with exposures of the Cape Granite Suite. The only part of the Bokkeveld worth hydrogeological consideration is the “weathered and fractured” zone (categorically distinguished from true fractured-rock aquifers on the 1: 500 000 DWAF hydrogeological map series), which may also be termed a “regolith” aquifer. The overflow from the deeper Nardouw aquifers generally leaks into and percolates through this superficial Bokkeveld regolith aquifer on Mountain slopes downhill from the TMG-Bokkeveld contact (see above), and the same applies to the granite regolith aquifers on slopes downhill from the basal Peninsula Aquifer contact.

In these instances of “bounding aquifers”, and also in relation to other Tertiary-Quaternary aquifers, which may overlie or be in lateral contact with TMG bed-rock, it may be sensible to adopt a more inclusive informal definition of “TMG-related aquizones”. Note, however, that in relation to the total volume of secondary fracture porosity within the deep, confined Peninsula Aquifer alone these bounding aquifers constitute a relatively trivial resource, and are probably also the most susceptible to negative environmental impacts on groundwater-surface water interactions. Furthermore it is expected that the recharge discharge cycle is similar to that of surface water.

On that account, there is a reasonable case for declaring them, and also the upper Nardouw, strictly off-limits to any future large-scale agricultural or urban abstraction. It is accordingly important to map them, but mainly for ecological Reserve purposes.

Informal aquizones

The existence of definite structural zones (faults, master joints, even structurally controlled cave systems) of particularly high hydraulic conductivity may also require that other kinds of water-bearing unit be recognised. These features are either contained within a larger, formally defined aquifer of generally lower permeability or as an aerially restricted permeable feature transecting an aquitard unit. Al-Aswad and Al-Bassam (1997) indicate that these may be informally named aquizones, outside of or apart from the formal hydrostratigraphic hierarchy. Aquizones can be defined in the study domain by the the identification and naming of particular main fracture systems and associated pseudo-karstic domains within the TMG, or by identifying particular flowpath-controlling elements of the bedrock palaeotopography underlying the intergranular aquifers of the West Coast - possibly also the alluvial aquifers.

3.5 GEOTHERMAL ACTIVITY

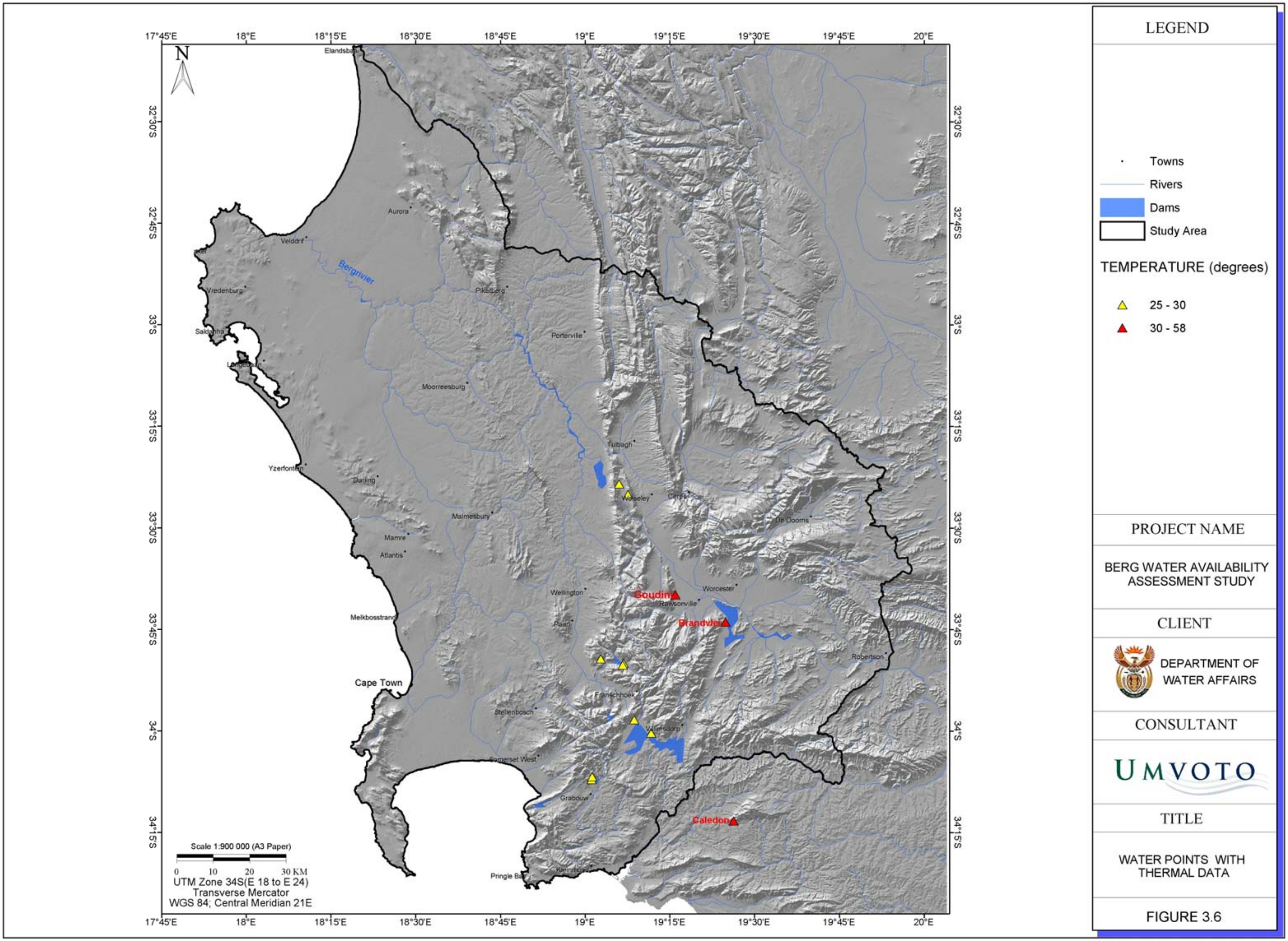
The TMG is well known for the occurrence of numerous spring systems. Of these, the most significant are the hot springs, among which is the hottest and strongest in South Africa. These geothermal phenomena not only provide direct evidence for deep circulations of groundwater, but locally also exert a significant control on the ambient temperature of wetland soils and surface-water streams in the discharge areas. Two significant TMG-related thermal springs occur within the study area, namely, Brandvlei and Goudini (red triangles in **Figure 3-6**), while several others lie just beyond the study boundaries, namely Caledon beyond its eastern boundary (**Figure 3-6**) and Warmwaterkloof and The Baths beyond its northern boundary.

Water temperature measurements in boreholes and streams provide a potentially important source of information about deep groundwater flow paths within the TMG aquifer system, and have therefore been recorded during routine surveys as part of the TMG groundwater exploration programme for the City of Cape Town (CCT, 2005b). A GIS-based analysis of water temperatures recorded in four hydrocensus surveys at six-monthly intervals between April 2003 and November 2004 revealed a few possible areas of geothermal anomaly, defined as the occurrence of borehole and/or surface water temperature in excess of 25°C. These possible geothermal anomalies were located at the following sites:

i. Along the Klein Drakenstein Fault near the south-eastern arm of the Wemmershoek reservoir (**Figure 3-6**);
ii. Along the Steenbras-Brandvlei Mega-fault (SBM) trend, on the north-western side of the Theewaterskloof reservoir (**Figure 3-6**);
iii. In the Breede River Valley, near Villiersdorp, on the north-eastern side of the Theewaterskloof reservoir;
iv. Along the SBM trend in the area north-west of Grabouw (**Figure 3-6**);
v. In an area southwest of the Houw Hoek Pass.

The temperature results from the May/June 2005 CCT hydrocensus, however, generally discounted the previous anomalous temperature indications at the above localities, except (v) which being outside of the exploration focus area was not revisited. In fact, most of the new results from the area between Grabouw and Franschhoek produced anomalously low surface-water temperatures (<15°C), which are ascribed to an early spell of cold and rainy weather that immediately preceded the start of the May/June 2005 hydrocensus.

In other areas of the Western Cape, e.g., in the region around the hot spring at The Baths near Citrusdal, there are local occurrences of emergent thermal groundwater mixing unobtrusively with Mountain stream flow, in such a way as to cause a relatively sudden and anomalous elevation in the temperature of the surface water flow. Warmwaterkloof, south of The Baths, and a stream crossing the farm Koringlandshoek, to the north of The Baths, are examples where thermal water inputs to surface flow are diffuse and are generally only detectable through along-channel mapping of water temperature, especially during mid-winter snowfall periods, when the contrast between the surface-water temperature and the groundwater temperature is greatest (Umvoto Africa, unpublished stream-survey data). These water-temperature results from the CCT programme further emphasize the importance of instrument (thermometer) calibration during the hydrocensus surveys, and the need for systematic standardization of temperature-measurement procedures, so as to ensure that measurements are strictly comparable between sites and between seasons.



17°45'E
18°E
18°15'E
18°30'E
18°45'E
19°E
19°15'E
19°30'E
19°45'E
20°E
32°30'S
32°45'S
33°S
33°15'S
33°30'S
33°45'S
34°S
34°15'S
N
Elandsbaai
Aurora
Velddrif
Bergrivier
Vredenburg
Piketberg
Saldanha
Porterville
Langebaan
Moorreesburg
Tulbagh
Yzerfontein
Darling
Wolseley
Ceres
Malmesbury
De Doorns
Mamre
Atlantis
Wellington
Goudini
Worcester
Rawsonville
Brandvlei
Melkbosstrand
Paarl
Robertson
Cape Town
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
Caledon
Kleinmond
Pringle Bay
Scale 1:900 000 (A3 Paper)
0 10 20 30 KM
UTM Zone 34S(E 18 to E 24)
Transverse Mercator
WGS 84; Central Meridian 21E
LEGEND
Towns
Rivers
Dams
Study Area
TEMPERATURE (degrees)
25 - 30
30 - 58
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS
CONSULTANT
UMVOTO
TITLE
WATER POINTS WITH THERMAL DATA
FIGURE 3.6

3.6 SPRINGS, PERENNIAL STREAMS AND GEOSTRUCTURAL INTERRELATIONSHIPS

Groundwater and surface water interact at many places throughout the landscape. These interactions can be highly dynamic as they respond to the variations and changes in the hydraulic gradients which drive the flows between them.

Groundwater discharge from the TMG is mostly locally restricted and directly linked to lineaments such as fractures and faults. However, it is important to distinguish between the two main TMG aquifers, namely the Skurweberg and the Peninsula. The Skurweberg aquifer contributes directly to river baseflow both via the river bottom and via springs at the Nardouw – Cedarberg contact. The Peninsula Aquifer also contributes to baseflow over significant sections where it is crossed by major river channels, such as the Molenaars, Sanddrifskloof, Amandel and Hex, in Michells Pass, and in Bain's Kloof (Witte River). Springs at the Peninsula-Cedarberg contact, fed from the underlying Peninsula Aquifer are important contributors to baseflow in certain areas. Springs related to the Nardouw contacts are often low volume springs and seasonal (depending on the short term rainfall patterns), while Peninsula springs mostly flow all year around and respond to longer-term climatic patterns, possibly influenced by years with exceptional winter snowfall and spring snow-melt in the recharge areas.

The following diagrams illustrate some of the main types of situations – type-settings – in the TMG aquifer showing the groundwater flow paths and the kinds of springs that are associated with these systems. Note that these diagrams are two-dimensional cross-sections. In some cases additional flow at an angle to the cross-section can occur in both the Peninsula in the overlying confined Skurweberg/ Nardouw aquifers.

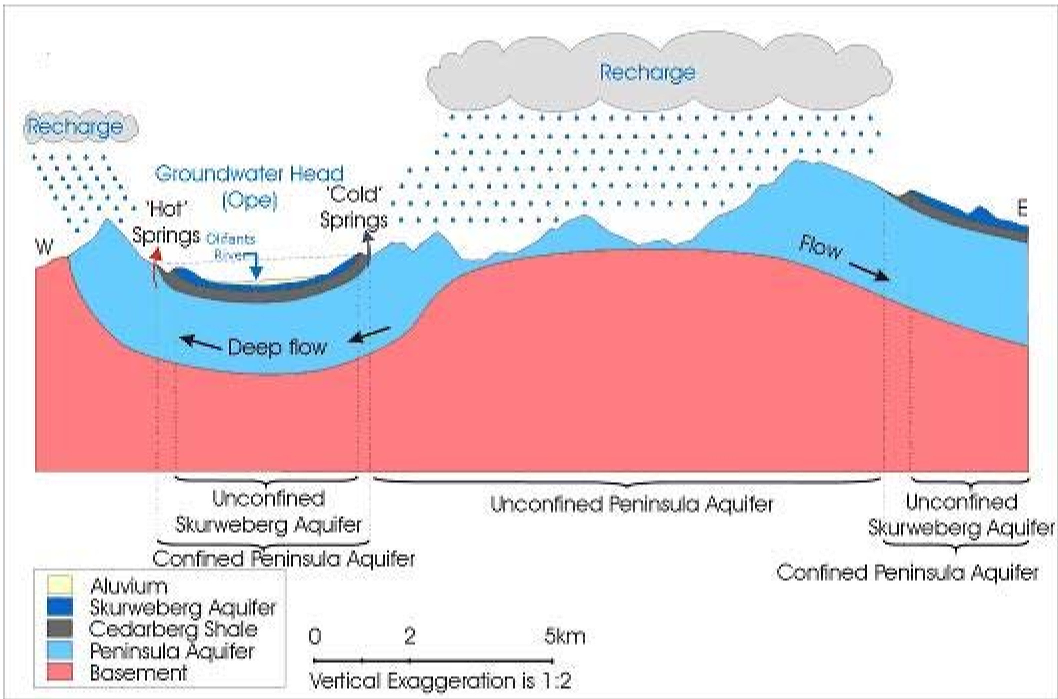


Figure 3-7 Cross-section of TMG-flow –fold & lithology controlled ('CAGE'-Type)

Recharge to exposed Peninsula either side of a folded syncline. Cold spring discharge from short flow paths. Hot springs discharge from long, deep flow paths. Flow follows the folded formation and is focussed by faulting (parallel to cross-section)

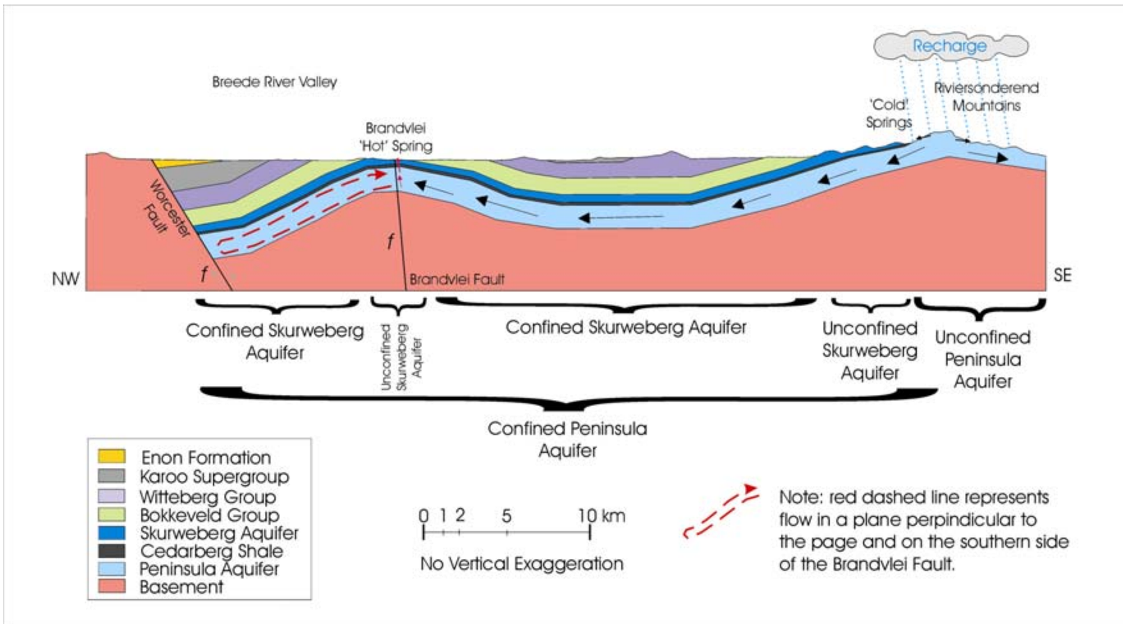


Figure 3-8 Cross-section of TMG-flow – 'Brandvlei'-Type, fault led

Fault itself is 'sealed' (impermeable) but fault zone has high permeability. Recharge in high elevation area of the Peninsula and flow controlled by lithology. Long, deep flow paths as shown by hot springs controlled fault zone creating hydraulic contact between Peninsula and Nardouw.

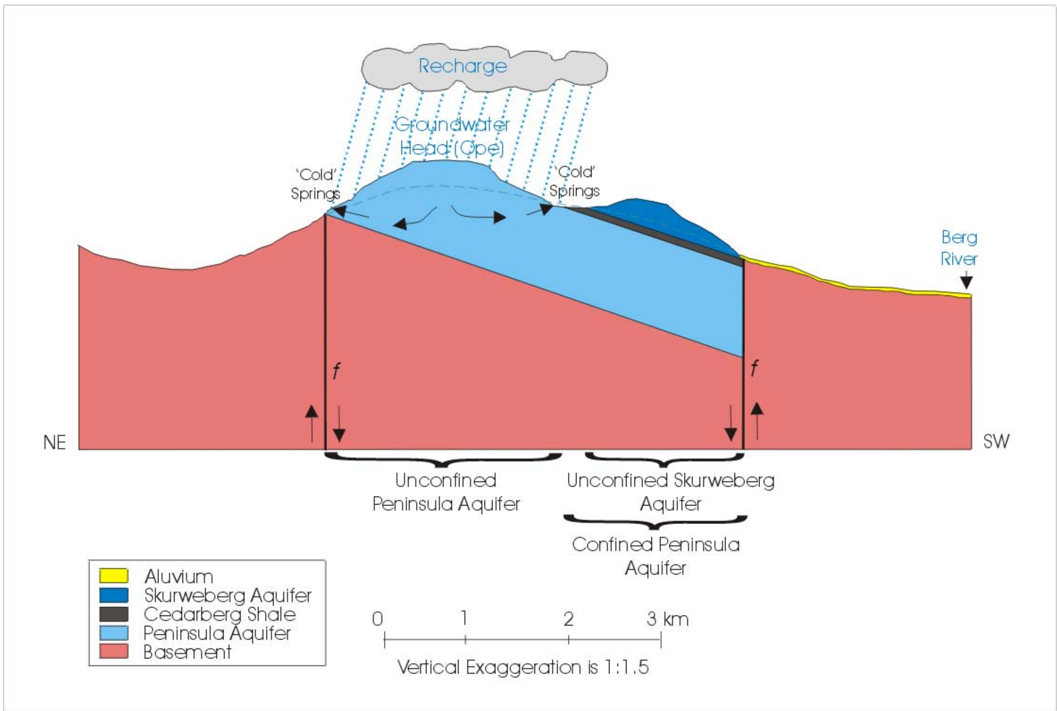


Figure 3-9 Cross-section of TMG-flow – 'Wemmershoek' – Type, fault bounded

Faulting throws up impermeable basement. Short local flow paths. Discharge to springs against impermeable basement and aquitard.

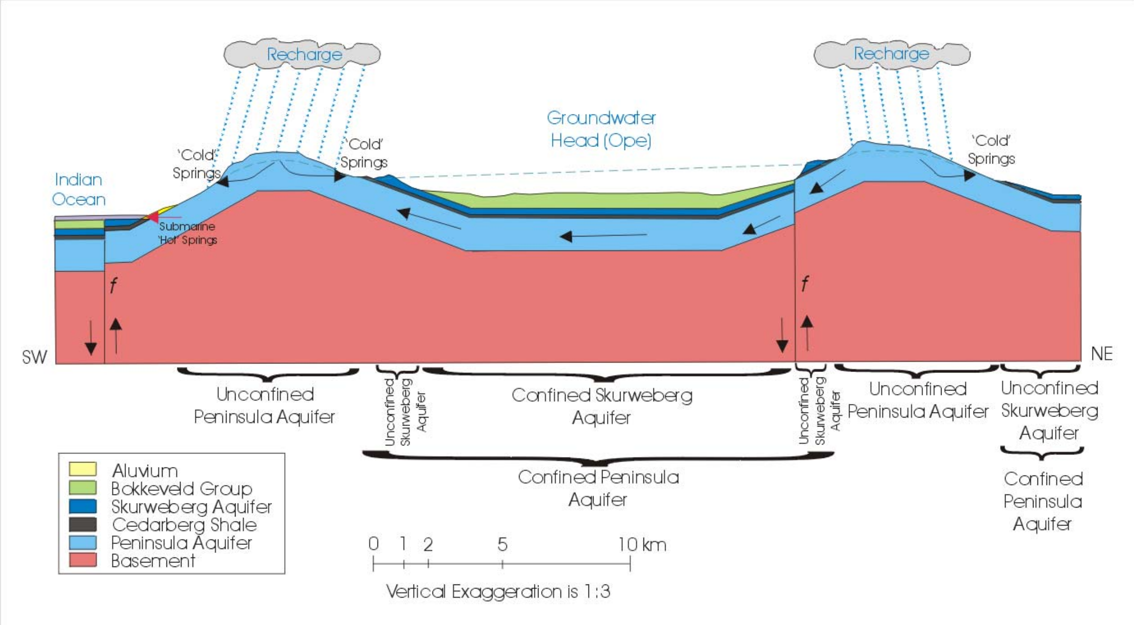


Figure 3-10 Cross-section of TMG-flow – Synclinal aquifer & fault led

Complex interaction of faults and folds. Short and long pathways to hot and cold springs, including coastal and sub-marine springs.

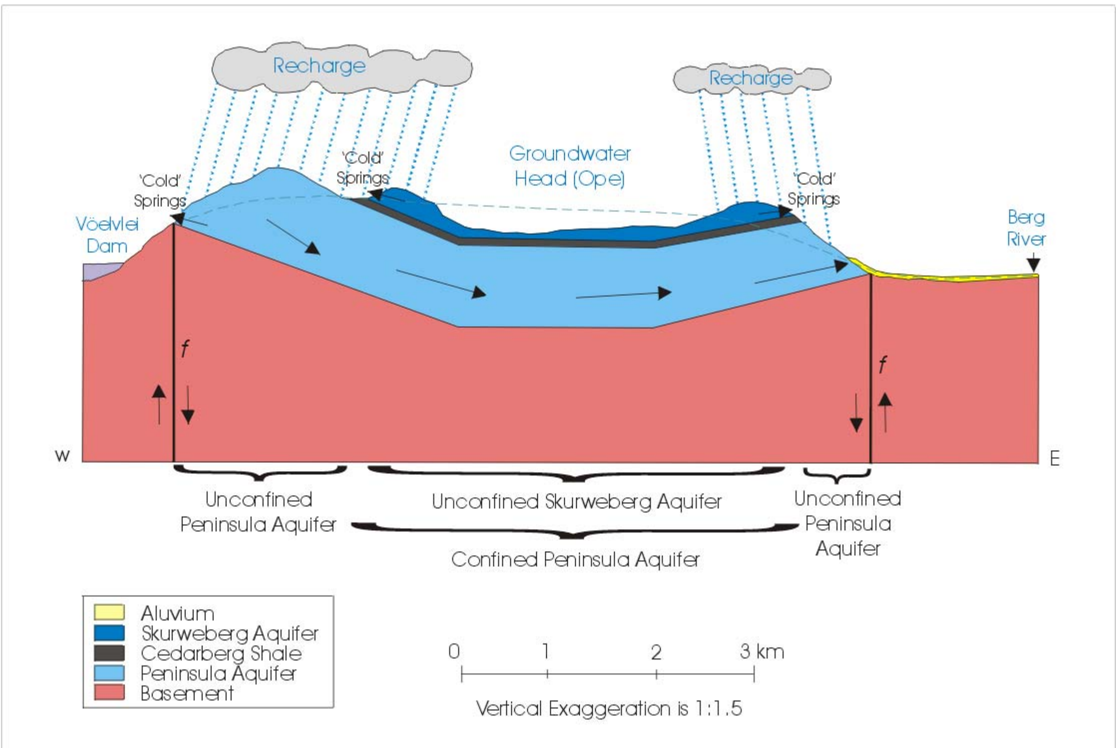


Figure 3-11 Cross-section of TMG-flow – 'Voëlvlei' type, synclinal aquifer & alluvium

Precipitation and topographic gradients drive longer flow paths in the Peninsula Aquifer. Discharge to springs and alluvium. Flow paths in Nardouw Aquifer are perpendicular to the cross-section.

3.7 WATER QUALITY

3.7.1 Hydrogeochemistry

An analysis of groundwater from different aquifers was also undertaken as part of the hydrocensus interpretation report (City of Cape Town, 2004b). Durov diagrams[4] were used to compare waters from both surface water and groundwater (**Figure 3-12**). Surface water (yellow symbols in **Figure 3-12**) has an EC that ranges between 1.8 and 6 mS/m and a pH that ranges from 4.4 to 5.8. In contrast, groundwater has a larger EC range from 3 to 34 mS/m and a pH of 4.5 to 8. Surface water has a Na-Cl character and groundwater Na-Cl to Na-Alk character.

During the monitoring of selected sites in the CCT hydrocensus study (CCT, 2005b) six-monthly field analyses of electrical conductivity (EC) and pH were undertaken since April 2003. Most measured EC results stayed relatively constant over the monitoring period, although a small variation between winter and summer readings was observed. No clear trend in pH change is apparent.

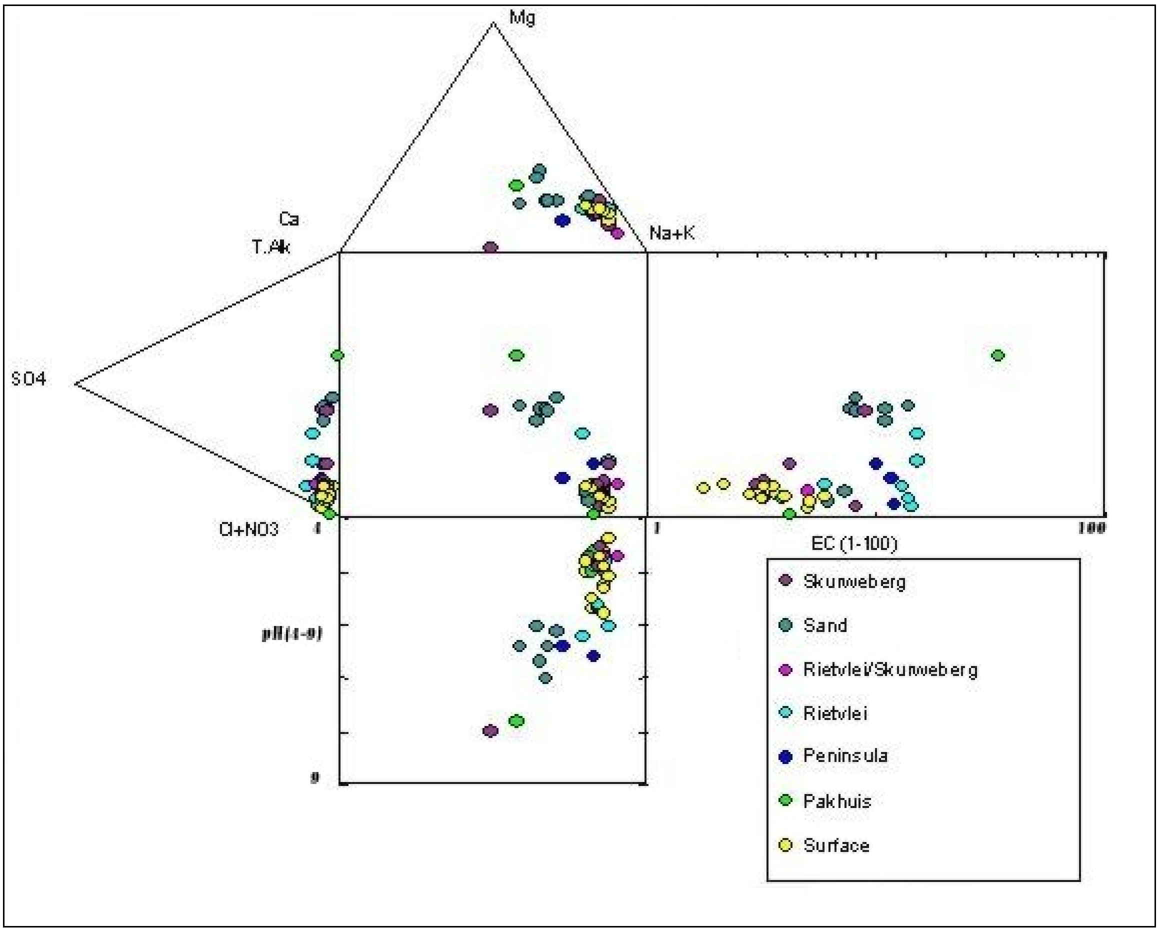


Figure 3-12 Water Quality (from CCT, 2005)

[4] The Durov diagram plots the major ions as percentages of milliequivalents in two base triangles. The total cations and the total anions are set equal to 100% and the data points in the two triangles are projected onto a square grid which lies perpendicular to the third axis in each triangle (Geoafrica website). Also added is EC and pH measurements.

In addition to the differences in the chemo-physical parameters, the analysis of macro and trace elements reveals aquifer specific water characteristics that can be used to define mixing between aquifers as well as discreet aquifer discharge sites.

During the CAGE study samples from throughout the study area and from different aquifers were analysed for trace elements. The results of these analyses are summarised below:

- The Peninsula Aquifer contains traces of Al[5], Fe and Mn, with variable trace evidence of Cu, As and other chalcophile elements. These are presumably derived from oxide (Fe,Mn) and sulphide (Al, Fe, Cu, As) mineralisation of the TMG
- The Nardouw Formation Aquifers are similar to the Peninsula Aquifer in that they contain Al, Fe and Mn, but show a marked elevated Mn, Sr and particular Ba content.
- The groundwater samples from the Malmesbury Group contain traces of Al, Fe and Mn, as well as boron, which is indicative that the rocks were laid down in a deep marine environment.
- The Bokkeveld aquifers are enriched in B, Sr and Ba. The Bokkeveld aquifers are relatively enriched in Sr, whereas the Nardouw are relatively enriched in Ba.

Peninsula Aquifer

Table 3-5 provides a breakdown of the general water chemistry characteristics expected for water abstracted from the Peninsula formation of the TMG aquifer. The water tends to be oligotrophic (low in nutrients), acidic and low in salinity, which is characteristic of water flowing through or over TMG formations.

Table 3-5 Typical water chemistry characteristics expected for water abstracted from the confined TMG aquifer.

All concentrations in mg/l unless otherwise indicated (Smith et al. 2002). *(Table Source: CCT, 2004: Wellfield Operation Report.)*

	EC (mS/m)	pH	Na	Mg	Ca	Cl	SO_4	Alkalinity as $CaCO_3$	Si	K	Fe	δD (‰)	$\delta^{18}O$ (‰)
Boreholes from Nardouw Subgroup													
Mean	30.0	6.0	30.8	5.8	10.2	56.2	27.6	42.8	6.4	5.1	3.3	-45.2	-7.3
Minimum	9.2	3.1	7.2	1.5	1.3	6.1	3.2	1.0	2.1	0.4	<0.1	-53.2	-7.9
Maximum	155.0	8.3	232.8	43.1	73.4	395.2	220.5	147.3	18.1	16.2	15.4	-27.7	-6.3
Boreholes from Peninsula Formation													
Mean	10.4	6.2	11.1	1.8	3.3	18.0	5.2	14.5	3.8	0.8	0.2	-42.8	-7.3
Minimum	2.6	4.3	2.0	0.9	0.4	4.5	1.0	3.5	1.4	0.2	0.1	-51.1	-7.7
Maximum	26.3	7.6	21.2	3.2	30.4	34.1	14.0	77.9	9.4	2.3	0.2	-35.5	-7.06

Unlike the water in the Nardouw Aquifer in the Western Cape, which tends to be high in iron and salts, the water from the Peninsula Formation can be expected to be relatively pure. In contrast results from a study in the Hermanus area show high iron content and higher EC values for water samples from the Peninsula Aquifer, probably due to the position of the water strikes close to the Cedarberg / Pakhuis contact (Umvoto, 2002).

[5] Al – Aluminium, Fe – Iron, Mn – Manganese, Cu – Copper, As – Arsenic, Sr – Strontium, B – Boron, Ba – Barium

During the TMGA study groundwater from the Peninsula aquifer had an electrical conductivity (EC) range between 3 mS/m and 53 mS/m. Approximately 70% of groundwater samples have an EC of less than 20 mS/m and 30% have an EC between 20 mS/m and 75 mS/m. The measured pH values for groundwater sampled from the Peninsula range between 4.7 and 10.3. 26% of groundwater sampled from the Peninsula has a pH that ranges between 7 and 7.5. Groundwater from the Peninsula has a mixed Ca Na – Cl Alkaline type water.

Table 3-6 is a summary of groundwater analysis from the Peninsula aquifer from Hermanus and CAGE areas.

Table 3-6 Water chemistry characteristics for water abstracted from the TMG aquifer at two different places.

All concentrations in mg/l unless otherwise indicated (Umvoto, 2000; 2002).

	Hermanus			CAGE		
Variable	**Average**	**Min**	**Max**	**Average**	**Min**	**Max** [1]
pH	5.24	4.00	6.5			
EC mS/m	42.14	33.00	58			
TDS mg/l	261.56	211.00	371			
Ca mg/l	18.53	2.90	32.60	20.69	1.1	229.2
Mg mg/l	8.57	7.00	11	30.31	1.5	304.5
Na mg/l	47.09	36.5	78	168.27	10.3	1251.1
Cl mg/l	101.17	80.00	146	360.75	18.8	2972.5
SO_4 mg/l	11.96	8.50	18	28.35	1.7	192.4
Fe mg/l	5.74	n.d.	12.90			
Mn mg/l	1.40	0.06	2.50			

n.d. – not detectable
1 – Maximum values influenced by connection to other aquifers, such as Bokkeveld

Water samples taken during the CAGE study (see **Figure 3-13**) indicates two main pH ranges. One is acidic mode of pH between 4.8-5.4 and a more neutral range between 6.6-7.2. Most of the groundwater has an EC of <80mS/m. Peninsula groundwater has a Na/Cl character with some waters having a bicarbonate character. The CAGE study devided the data sets into three regional areas with the West region being of importance to the Berg WAAS. This area covers the Piketberg Mountains and coastal hills inland from Verlore Vlei and Elands Bay and southern Witzenberg. The Peninsula West shows an wide pH range skewed around the neutral range with a low salinity (<80 mS/m). Groundwater has a Na/Cl type character with Cl/SO_4 and Na/Cl ratios of ~10 and ~8 respectively.

Nardouw Aquifer

Electrical conductivity (EC) range between 2 mS/m and 120 mS/m. Approximately 75 % of groundwater samples have an EC of less than 20 mS/m. The measured pH values for groundwater sampled from the Skurweberg range between 4.8 and 6.11. Groundwater from the Skurweberg has a similar character as that of Peninsula aquifer.

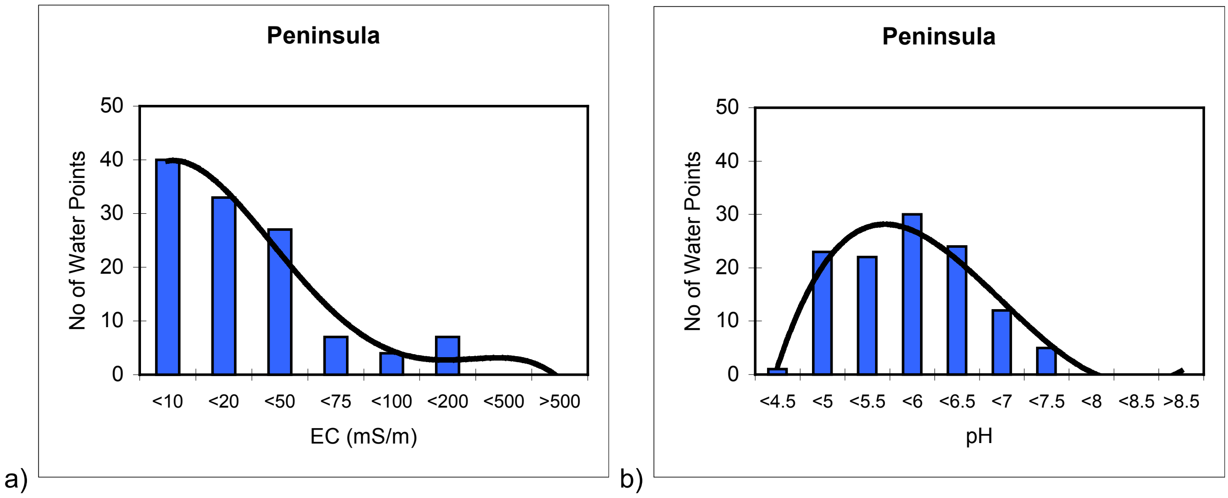


Figure 3-13 Hydrochemical analysis graphs of Peninsula aquifer in CAGE study area, solid line shows polynomial trendline;

a) EC-distribution, b) pH-distribution (DWAF, 2000)

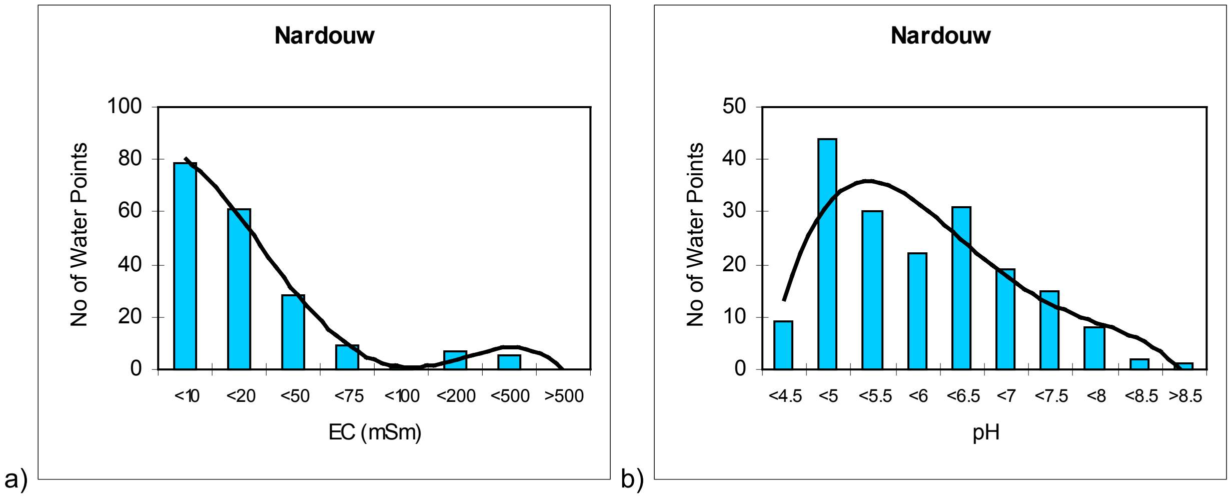


Figure 3-14 Hydrochemical analysis graphs of Nardouw aquifer in CAGE study area (northern Cederberg area), solid line shows polynomial trendline;

a) EC-distribution, b) pH-distribution (DWAF, 2000)

Coastal Aquifers

Groundwater from the coastal aquifers has an alkaline character with most pH falling in the range of 7.2 to 7.8. EC shows a wider range with some waters having an EC of more than 800 mS/m. Most groundwater has an EC between 80-160 mS/m.

Groundwater from the coastal region has a stong NaCl character. Typical Cl/SO_4 and Na/Cl ratios are ~6-10 and ~10-20, respectively. Similar to the Peninsula Northwest case, there is a slight suggestion of an inverse correlation of higher Na/Ca with lower Cl/SO_4. Whether these similarities can be interpreted as a reflection of a significant TMG groundwater contribution to Coastal aquifers remains an open question.

SRK (2003) found that the different aquifers along the West Coast differ in water quality. The upper units of the Langebaan Road Aquifer have a high EC, mainly due to high watertables and evaporation which leads to salt accumilation in the aquifer, while the confined lower unit of the LRA has an lower EC ranging between 40 to 110mS/m. The Adamsboerskraal Aquifer, north of the Berg River has an EC range between 150 to 1300 mS/m (SRK 2004). Most of the EC is more than 200mS/m (**Figure 3-15**). Groundwater from the Adamboerskraal aquifer has a range between 6 to 9, with most of pH values between 7.0 and 7.5.

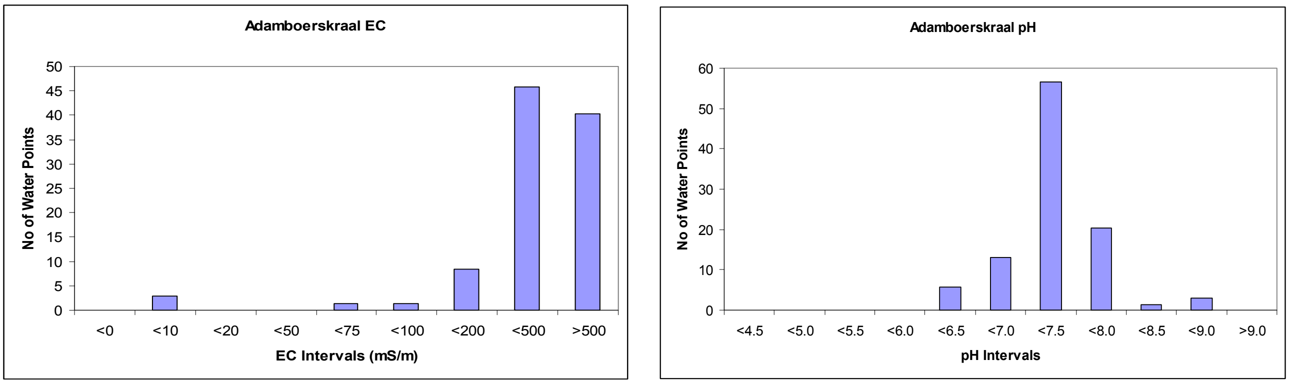


Figure 3-15 Hydrochemical analysis graphs of Adamboerskraal aquifer (after SRK 2004)

3.7.2 Water Quality

According to the Water Quality Guidelines (DWAF, 1996) salt-tolerant crops can be irrigated up to a TDS of 1 755 mg/l (equals 270 mS/m). Salt-sensitive and moderately salt-sensitive crops cannot be irrigated with water containing more than 600 mg/l TDS (equals 90 mS/m). For salt sensitive crops like citrus an EC below 40 mS/m is the target water quality range. **Table 3-7** presents a summary of water quality guidelines for irrigation (DWAF 1996b).

Table 3-7 Summary of water quality guidelines for irrigation.

Constituent	Target Range	Comment
EC (mS/m)	<40	A yield decrease with increase of salinity
pH	6.5-8.4	Increasing problems with foliar damage and could give rise to yield reduction
Na (mg/l)	<70	Crops sensitive to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decrease.
Cl (mg/l)	<100	Should prevent the accumulation of chloride to toxic levels in all but the most sensitive plants, even when chloride uptake is through foliar absorption.
NO_3 (mg/l)	<5	Salt sensitive crops increasingly likely to be affected.

Table 3-8 is a summary of some water quality guidelines for domestic use. The average concentrations of constituents (from **Table 3-6**) were used for classifying the water according to the Class of water. From the table it is evident that most Peninsula and Nardouw waters are Class 0 with the exception of Iron. Treatment would be necessary to drop the iron concentrations.

Table 3-8 Summary of water quality guidelines for Domestic use.

Constituent mg/L	**SA Drinking Water Guideline** Class 0	**Class 1**	**Class 2**	**Class 3**	**Class 4**
TDS	< 450	450 - 1000	1000 - 2400	2400 - 3400	> 3400
EC (mS/m)	< 70	70 -150	150 - 370	370 - 520	> 520
Chloride	< 100	100 -200	200 - 600	600 - 1200	> 1200
pH	5 - 9.5	4.5 - 5 or 9.5 - 10	4 - 4.5 or 10 - 10.5	3 - 4 or 10.5 - 11	< 3 or > 11
Iron	< .01	0.5 - 1	1 - 5	5 - 10	> 10

The geochemistry for each modal domain will be handeled in more detail in each report.

3.7.3 Stable Isotope Composition

The oxygen and hydrogen isotope composition of rainwater varies in a semi-predictable way, depending on source region, climate (temperature, amount of precipitation) and geographic location (altitude, continentality), and thereby provides the basis for “O- and H-isotope hydrology” (e.g., Clark and Fritz, 1997; Harris and Talma; 2002). Samples for analysis of stable isotopes of oxygen ($\delta^{18}O$) and hydrogen (δD) were collected at eight selected localities and submitted to the University of Cape Town.

The results (**Table 3-9** and **Figure 3-16**) cluster around mean values of –4.29 ($\delta^{18}O$) and –20.30 (δD). The total suite of samples (from both spring 2004 and autumn 2005 collections) lie along by the trend line $\delta D = 5.69*\delta^{18}O – 4.20$ (dash-double dot line; **Figure 3-16**). The distinctly lower gradient than the typical meteoric water lines is mainly governed by the samples from the spring 2004 hydrocensus. Compared to the previous season’s results (diamond symbols, **Figure 3-16**), the data from the autumn 2005 hydrocensus (square symbols; **Figure 3-16**) define a better linear trend through mean values of –4.55 ($\delta^{18}O$) and –21.7 (δD).

The spring 2004 results lie along a linear array described by the trend line $\delta D = 3.87*\delta^{18}O – 3.47$, which has distinctly lower gradient than the typical meteoric water lines. It has been recognized for some time that the “Global Meteoric Water Line” (GMWL; **Figure 3-16**), does not fit rainwater results from the Western and Southern Cape, for which a “Cape Meteoric Water Line” (CMWL; **Figure 3-16**) has been defined (Diamond and Harris, 1997). A “Cape Hot Springs Line” (CHSL; **Figure 3-16**) is also recognised from isotope analysis of groundwater samples from widely distributed thermal springs in this region (Diamond, 1997).

The autumn 2005 results define a linear trend that is best fitted by the line $\delta D = 6.44*\delta^{18}O – 8.00$. The gradient of this line is intermediate between that (8.0) of the “Global Meteoric Water Line” (GMWL; **Figure 3-16**) and that (6.2) of the “Cape Meteoric Water Line” (CMWL; **Figure 3-16**). The present data trend lies close to the “Cape Hot Springs Line” (CHSL; **Figure 3-16**), between the GMWL and the CMWL. Sample ZK6 ($\delta^{18}O = -4.06$, $\delta D = -16$) shows the least divergence from the CMWL, while nearby sample ZK3 ($\delta^{18}O = -4.06$, $\delta D = -16$) is furthest from the CMWL but close to the GMWL (**Table 3-9** and **Figure 3-16**).

Table 3-9 Results of oxygen and hydrogen (deuterium) isotope analyses (after CCT, 2005)

	Date	Lat. °N	Long. °E	Elev. (m)	$\delta^{18}O$ (per mil)	δD (per mil)
Spring 2004 Hydrocensus						
D5B1	09/02/2005	34.03439	19.04130	848	-4.33	-20.61
HH1 B1	09/02/2005	34.03210	19.02281	813	-3.96	-19.05
PR B1	09/02/2005	34.04068	19.03010	782	-4.07	-20.47
XB1	09/02/2005	34.02300	19.02150	1245	-4.79	-21.84
W7eB	27/01/2005	33.80289	19.08889	342	-4.54	-21.28
W7f	27/01/2005	33.82227	19.05833	273	-4.00	-17.92
ZK3B(1)	27/01/2005	33.82824	19.03682	295	-4.38	-20.14
ZK6(3)B	27/01/2005	33.82229	19.05832	273	-4.15	-18.89
Autumn 2005 Hydrocensus						
D5	17/05/2005	34.06796	19.04747	562	-5.21	-25
HH1	14/05/2005	34.05513	19.03611	648	-5.26	-25
PR	13/05/2005	34.06855	19.05026	557	-5.78	-29
X	13/05/2005	34.03589	19.03984	758	-5.94	-31
SWM6	19/05/2005	33.80289	19.08889	335	-4.54	-21
Wms13	19/05/2005	33.82227	19.05833	256	-4.43	-21
ZK3	13/06/2005	33.82826	19.03692	295	-4.24	-22
ZK6	13/06/2005	33.82226	19.05831	273	-4.06	-16

Analysis by C. Harris, Department of Geological Sciences, University of Cape Town.
Data in delta values [$\delta = (R_{sample}/R_{SMOW} - 1)*1000$] relative to Standard Mean Ocean Water (SMOW), where $R = {}^{18}O/{}^{16}O$ or D/H (${}^{2}H/{}^{1}H$).
Estimated errors better than 1 per mil for δD, and better than 0.15 per million for $\delta^{18}O$.
Errors based on repeated analysis of standards.

The relatively small number of stable-isotope data for the Berg WMA study area precludes any more detailed discussion, which must await the accumulation of more data through extension of sampling to other localities, and repeated re-sampling at the existing and future sites so that a time-series of observations is acquired. Comparison of these results with further analysis of fresh local rainfall, stream-flow, and groundwater from different parts of the TMG aquifer system, can – in conjunction with other hydrochemical data – be expected to provide important constraints on the processes and rates of recharge to the system (Diamond and Harris, 2000; Harris and Diamond, 2002).

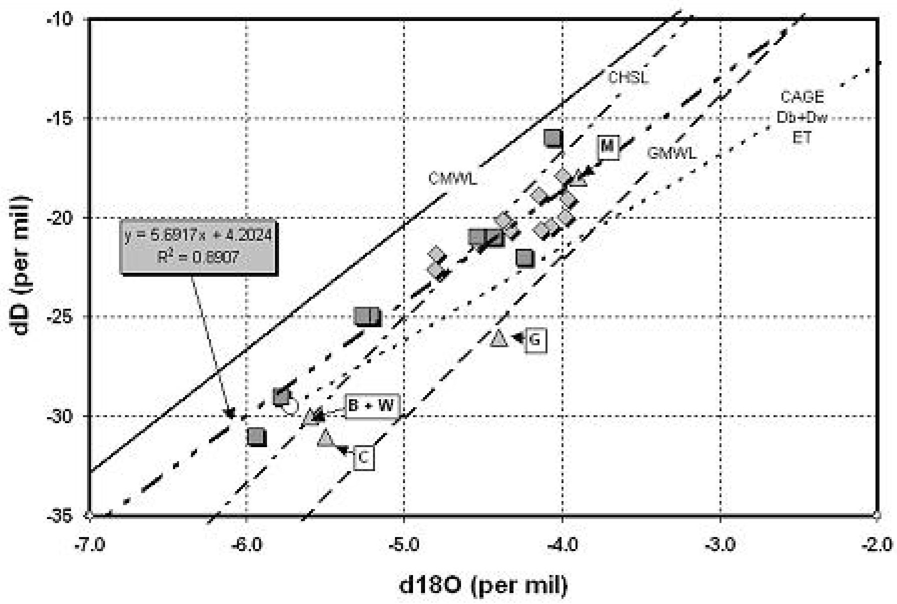


Figure 3-16 Stable isotope results for eight samples (Jan 2005: diamond symbols; June 2005: square symbols. (after CCT, 2005)

The Cape Meteoric Water Line (CMWL: $\delta D = 6.2*\delta 18O +10.6$; Diamond & Harris, 1997), the Cape Hot Springs Line (CHSL: $\delta D = 8.32*\delta 18O +16.5$; Diamond, 1997) and the Global Meteoric Water Line (GMWL: $8.0*\delta 18O +10$; Craig, 1961) are shown for reference. Also shown is an Evaporation Trend line for Citrusdal Artesian Groundwater Exploration (CAGE) results from Bokkeveld Group (Db)- and Witteberg Group (Dw)-related samples (short-dashed line anchored by circle at lowest value in $\delta 18O$ range; E.R. Hay, unpublished PhD thesis data). Mean values from thermal springs (triangle symbols) in the study region are provided for Brandvlei (B,) Witzenberg (W), Caledon (C), Goudini (G) and Malmesbury (M), from Diamond and Harris (2000).

4. CONCEPTUAL FLOW MODEL

The ultimate purpose of the present modelling study is to provide a sound quantitative basis for resource assessment into the future. Ensuring that any identified recharge zone can physically be connected to an identified discharge zone is most important in any calculations of an aquifer specific mass balance and or catchment mass balance. There is simply an inherent flaw in any numbers produced if this is not done on a physical scale that is appropriate to the process that will impact both surface water and groundwater mass balances. The first step in realizing physically real mass-balance numbers is to define the recharge areas based on physically measurable aquifer outcrop areas underlying rainfall isohyets. The second step is to iteratively correlate the known discharge sites (considering volume, water quality, isotopic character and temperature) with likely flow paths defined by 3D structural geology and hydrostratigraphic relationships. Cross checks as regards temperature, chemistry and isotopic character of discharge water allows qualitative evaluation of the conceptual flow model.

The third critical step, preparation of a steady-state regional water balance involves calculation of recharge and discharge volumes reliably linked by physically real and identified flow paths using hydroclimatic and hydrographic data.

Regional flow systems applicable to the main aquifer units must be defined separately since they are in folded and faulted terrain. It is quite likely that the scales of the flow paths in the Peninsula and in the Skurweberg aquifers are different simply because the Skurweberg Aquifer is often contained within a single synclinal valley while the Peninsula Aquifer extends across more than one valley resulting in inter-catchment and even interbasin transfers.

Thus even though it is the lowest and – in the eastern part of the Berg WMA – locally the deepest of the units, the Peninsula Aquifer takes precedence in the broad definition of the flow system, because it is the topographically dominant unit, building most of the high mountain ranges and summit ridges. Due to the strong orographic control on rain and snowfall in the mountain ranges of the Western Cape province, the Peninsula therefore has the widest aerial extent in the areas of maximum precipitation and recharge potential, and provides the primary topographic control on both surface and groundwater flow systems at their common source. Since it is also the thickest aquifer and the most regionally extensive it also discharges the most water, either at the site of perennial and geothermal springs or into the ocean.

The aquifer-specific regional models and individual area models discussed in this report are understood to be tentative and provisional. Aquifer-specific components of these conceptual models are to be more fully addressed during the construction of the individual numerical models, and will be reported comprehensively in Volumes 5-9 in this series (see Section 1.1.4 above). The purpose of the present volume is to stimulate creative debate within and among the Berg WAAS research team, the external review team and the DWAF client personnel about model assumptions and boundary conditions, aquifer definitions, hydraulic parameters, possible flow paths, and groundwater-surface water interactions. Hence, the various components of the models remain open to fundamental re-evaluation after the collation and analysis of further data, and consideration of alternative interpretations. The integration of complex concepts of shallow and deep groundwater flow into the numerical models is indeed the most challenging element of this project (L. Botha, 2007), for which there is little precedent in South African hydrogeology. The geoscientific method of ”multiple working hypotheses” is therefore most appropriate in this case, where “the effort is to think independently, or at least individually, in the endeavor to discover new truth, or to make new combinations of truth, or at least to develop an individualized aggregation of truth” (Chamberlin, 1890).

4.1 RECHARGE AREAS

In order to map the most relevant recharge areas, it is required to distinguish between the different types of recharge occurring in the study area.

- Direct recharge through infiltration occurs for all aquifer types. The recharge areas to the different aquifers are defined where the aquifer exposure coincides with high potential infiltration zones.
- Lateral recharge happens where groundwater from one aquifer discharges into an adjacent or overlying aquifer.
- Flood recharge occurs mainly in the alluvium aquifers along river reaches during high flooding events.

In the present approach to conceptual modelling it is recognized that within the spatial domain of "representative elementary watersheds" (REWs), there is a need to distinguish between subregions of infiltration (recharge), comprised of zones of the unsaturated zone and zone of concentrated overland flow, and subregions of exfiltration (discharge) comprised of the zone of saturation and stream/river channel reach (Reggiani et al., 1998). The intersection of the water table with the land surface defines the extent of "overland flow zone" adjacent to the channel reaches (the "saturation-excess overland flow domain"; Zhang and Savenije, 2005, Fig. 1, p. 245), and hence limits the surface extent of the recharge/infiltration area (the "infiltration-excess overland flow domain"; op. cit., Fig. 1). The changing area fractions between these domains is accounted for in REW-scale water-balance equations that incorporate Darcy's law, Manning's law, and the Saint-Venant equations for subsurface, overland and channel flow, respectively (Zhang and Savenije, 2005).

REW-scale balance equations for mass, momentum, energy and entropy implicitly incorporate the effects of hillslope inclination on surface-water/ groundwater interactions. This principle is followed in an approximate manner through recognition that the unsaturated zones with low slope angle (flat gradients) will have a higher proportion of recharge from rainfall and steep gradients will generally have a lesser proportion. In other words, instead of displaying the rainfall as recharge from precipitation, we take account of the effect of slope on the separation of runoff from infiltration. This proportionation cannot, however, be taken as direct measure of recharge quantity, since there are other factors (e.g., evapotranspiration and run-off from a real data set) that have not yet been taken into account. The factors are considered in the Water Mass Balance Report.

The different recharge areas relevant to the Peninsula, Skurweberg and Sandveld aquifers respectively are listed in the sections that follow and are considered in order of priority.

4.1.1 Recharge areas for Peninsula Aquifer

The main recharge areas for the Peninsula Aquifer are shown in **Figure 4-1** and listed below in order of relevance, based on outcrop area and proportion of infiltrating rainfall (proportionated as the cosine of the slope angle):

Pr1. Hottentots Holland Mountain range between Franschhoek and Somerset West, including Franschhoek Mountains, Groot Drakenstein Mountains, Jonkershoek Mountains, Stellenbosch Mountains and Hottentots Holland Mountains, receiving a MAP of up to 3400 mm/a

Pr2. Hottentots Holland – Haweqwas Mountain range between Wellington, Rawsonville and Franschhoek, including the Du Toits Mountains, Wemmershoek Mountains, Stettyns

Mountains, Slanghoek Mountains and Limiet Mountains, receiving an MAP of up to 3400 mm/a

Pr3. Hexriver Mountain range north of Worcester, including Hex River Mountains, Langeberge and Waaihoek Mountains, with an average MAP of 2000 mm/a

Pr4. Kogelberg between Grabouw and Pringle Bay, with an average MAP of 1000 mm/a

Pr5. Groot Winterhoek and Witzenberg Mountains north of Tulbagh, with an average MAP of 1000 mm/a

Pr6. Riviersonderend Mountains, with an average MAP of 800 mm/a

Pr7. Cape Peninsula south of Cape Town, with an average MAP of 800 mm/a

Pr8. Piketberg between Piketberg and Aurora, with an average MAP of 600 mm/a.

4.1.2 Recharge areas for Skurweberg Aquifer

The recharge areas for the Skurweberg Aquifer are shown in **Figure 4-1** and listed below. They receive less rainfall than the Peninsula Aquifer outcrop areas and are more scattered, often forming the hillslopes of higher Mountains of sandstones from the Peninsula Formation. The main areas of relevance are:

Sr1. Northern part of the Kogelberg

Sr2. Northern slopes of the Groenland Mountains

Sr3. Skurweberge, north of Ceres

Sr4. Northern slopes of the Hex River Mountains

Sr5. Northern and western parts of the Riviersonderend Mountains

Sr6. Olifants River valley

Sr7. Waterval valley between Elandskloof Mountains and Watervals Mountains

Sr8. On both sides of the Hexriver valley, extending into Kwadous Berg and Waboom Mountains

4.1.3 Recharge areas for the Sandveld aquifers

The recharge pattern for the Sandveld aquifers differs in that direct vertical recharge from rain infiltration accounts only for part of the recharge, due to a significantly lower rainfall and higher evaporation along the coast. Additional recharge occurs through surface run-off from surrounding bedrocks, infiltrating the alluvial deposits, and through periodical flood events of the main rivers intersecting the alluvium aquifers. The main recharge processes and areas are shown in **Figure 4-2** and listed below:

Qr1. Cape Flats Aquifer: localised direct recharge from orographic precipitation on west (lee of Table Mountain) and flood recharge mainly from Kuilsrivier

Qr2. Breede River Alluvium: localised direct recharge, surface run-off infiltration, lateral recharge from TMG Aquifer and flood recharge from Breede River

Qr3. Langebaan Road Aquifer: flood recharge from Berg River and localised direct recharge

Qr4. Geelbek Aquifer: localised direct recharge, surface run-off infiltration and flood recharge from Groen River and Sout River

Qr5. Atlantis Aquifer: localised direct recharge and artificial recharge

Qr6. West Coast Aquifers north of Berg River: localised direct recharge and lateral recharge from TMG

Qr7. Smaller river alluviums: localised direct recharge and surface run-off infiltration; partly lateral or flood recharge.

4.2 DISCHARGE AREAS

Groundwater commonly discharges into surface-water bodies or into the sea. However, depending upon the interconnection between the aquifer and the surface-water body, the discharge can be restricted to specific river reaches or even discrete points, such as springs and seep zones, as discussed in **Section 3.6**. The spatial distribution of discharge points or areas and the type of discharge varies depending upon the aquifer from which the groundwater originates.

4.2.1 Discharge areas for the TMG aquifers

Discharge from the TMG aquifers occurs in several lithologically and structurally controlled situations. It is evident that

- The Peninsula Aquifer discharges mainly into the ocean along the major fault systems or via high lying springs or seep zones that often form the beginning of perennial streams (see red dots in **Figure 4-3**).
- The occurrence of these springs and seep zones is lithologically (at the basal contact fo the aquifer) and or structurally (at aquifer-fault intersections) controlled (see **Section 3.6**).
- The most prominent inland discharge sites from the Peninsula aquifer are the hot springs, viz. Brandvlei and Goudini.
- The Skurweberg Aquifer discharges mainly via springs or seep zones, forming the beginning of or contributing to perennial streams. The direct discharge into river reaches is possible in some areas, where the river crosses the aquifer outcrop, for example in the Mitchels Pass.

A gradational contact exists between areas of recharge and discharge, as a result of temporal changes in the groundwater water levels. Areas that may be recharged in the low rainfall periods are in fact discharged in the high rainfall periods.

Discharge is a function of both topography and hydraulic gradine. While the Hex River Mountains receive high rainfall, steep slopes limit the amount of recharge. The hydraulic gradient and the elevated position of the base of the Peninsula Aquifer in these Hex River Mountains cause the Peninsula Aquifer to discharge instead.

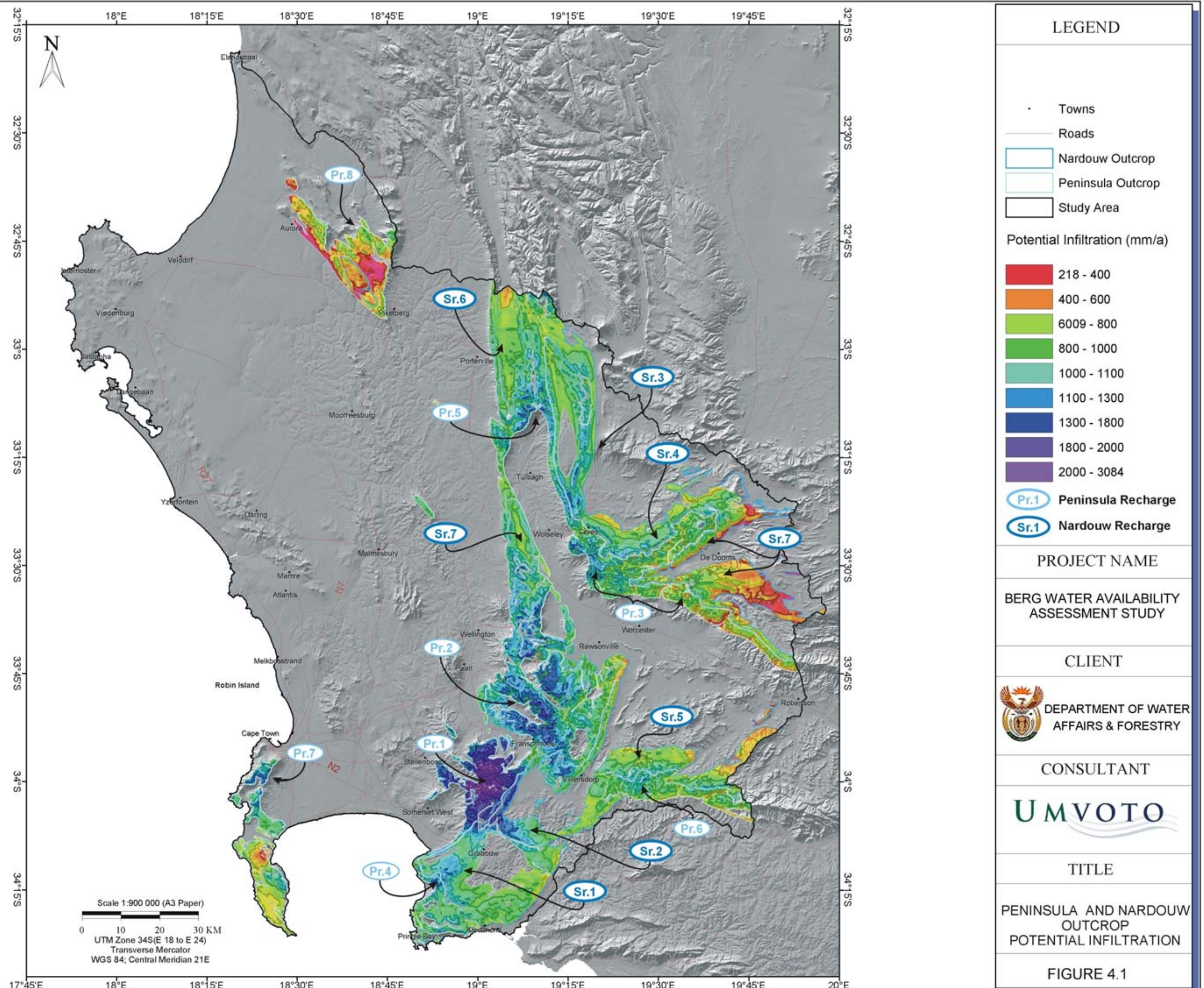
The main areas of discharge in the TMG aquifers are illustrated in **Figure 4-3** (shaded in tones of red).

4.2.2 Discharge areas for the Sandveld aquifers

Primary aquifers are unconfined and discharge in areas where the water level rises above the ground level.

- The Sandveld aquifers along the coast discharge mainly directly into the ocean as diffuse discharge along the coastline or into river reaches (e.g. Berg River, Kuils River).
- The inland Sandveld aquifers interact with the river reaches and mostly discharge into the river along specific reaches or over the whole length (generating influent rivers).
- The Sandveld aquifers discharge into local depressions along the coastal interior forming pans and vleis.

The discharge areas of the Sandveld aquifer are illustrated in **Figure 4-4**. Main discharge locations include the West Coast and the coastline in False Bay and along some of the main river reaches including along the lower Berg River (areas shaded tones of blue in **Figure 4-4**.



PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

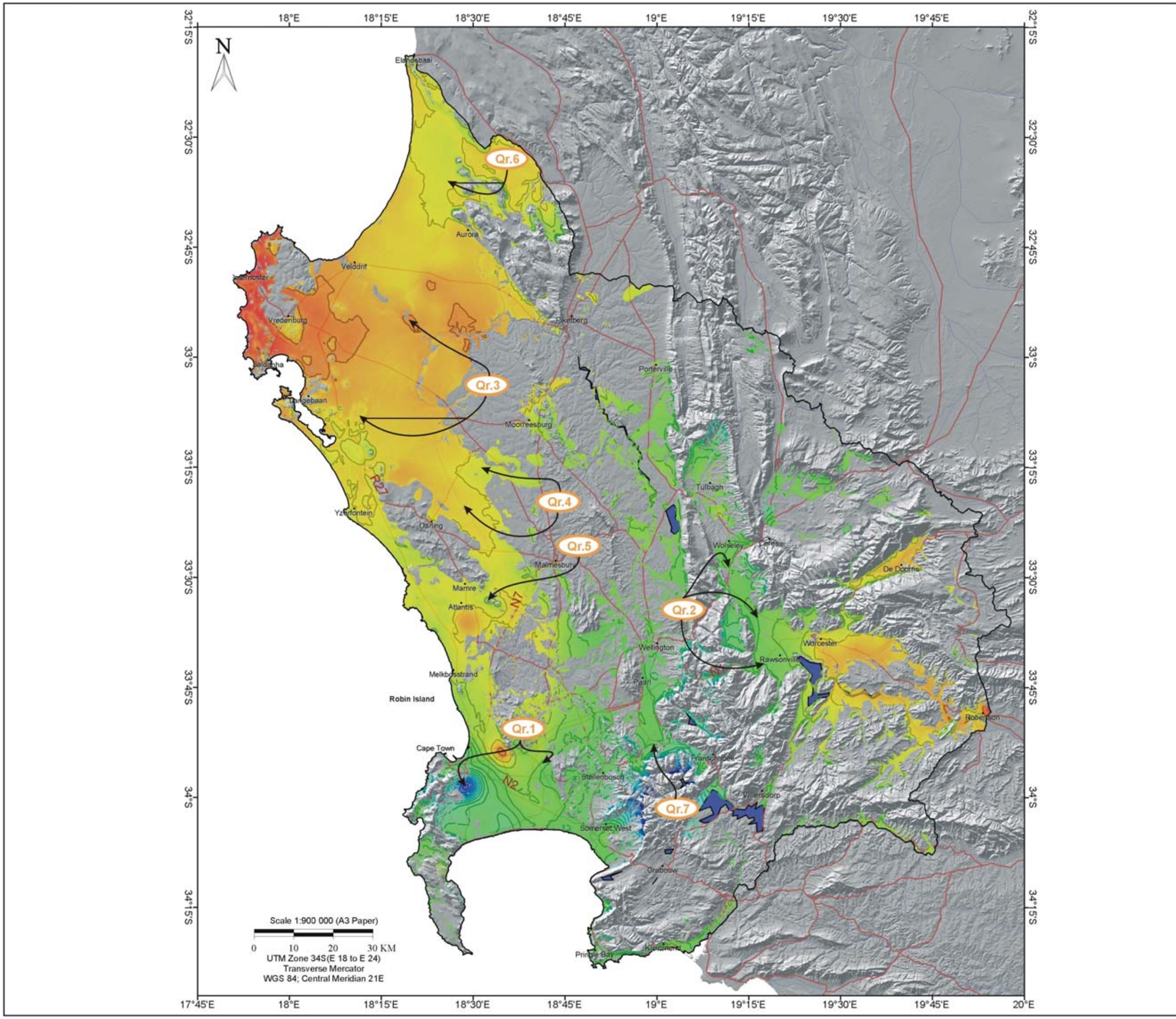
CONSULTANT

UMVOTO

TITLE

PENINSULA AND NARDOUW OUTCROP POTENTIAL INFILTRATION

FIGURE 4.1



PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

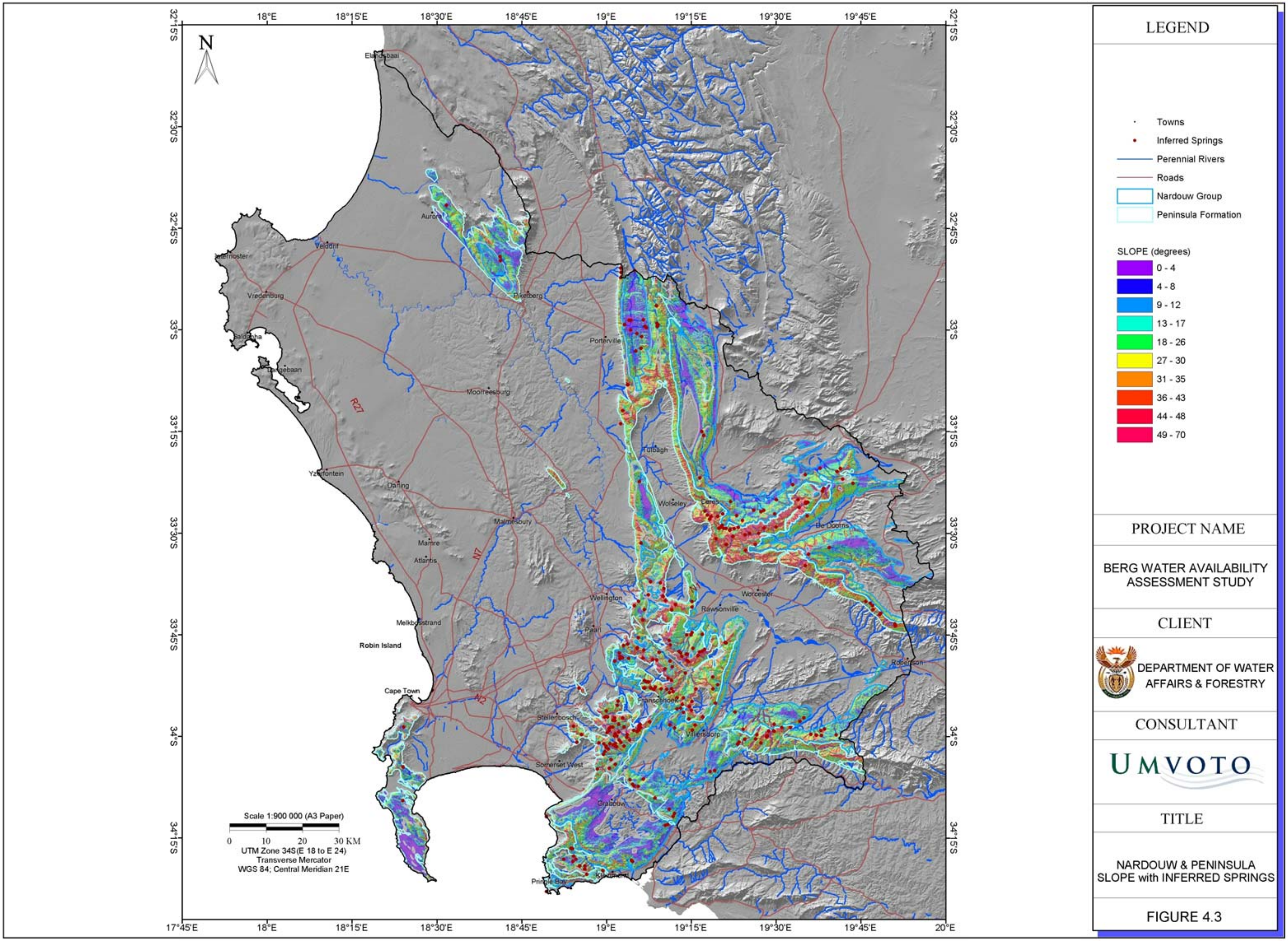
CONSULTANT

UMVOTO

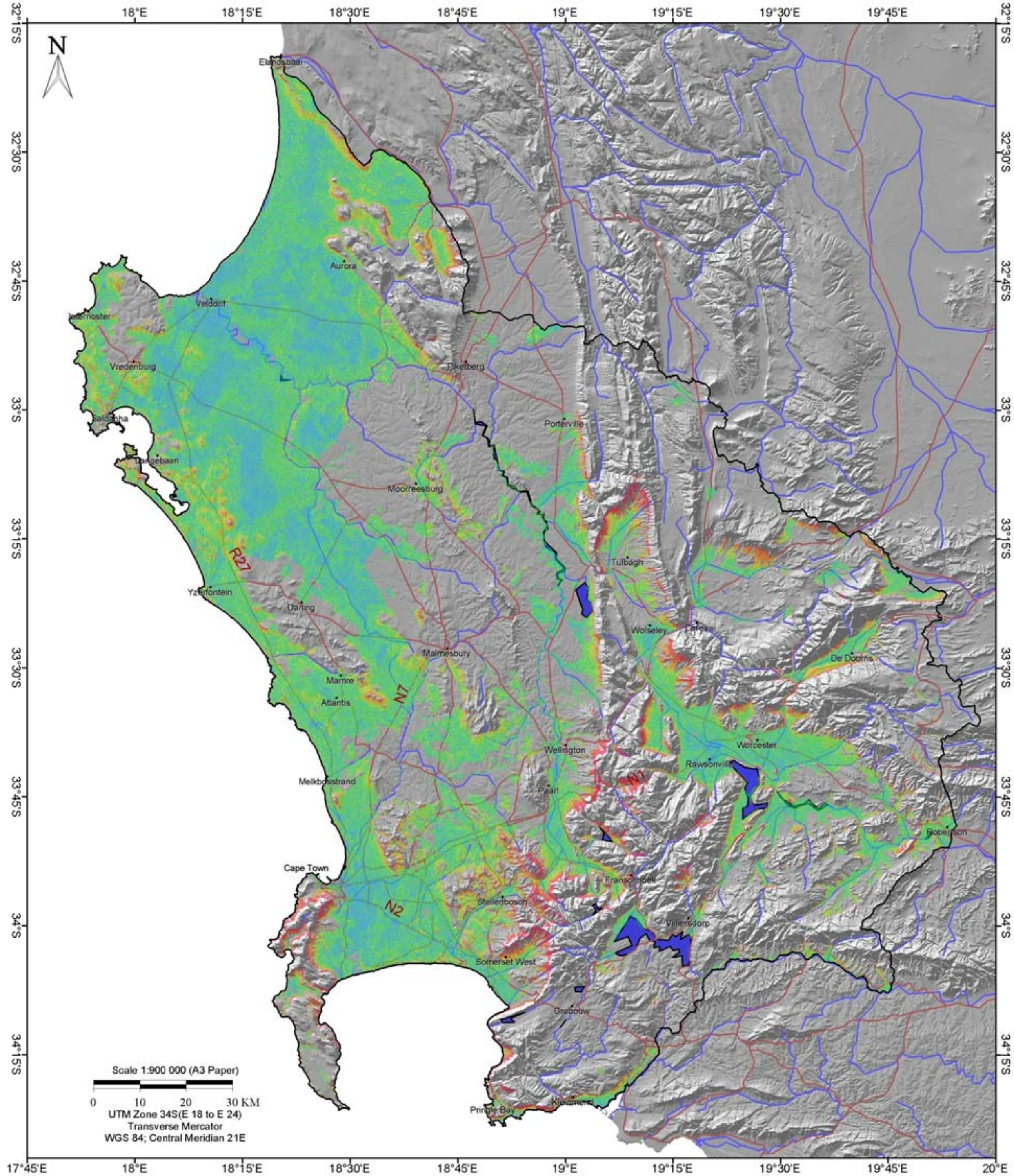
TITLE

SANDVELD OUTCROP POTENTIAL INFILTRATION

FIGURE 4.2



LEGEND
Towns
Inferred Springs
Perennial Rivers
Roads
Nardouw Group
Peninsula Formation
SLOPE (degrees)
0 - 4
4 - 8
9 - 12
13 - 17
18 - 26
27 - 30
31 - 35
36 - 43
44 - 48
49 - 70
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS & FORESTRY
CONSULTANT
UMVOTO
TITLE
NARDOUW & PENINSULA SLOPE with INFERRED SPRINGS
FIGURE 4.3
N
Scale 1:900 000 (A3 Paper)
0 10 20 30 KM
UTM Zone 34S(E 18 to E 24)
Transverse Mercator
WGS 84; Central Meridian 21E
17°45'E
18°E
18°15'E
18°30'E
18°45'E
19°E
19°15'E
19°30'E
19°45'E
20°E
32°15'S
32°30'S
32°45'S
33°S
33°15'S
33°30'S
33°45'S
34°S
34°15'S
Elandsbaai
Aurora
Velddrif
Vredenburg
Saldanha
Langebaan
Piketberg
Porterville
Moorreesburg
Yzerfontein
Darling
Malmesbury
Mamre
Atlantis
Tulbagh
Wolseley
De Doorns
Worcester
Rawsonville
Wellington
Paarl
Melkbosstrand
Robin Island
Cape Town
Robertson
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
Kleinmond
Pringle Bay
R27
N7
N2



LEGEND

- Towns
- Roads
- Major Rivers
- Major Dams
- Study Area

SLOPE (degrees)

- 0
- 4 - 7
- 8 - 12
- 13 - 24
- 25 - 66

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

MAIN DISCHARGE AREAS FOR THE SANDVELD

FIGURE 4.4

4.3 REGIONAL FLOW SYSTEMS

4.3.1 Potentiometric surfaces and hydraulic gradients

Directions of flow within an aquifer are governed in the first instance by hydraulic gradients. In unconfined intergranular aquifers the gradients are obtained by the systematic mapping of piezometric data on the rest levels of water tables from boreholes and/or the levels of surface-water bodies in close hydraulic connection to the aquifer. In confined or semi-confined aquifers, a potentiometric surface is constructed from hydraulic head information from artesian boreholes, where these exist or are accessible, combined with head information from the exposed recharge and discharge zones of a continuous aquifer compartment.

In the case of the construction of gradient maps for the Sandveld aquifers, there is is large amount of piezometric information from borehole water levels. However, in the case of the Peninsula and Skurweberg aquifer systems, the borehole water-level information is very sparse, in some areas of the Peninsula Formation almost non-existent and generally restricted to the exposed, unconfined areas and the nearby marginal zones of the confined sections. Under these circumstances, models of the potentiometric surfaces have been constructed by making use of the elevations along the reaches of perennial streams over unconfined areas, and the elevations where streams cross key aquifer-aquitard contacts between unconfined and confined sections of the aquifers.

In addition to these marginal constraints around the extensive confined aquifers, the role of fracture anisotropy on hydraulic conductivity and aquifer-compartmentalization by major faults systems, has also to be considered in the construction of a model potentiometric surface.

4.3.2 Hydrotects

On further inspection of the major fault systems, definite structural zones of increased hydraulic conductivity are identified. These are related to the “Informal Aquizones” described at the end of **section 3.4.2**. These water-conductive structural zones were defined as hydrotects in a previous work on the CAGE study (DWAF, 2000); a hydrotect being defined as:

> *“A distinct planar or linear feature – such as a fracture, a fault, a line of intersection between planar structures, or a fold closure – which is characterised by a permeability or hydraulic conductivity that is greater by (at least) three orders of magnitude relative to the surrounding country-rock matrix (DWAF, 2000)”.*

Eleven hydrotect systems (**Table 4-1**) have been identified and named, based purely on a structural investigation and scientific knowledge and understanding of the TMG aquifer system. Two of these systems fall completely outside the current groundwater study area but are included here for the purpose of generating a regional picture of the hydrotect occurrence pattern.

The evidence for the existence of hydrotects takes the form of a definite spatial association between springs and high-yielding boreholes, on the one hand, and major geological fracture systems, on the other hand. The spatial distribution of borehole yields and springs, as well as the hydrochemistry and isotope results, indicate that the premise is sound. Other physical parameters gathered during the course of hydrocensus surveys, such as anomalously high groundwater temperatures that can only be explained by deep circulation, have also furnished evidence for highly conductive hydrotects. Hydrotects are the preferred flow paths that link the major recharge zones to the discharge sites within any one aquifer.

Table 4-1 Hydrotect Systems

Abbr.	Hydrotect	Comments
KKM	Krakadouw – Klawer Megafault Zone	Outside, N of study area
TLM	Twee Riviere – Leopoldville Megafault Zone	Outside, N of study area
GVM	Gydo – Verlore Vlei Megafault Zone	NW/SE, on NE boundary of study area; possible inter-basin transfer conduit between Olifants and upper Breede
SAM	Saron – Aurora Megafault Zone	NW/SE trend, in NW part of study area
GBF	Groenhof – Bokkerivier Fault Zone	E/W tend, in NE part of study area
WPM	Worcester – Pletmos Megafault Zone	E/W trend; enters E part of study area near Robertson; links to SE extension of SAM
SBM	Steenbras – Brandvlei Megafault Zone	NE/SW major system; possible inter-basin transfer conduit between Breede and upper Riviersonderend
RRM	Robertson – Rooiels Megafault Zone	Subparallel to SBM, near SE boundary of study area
CHF	Caledon – Hawston Fault Zone	Outside, SE of study area
KLF	Klein Drakenstein – La Motte Fault Zone	NW/SE trend; joins SE end of Colenso Fault to SBM
RGF	Riviersonderend – Greyton Fault Zone	E/W, subparallel to WPM in SE part of study area; joins RRM

Previous hydrogeological investigations (CCT, 2004) identified three major structural features of prime importance to deep groundwater flow and confined-aquifer storage (“hydrotects”) within the Peninsula Aquifer in the south-eastern part of the Berg WAAS area:

a) ***Steenbras-Brandvlei Megafault Zone (SBM)***, a little recognized, continuous braided-fracture and connected-fold system extending from the coast of False Bay near the Steenbras River mouth to beyond the fault from which the powerful and scalding Brandvlei hot spring emerges;

b) ***Klein Drakenstein and La Motte Fault (KLF)***, and associated, connecting/ branching splays at the south-eastern termination of the older, reactivated basement fault zone between the Tygerberg and Swartland tectonostratigraphic terranes in the pre-TMG Malmesbury Group and Cape Granite Suite;

c) ***Worcester-Pletmos Megafault Zone (WPM)***, in particular the *Elandskloof Fault and Tulbagh Road Fault*, branching splays in a forked pattern at its apparent western termination.

An earlier hydrogeological study in the Citrusdal Artesian Groundwater Exploration (CAGE) Project (DWAF, 2000) had identified four NW/SE-trending megafault zones*:*

d) ***Krakadouw – Klawer Megafault Zone (KKM)***;

e) ***Twee Riviere – Leopoldville Megafault Zone (TLM)***;

f) ***Gydo-Verlorenvlei Megafault Zone (GVM)***, partly coinciding with the northern boundary of the groundwater study area;

g) ***Saron-Aurora Megafault Zone (SAM)**,* a clearly developed fault zone separating lower order TMG rocks with sediment covered Malmesbury basement.

The latter two are located in the northern part of the Berg WAAS area, while the first two are outside of the study area.

The SAM structure is probably connected via a seismically active structure at depth below the Tulbagh-Ceres area, with the

h) ***Groenhof-Bokkerivier Fault Zone (GBF)***, consisting of a network of parallel subvertical right-lateral fault slip zones, in the Warm Bokkeveld.

The GBF connects eastward with the Touws River Fault, which has a branching splay that connects with the south-eastern end of the GVM zone.

Around the south-eastern border of the extended Berg WAAS area, two major fault zones are recognized:

i) ***Robertson-Rooiels Megafault Zone (RRM)*** extends from the *WPM* to the Cape South Coast where it splays into a complicated braided pattern of fracture networks.

j) ***Caledon-Hawston Fault Zone (CHF)***, and associated fault splays in the region of Riviersondered.

The middle section of the RRM and the eastern end of the (extended) CHF are linked by the:

k) ***Riviersonderend (-Greyton) Fault (RGF)***, an ESE/WNW-trending structure at depth in the Bot River Valley, intersecting the Groenlandberg Fault in the west.

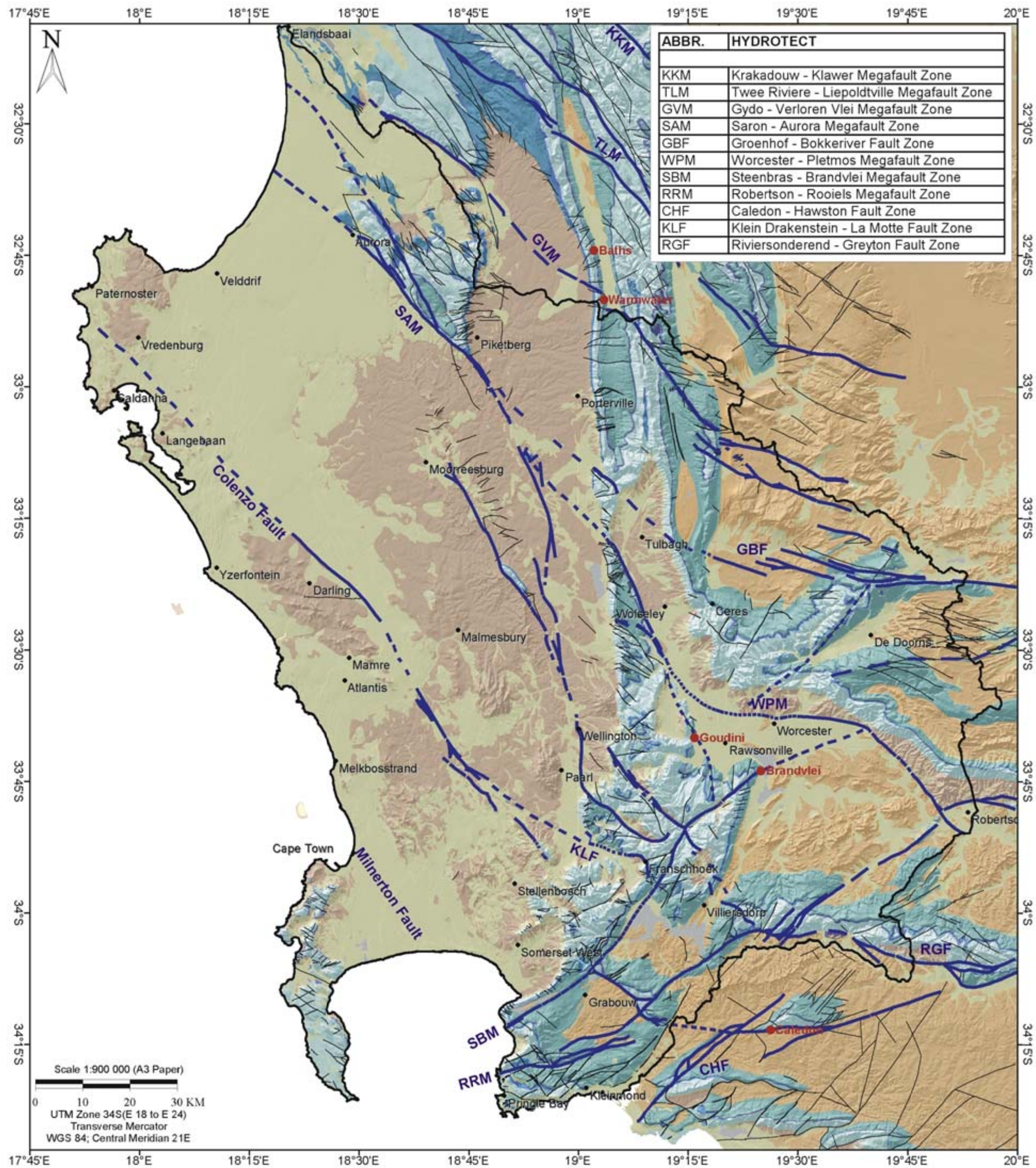
Between the RRM and the SBM structures, there are bridging fault zones with roughly NW/SE trend, such as the Groenlandberg fault, near Grabouw, and a fault with similar strike and south-westerly downthrow, farther to the southwest between Rooiels and Betty's Bay. These particular structures may be south-eastern extensions, across the NE/SW-trending SBM, of the Colenzo Fault and the Milnerton Fault. The Colenzo Fault is potentially a kilometric scale structure associated with granite plutonism that is overlain by tertiary and quaternary sediments. While the exact location of these faults is not known, their orientation agrees with the regional trend of already identified Megafault structures.

Three additional hydrotects are considered in this study. Their existence is inferred from an in-depth understanding of the regional overview of hydrological flow structures and compartments in the study area. These hydrotects are called megafault zones but remain dashed until further data is obtained to accurately identify their location.

l) ***Franschhoek-Saldanha Megafault Zone (FSM),*** connecting the identified Colenzo fault with the Franschhoek fault by means of the *KLF*.

m) ***Milnerton-Rooiels Megafault Zone (MRM),*** transects the Cape Flats separating the Cape Peninsula from the TMG dominated eastern half of the study area.

n) ***Du Toitskloof-Moorreesburg Megafault Zone (DMM),*** an extension between the Du Toits Fault and the Malmesbury Fault. Evidence for deep-water flow is the Malmesbury hot spring. The parallel nature and equidistant spacing of the identified hydrotects suggests that the DMM may extend to the coast and have a controlling influence on the course of the current day lower Berg River.



ABBR.	HYDROTECT
KKM	Krakadouw - Klawer Megafault Zone
TLM	Twee Riviere - Liepoldtville Megafault Zone
GVM	Gydo - Verloren Vlei Megafault Zone
SAM	Saron - Aurora Megafault Zone
GBF	Groenhof - Bokkeriver Fault Zone
WPM	Worcester - Pletmos Megafault Zone
SBM	Steenbras - Brandvlei Megafault Zone
RRM	Robertson - Rooiels Megafault Zone
CHF	Caledon - Hawston Fault Zone
KLF	Klein Drakenstein - La Motte Fault Zone
RGF	Riviersonderend - Greyton Fault Zone

LEGEND

- Towns
- Hot Springs
- Faults
- Hydrotects
- Study Area

SIMPLIED LITHOLOGY

- Quaternary Sediments
- Post_TMG
- Nardouw Group
- Cedarberg Formation
- Pakhuis Formation
- Graafwater Formation
- Peninsula Formation
- Piekenierskloof Formation
- Pre-Cape
- Dams

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

HYDROTECT SYSTEMS

FIGURE 4.5

4.3.3 Regional flow systems in the Peninsula Aquifer

The aspects used to define a regional conceptual model for the Peninsula Aquifer hydrogeology are:

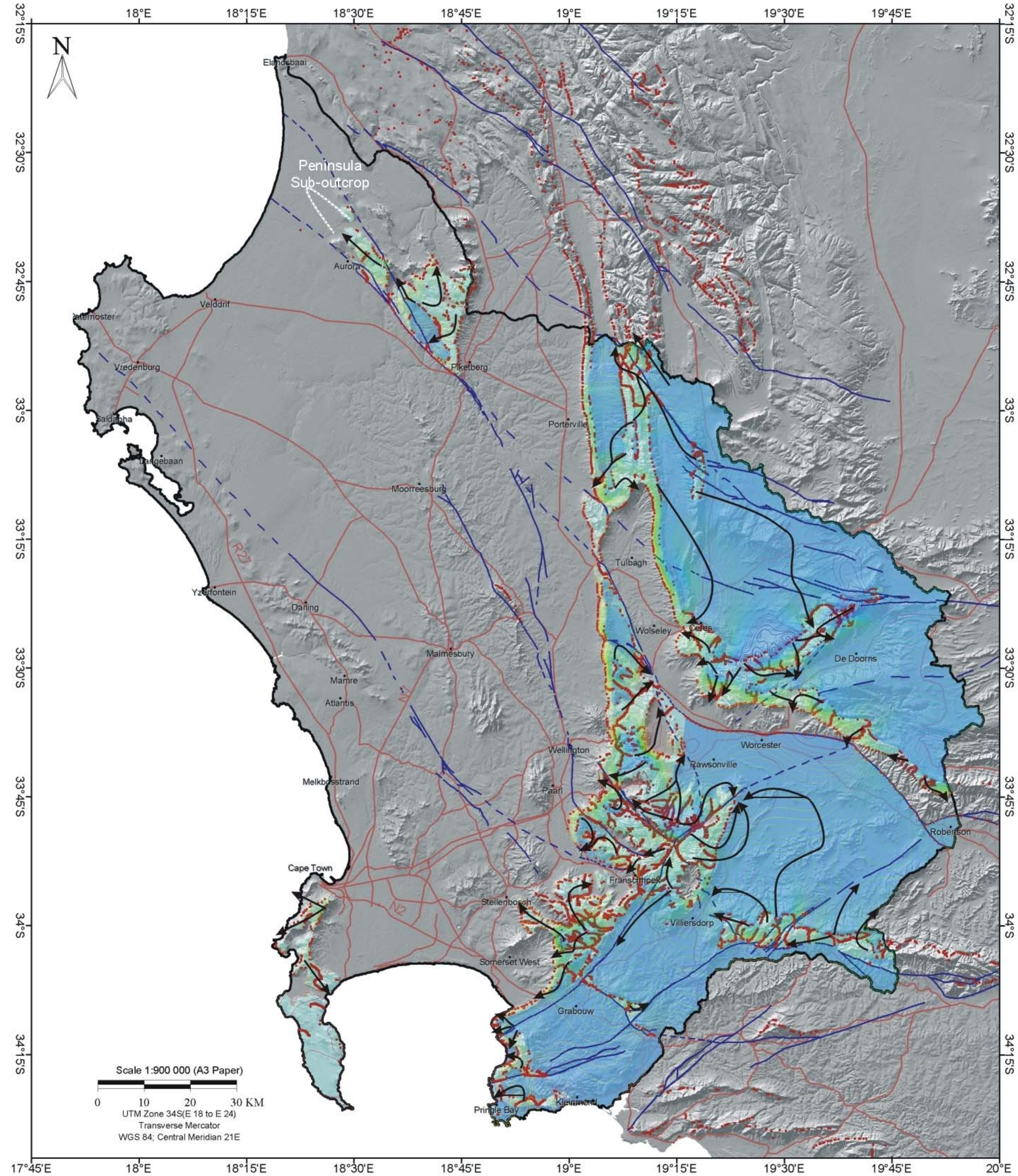
- surface topography;
- the surface and inferred subsurface geology (i.e. aquifer outcrop, bedding orientation, folding and faulting);
- the results of aerial photo interpretation (principally fracture/fault patterns);
- the results of wider hydrocensus surveys;
- the hydrogeochemical and geothermal observations.

The main elements of this model are summarised graphically in **Figure 4-6**.

Two major flow systems are identified in the eastern part of the study area (viz. north and south of the Worcester Fault), while the Piketberg and the Cape Peninsula in the western part are considered isolated flow systems.

- The flow system in the area north of the Worcester Fault is characterised by long flow path from the recharge area in the Grootwinterhoek and Witzenberg mountains across the synclinal structure into the Hex River valley. The flow paths are controlled by the SAM and GBF structures. Most of the groundwater is expected to discharge into the Hex River and other tributaries of the Breede River.
- Additionally more local flow occurs from the eastern limb of the Olifants River Syncline towards the western limb, resulting in discharge either into the Klein Berg River or the northern hot springs at Warmwater or The Baths.
- The flow system in the area south of the Worcester Fault is two fold. In the northern part the water flows from the high recharge areas in the Du Toits, the Stettyns and the Riviersonderend Mountains as deep flow towards the Goudini and Brandvlei hot springs.
- In the southern part the flow from the Wemmershoek and Franschhoek Mountains is diverted along the SBM towards the ocean. Locally some flow might be diverted from this general direction and discharge in perennial springs.
- At both localised systems, i.e. Piketberg and Cape Peninsula, the groundwater flow is generally directed towards the sea, controlled by faults and fractures. In the Piketberg area, it is expected that the Peninsula Formation continues under the sediment cover and connects the Peninsula Aquifer either with the Sandveld Aquifer or directly to the ocean.

A detailed description of the flow controlling megafault zones and fault zones, relevant to the Peninsula Aquifer in the study domain, follows below.



LEGEND

- Towns
- Water Level Points
- Roads
- Hydrotects
- Peninsula Outcrop
- Peninsula Suboutcrop
- Study Area

Water Level Contours (mamsl)

- -4 - 100
- 100 - 200
- 200 - 400
- 400 - 600
- 600 - 800
- 800 - 1000
- 1000 - 1200
- 1200 - 1400
- 1400 - 1600
- 1600 - 1846
- Flow Paths

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

REGIONAL FLOW IN THE PENINSULA AQUIFER

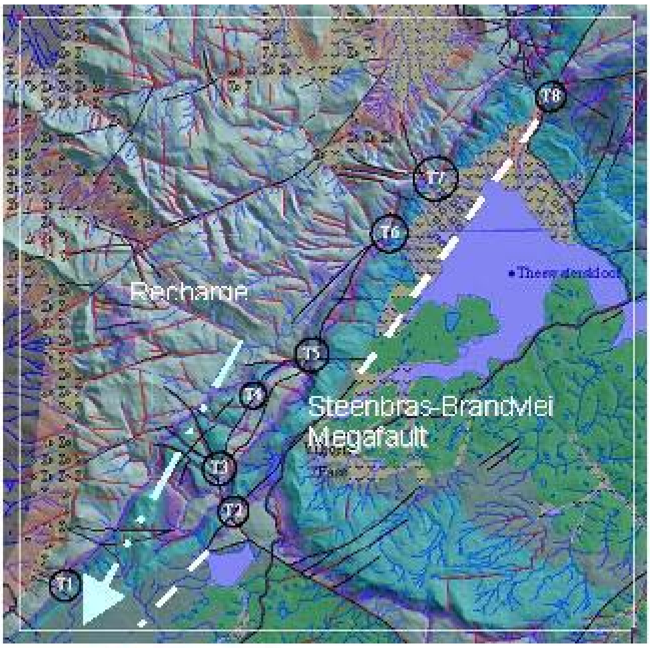
FIGURE 4.6

Steenbras-Brandvlei Megafault Zone (SBM)

The central part of the Steenbras-Brandvlei Megafault Zone (SBM), between the towns of Grabouw and Villiersdorp is the most promising area of groundwater resource potential and became the main focus area of later desktop studies and hydrogeological fieldwork. This area straddles the catchment divide between the Riviersonderend and Palmiet river systems, and therefore has the potential to supply in the direction of either Theewaterskloof or Steenbras (via Palmiet-Steenbras interbasin transfer).

The conceptual groundwater flow model for the southern SBM involves recharge in the high-rainfall area of the Hottentots-Holland Mountains, a hypothetical deep flow guided by the NE-SW fracture systems and the hinge zone of the Steenbras Syncline to discharge along extensions of the SBM, and possible submarine discharge of warm, fresh groundwater near the coast of False Bay (see **Figure 4-7**).

a)



b)

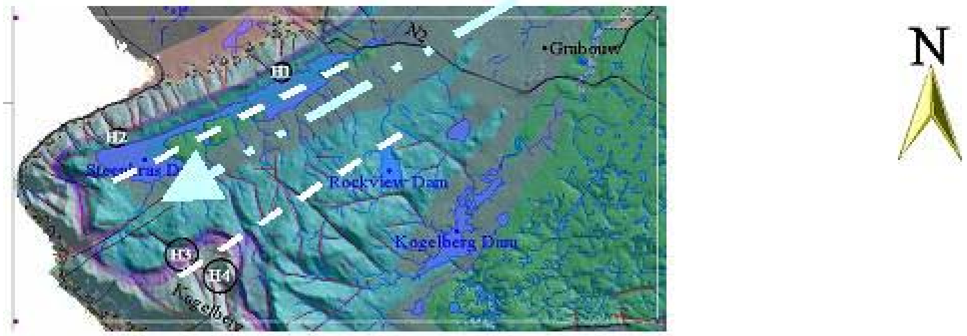


Figure 4-7 Conceptual flow model for Steenbras-Brandvlei Megafault; a) recharge area, b) discharge area, (CCT, 2004)

Klein Drakenstein Fault and La Motte Fault (KLF)

The Klein Drakenstein Fault and La Motte Fault (KLF) are associated splays at the south-eastern end of the fault zone between the Tygerberg and Swartland tectonostratigraphic terranes in the pre-TMG basement.

The conceptual flow model for the KLF involves recharge from precipitation in the Klein Drakenstein and upper Stettynskloof Mountains, and also from the Wemmershoek reservoir where it submerges fractured Peninsula Aquifer rocks, and discharge from the Zachariashoek Syncline in springs around the lower Wemmershoek and also by lateral flow into the Berg River alluvial aquifer where it covers faulted and fractured Peninsula suboutcrops along the La Motte Fault trace (see **Figure 4-8**).

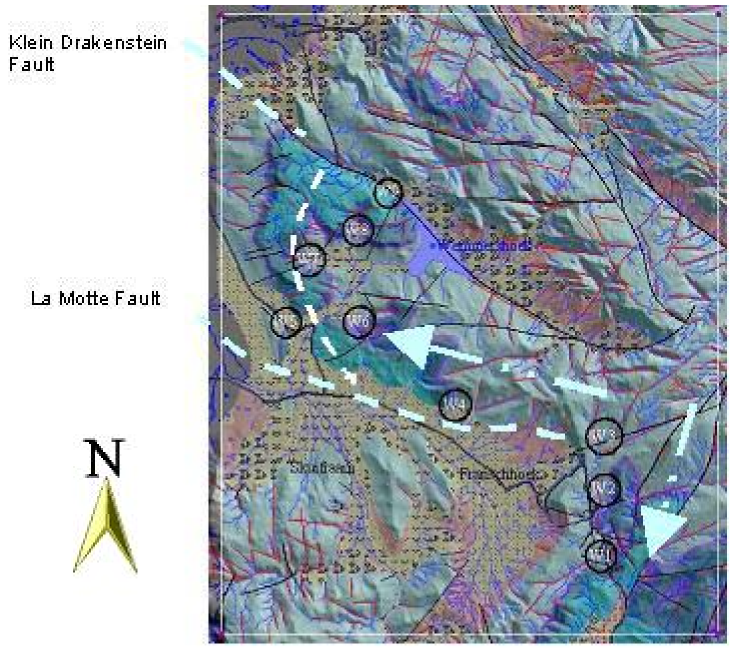


Figure 4-8 Conceptual flow model for Klein Drakenstein and La Motte Fault system (after CCT, 2004)

Western Worcester-Pletmos Megafault Zone (WPM)

The conceptual flow model for the western WPM, i.e., the *Elandskloof Fault and Tulbagh Road Fault splays*, involves lesser recharge from the mountain range overlooking the Voëlvlei reservoir and also from the northern end of the Waterval Syncline, and discharge along the NW-SE-striking Elandskloof Fault in both a NW direction (spring flow towards Voëlvlei) and a SE direction (towards the Breede River where the latter is incised within the fractured Peninsula Aquifer north of its confluence with the Witte River).

Saron-Aurora Megafault Zone (SAM)

The *Piketberg Fault* is located on the SAM at the southern border of the Piketberg Mountains, and is thought to connect via a subsurface structure below the Malmesbury Shales to the *Tulbagh Road Fault* at the western extension of the *Groenhof Bokke River Fault Zone.*

The conceptual flow model involves both groundwater flow in the overlying quaternary sediments and alluvium as well as groundwater flow in the Peninsula Formation. The Peninsula Formation outcrops in the Piketberg Mountain where groundwater is recharged by elevated precipitation, and extends for an unknown distance to the west below the quaternary sediments, (marked Peninsula Outcrop on **Figure 4-6**). This groundwater is discharged either into these overlying sediments or into the sea.

The Malmesbury basement is incised by the Verlorenvlei River Palaeochannel that extends west to east to the coast through the Bottelfontein Farm. Groundwater is recharged by flooding of the Verlorenvlei River, is supplemented by groundwater flow in the Peninsula Aquifer where the two aquifers are in contact with one another and is discharged into the sea,

Groenhof-Bokke River Fault Zone (GBF) (Western part of Cango Megafault Zone)

The Groenhof Fault near Ceres is one of an en-echelon group of WNW/ESE-trending fractures, arrayed E/W across the Ceres Basin from Groenhof in the west to Bokke River in the east (**Figure 4-6**). Newton (1975, p. 28) notes that the "faults of the Groenhof-Bokrivier *(sic)* zone ... extend across the adjacent area ... south of Touws River, and may join *(sic)* up with the fault south of Anysberg. This would make them part of the western termination of a major zone of E-W faults of which the Cango Fault is the most important member". The entire, semi-continuous fault system extends for about 500 km from the Witzenberg Range in the south-western Cape to the Baviaanskloof range in the Eastern Cape, and may consequently be termed the "Cango Megafault".

The *Groenhof-Bokke River Zone* has the typical appearance of a “horse-tail termination splay” system along a left-lateral strike-slip fault. API interpretation in the Verlorenvalley area (Hartnady and Hay, 2001) demonstrates greater continuity of the faulting, and high E/W fracture densities within the sandstone fault blocks surrounding the fault zone itself. A significant fault of roughly E/W strike crosses the southern part of the Verlorenvlei farm, extending westwards across the southern part of the Sekelkoppe and possibly linking with a larger fault zone just south of the Theronsberg Pass.

Kleinberg Fault and associated NE/SW fractures

A NE/SW-striking fault structure crosses the area along the Sonkliprug, and is continuously traceable from Kanetvlei in the southwestern part of the Hex River valley, where a substantial fault-breccia zone occurs in the valley leading up to Kleinberg (Topo Sheet 3319BC). This *Kleinberg Fault* apparently displaces the hinge-line of the major syncline horizontally in a right-lateral sense, i.e., the SE fault block has moved southwestward.

The Kleinberg Fault and associated sub parallel faults evidently represent an important “transfer zone”, through which substantial displacement on the Touws River-Bokkerivier segment of the Cango Megafault is absorbed and relayed to the westerly continuation of the Worcester fault and to the set of en-echelon faults striking WNW/ESE crossing the Kouebokkeveld Mountains from the Theronsberg Pass area.

Robertson-Rooiels Megafault Zone (RRM)

The RRM splays off the *Worcester-Pletmos Megafault Zone* and extends NE-SW to the coast where it braids into numerous anastamosing faults on the South Coast Peninsula to Rooiels. The RRM is complicated by fault intersections east of Villiersdorp where a possible extension to the *Klein Drakenstein-La Motte Fault Zone* extends eastward and in the region of Riviersonderend where the *Riviersonderend-Greyton Fault Zone* occurs. This large strike slip structure bounds and compartmentalizes the downthrown blocks south of the kilometric scale *Worcester Fault*.

Riviersonderend(-Greyton) Fault (RGF) Groenlandberg Fault

The RGF is a possible offsplay of the *Caledon-Hawston Fault Zone*, trending east west and intersecting both the *Robertson-Rooiels Megafault Zone* and the *Steenbras Brandvlei Megafault Zone*. It may link up with the *Franschhoek-Saldanha Megafault Zone* in the subsurface. The downthrown to the south RGF assists in compartmentalizing the blocks of the southern part of the study area.

4.3.4 Regional flow systems in the Nardouw aquifers

The aspects used to define a regional conceptual model for the Skurweberg Aquifer hydrogeology are:

- surface topography;
- the surface and inferred subsurface geology;
- the results of aerial photo interpretation (principally fracture/fault patterns);
- the results of the wider hydrocensus survey;
- the hydrogeochemical observations.

The main elements of this model are summarised graphically in **Figure 4-9**.

The Skurweberg aquifer has a smaller outcropping area than the Peninsula Aquifer. Groundwater flow is limited to the eastern half of the study area with only a minor occurrence outside of this in the Piketberg Mountains.

Beginning in the south, groundwater in the Skurweberg Aquifer is recharged in the Hottentots Holland Mountains and discharged in the sea. Flow occurs along the *Steenbras-Brandvlei Megafault Zone*, NE-SW along the Kogelberg Anticline. Part of this flow is diverted and goes into deep storage in the southern extension of the Villiersdorp Syncline. Flow in the Skurweberg Aquifer in the South Coast Peninsula is controlled by the NE-SW trending *Robertson-Rooiels Megafault Zone* and is discharged into the sea.

Recharge in the Franschhoek Mountains is diverted into the Villiersdorp Syncline to great depths before it is forced upward at the intersection of the *Steenbras-Brandvlei Megafault Zone* and discharged at Brandvlei Hot Spring. Similarly, recharge in the Riviersonderend Mountains flows NE along the *Robertson-Rooiels Megafault Zone*, is rerouted by the *Worcester Fault* and is forced to surface, discharging at the Brandvlei Hot Spring.

The highest mean annual precipitation occurs in the Drakenstein and Du Toitskloof Mountain Ranges, which are comprised mainly of Peninsula Aquifer but are flanked by the Skurweberg Aquifer along their boundaries. Recharge into the Skurweberg Aquifer is controlled by sub-surface fault structures and emerge as discharge to the Goudini Hot Springs. Some of this water circulates clockwise south of the *Worcester Fault*, back along the *Steenbras-Brandvlei Megafault Zone* and is discharged at the Brandvlei Hot Spring.

Recharge in the Kwadouwsberge is confined and flows at depth along the Koo Valley to be discharged at some point beyond the study area. A small portion of water flows down the northwestern flank of the Kwadousberge to join with water recharged at the base of Hex River Mountains in the Hex River Valley. This water is controlled by the *Hex River Fault*, flowing to the SW and is discharged into the Hex River.

The southern portions of the Hex River Mountains receive high mean annual precipitation, part of which enters the Skurweberg Aquifer as groundwater flow. This flow is diverged in the Warm Bokkeveld Syncline: flow to the west enters into the *Groenhof-Bokke River Megafault Zone* to be discharged at some point outside the study area while flow to the east circles anticlockwise through the Mitchell's Pass and enters as discharge into the Klein Berg River. Similarly, groundwater flow recharged in the Agter-Witzenberg Mountains, flows southward into the Mitchell's Pass.

Recharge in the form of precipitation in the southern extension of the Olifants River Syncline as well as from flooding of the Olifants River flows north along the synclinal axis, and is discharged at some point north of the study area. Some of this flow may be rerouted into the transecting *Gydo-Verlorenvlei Valley Megafault Zone*.

Recharge on the unconfined Skurweberg Aquifer in the Piketberg Syncline flows NW along the synclinal axis where after it acts as recharge to the Peninsula Aquifer. This water is eventually discharged in the sea on the West Coast.

4.3.5 Regional flow systems in the Sandveld aquifers

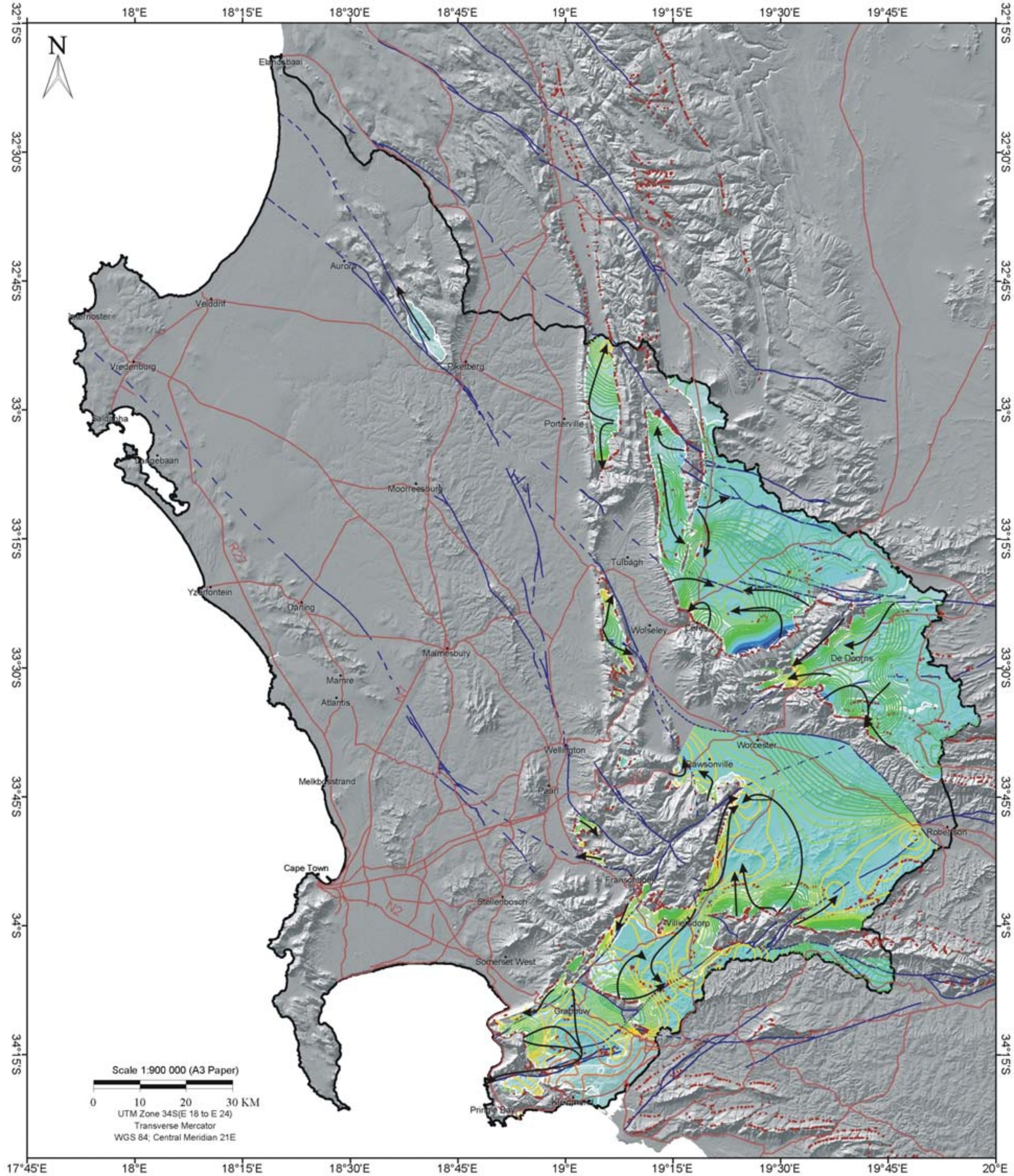
As a rule of thumb, groundwater flow occurs from areas of recharge, usually inland to areas of discharge, usually at the coast. In addition, flow occurs either toward a large surface water body (e.g. river) or away from it, depending on the time of year and the water levels in the relevant surface water body. This remains true for most of the Sandveld aquifers, except where complications arise in the subsurface due to inconsistencies in the subsurface such as the presence of a palaeo channel.

Palaeo channels determine the flow pattern for the following areas along the coast:

- Piketberg towards Verlorenvlei,
- Langebaan,
- Geelbek,
- Atlantis and
- Cape Flats.

Groundwater flow in the Sandveld Aquifer occurs from inland, centered to a local palaeo channel and routed to the coast where it enters the sea at right angles to the coastline (**Figure 4-10**). Inland recharge occurs primarily as rainfall or as flood recharge from transecting rivers at sporadic intervals. Only in the case of Piketberg, is there interaction with another groundwater source from the Peninsula Aquifer below.

Inland, the Sandveld Aquifers are primarily recharged in the surrounding high-lying mountain peaks by means of surface water run-off and discharged at topographic lows into larger surface water bodies. These inland Sandveld Aquifers are additionally recharged from below by alternative groundwater sources from either the Peninsula or Skurweberg Aquifers or both. This phenomenon is explained in more detail in **Section 6.6**.



LEGEND

- Towns
- Water Level Points
- Roads
- Hydrotects
- Nardouw Outcrop
- Nardouw Suboutcrop
- Study Area

Water Level (mamsl)

- 60 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1000
- Flow paths

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

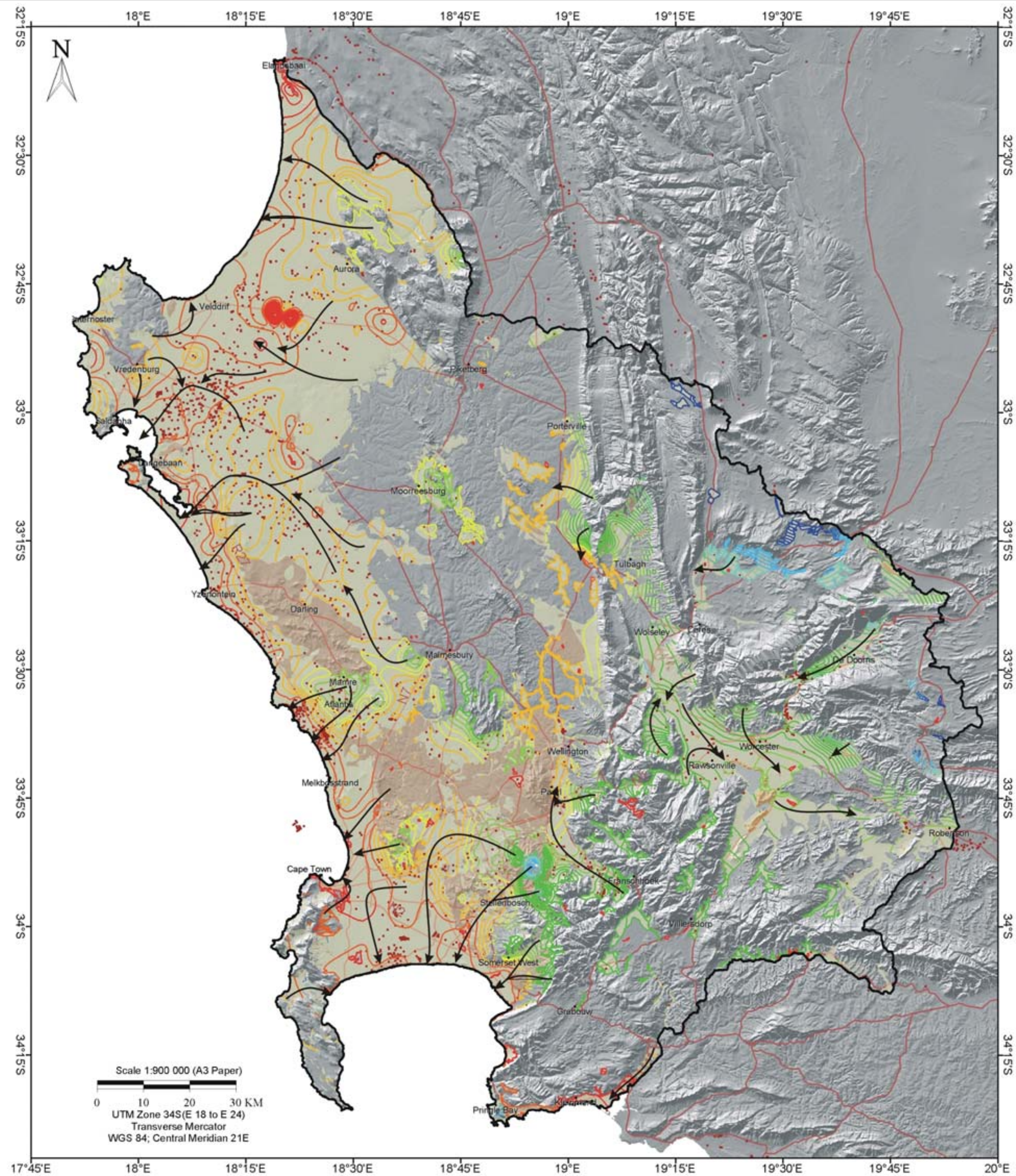
CONSULTANT

UMVOTO

TITLE

REGIONAL FLOW IN THE NARDOUW AQUIFER

FIGURE 4.9



LEGEND

- Towns
- Water Level Points
- Roads
- Sandveld Outcrop
- Study Area
- **Flow lines**

Water Level (mamsl)

- -243 - 0
- 0 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- 200 - 300
- 3000 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 1017

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

REGIONAL FLOW IN THE SANDVELD AQUIFER

FIGURE 4.10

5. IWRM DOMAINS

An aquifer-specific conceptual model requires identification of the groundwater recharge and discharge zones, the preferred flow paths linking these two zones, and the preparation of a piezometric map for the aquifer. The conceptual flow relationship between groundwater and surface-water regimes is based on the 3D characterisation of the aquifers, their likely spatial and temporal relationship with the stream-drainage system, as well as any lateral and vertical recharge between bounding aquifers. It has five intended outputs (DWAF, 2005, p. 39): viz.,

i. "… the delineation of Integrated Water Resource Management Domains within which the spatial relationship between surface and groundwater interactions … (are)…defined on an aquifer-specific basis within any one quaternary and between quaternaries" ;

ii. "… the delineation of hydrogeological boundaries and likely boundary conditions to be used in the mass balance and other numeric models …(applied) …at a regional (if 1:250 000 data used) and at a quaternary scale (if 1:50 000 data used);

iii. "… a documented decision-making process as regards model complexity and simplification together with the impacts on model results";

iv. "… the write-up of data availability, evaluation, data processing and use and recommendations for data acquisition in order to improve model results";

v. "… iterative evaluation of the conceptual model of surface groundwater interaction by both the surface water and the groundwater team members in mutual evaluation of the interpretation of the hydrographic and hydroclimatic databases".

5.1 DEFINITION OF IWRM DOMAINS

In the Hydrogeological Reconnaissance Report for the City of Cape Town (CCT) Table Mountain Group Aquifer Feasibility Study and Pilot Project (CMC, 2004), the concept of an IWRM domain was introduced, in some way comparable to what was previously termed a hydrogeological response unit (McKay, 1999). The explicitly-stated purpose of establishing IWRM domains was to "initiate the planning for the groundwater modelling as well as the Water Resource Yield Model (WRYM) development and to promote the integration of surface water, groundwater and ecological monitoring within a domain that conceivably responds differently in time but has the same boundary conditions" (CMC, 2004).

It is appropriate here to briefly note the terminological differences between "geohydrological region types" [6] (Braune and Dziembowski, 1997), "homogeneous response units" [7] and "geohydrological response units" [8] (McKay, 1999), "groundwater management units" (SRK, 2003), and the IWRM domain concept, which has explicit purposes related to the integration and sustainable management of surface and groundwater. The previous application of the term groundwater management unit in the West Coast area has more in common with the definition of the geohydrological response unit, in that the GMU areal extents generally correspond to fifth-order subdivisions (quintenary catchments) of the surface-water drainage system.

[6] Geohydrological Region: An area within a significant water resource or homogeneous response unit with similar geohydrological characteristics, which result in the area fulfilling a unique and specific role in the hydrological system (from http://www.pasgc.co.za/files/glossary.pdf).

[7] Homogeneous Response Unit: Similar to an eco-region but is based on geohydrological considerations, groundwater systems with similar geohydrological properties and respond in a similar manner (op.cit.)

[8] Geohydrological Response Unit: Smallest groundwater unit considered and is demarcated on the basis of homogeneous response unit and geohydrological region type (op.cit.)

The current South African usage defines a "Groundwater Resource Unit" (GRU) [9] with a qualifiying description practically identical to the definition of the geohydrological response unit, and a sense that is hard to distinguish from the conventional use of the term "aquifer", especially as the latter is defined in a formal hydrostratigraphic sense (**Table 3.2**). It also defines a "Groundwater Management Unit" (GMU) [10] with regard to a delineation based on management considerations, relating to use and/or protection, rather than geohydrological criteria.

The Australian definition of a Groundwater Management Unit [11], based around the concept of "hydraulic connectedness", has a similarly utilitarian dimension indicated by reference to "an appropriate scale at which resource issues and intensity of use can be incorporated". In the latter sense, the usages (South African and Australian) of the GMU most resemble the concept of the IWRM domain, except for their focus on "groundwater systems" and the "groundwater resource". In contrast the IWRM-domain definition aims to integrate the surface-water, groundwater and ecological dimensions of water resource management within a unified geographical framework.

The hydraulic principles underlying the current definition of the IWRM domains are:

- Boundaries generally follow major watersheds and topographic divides, and/or important lithological boundary changes (aquifer-aquitard contacts);
- Certain major faults are hydraulically sealed in their central core sections by impermeable fault-gouge and secondary quartz-veining, and therefore constitute hydrogeologic boundaries to transverse flow and appropriate domain boundaries, eventhough fracture permeability may be strongly enhanced in aquifers adjacent to the outer sections of the fault zone ("hydrotects");
- Discrete areas where there is mass-balance exchange between IWRM domains can be identified on the basis of hydrogeological or surface water 'connections';
- The preferred groundwater flow paths are along the main hydrotects, as defined in the sections above;
- The hydrotect systems incorporate (generally high-altitude) recharge zones that can be defined as clusters of quaternary catchments, or portions of such, with discrete recharge networks defined on the basis of fracture-connectivity patterns;
- The Peninsula Aquifer and Skurweberg Subaquifer operate on longer time-scales (probable order of hundreds of years) that are approximately given by groundwater mean-residence times, equal to their respective storage volumes divided by the annual rate of recharge;
- Little or no hydraulic exchange occurs across the Winterhoek Mega-aquitard between the Peninsula Aquifers and the Skurweberg Subaquifer, and only limited exchange may occur at discrete locations where the two aquifers are in faulted contact, but the rate of exchange (leakage) is not such that the two aquifers are in hydraulic equilibrium.

[9] Groundwater Resource Unit: A groundwater body that has been delineated or grouped into a single significant watrer resource based on one or more characteristics that are similar across that unit (DWAF groundwater dictionary) [*Description is nearly identical to definition of geohydrological response unit in footnote 5.*]

[10] Groundwater Management Unit: An area of a catchment that requires consistent management actions to maintain the desired level of use and/or protection of groundwater (DWAF groundwater dictionary)

[11] "A Groundwater Management Unit (GMU) is a hydraulically connected groundwater system that is defined and recognised by State and Territory agencies. This definition allows for management of the groundwater resource at an appropriate scale at which resources issues and intensity of use can be incorporated into groundwater management practices" (from http://adl.brs.gov.au/anrdl/metadata_files/a_agmu_r9nnd_00311a00.xml)

- The Rietvlei Subaquifer, the Malmesbury or Bokkeveld regolith aquifers, and the shallow unconfined Sandveld aquifers respond on similar short time-scales to surface-water interactions, and are therefore best managed on an annual-recharge cycle, but in the case of the large-scale primary aquifers with greater volumes in storage (e.g. Breede and the Hex River basins) the response time may require further evaluation.

Parameters for delineating the IWRM Domains

Integrated Water Resource Management requires an understanding of the spatial and temporal distribution of both surface and groundwater in any given domain. Therefore each domain is chosen such that the domain can effectively be considered a self-contained unit. This is done with an understanding of the overall three-dimensional location of groundwater and distribution of groundwater flow, in addition to knowledge of the water recharge, storage and discharge areas.

Surface water movement depends largely on the topography. Surface water catchments and watersheds therefore play a leading role in delineating IWRM domains. This study has put particular focus on quaternary and tertiary water catchments. The source region of the rivers and their preferred flow paths was one of the parameters used in delineating the IWRM domains. A large component of surface water flow occurs as surface run-off in the form of rivers, while the remainder is evaporated, taken up by vegetation or infiltrated into the ground as recharge.

The amount of water entering the ground as recharge is governed by the surface over which it flows. An in-depth understanding of the geology and the rock types over which the rivers flow provides some indication of the percentage of water that enters the ground as opposed to that remaining as surface flow. A further three-dimensional understanding of the geology is required to predict the flow path of the base groundwater-flow.

Rock lithologies that host water and allow water to flow through them are termed aquifers. It is these lithologies that we target for sustainable abstraction of groundwater. That is not to say that other rock lithologies do not host water. Other rock lithologies, although they store minor amounts of water, do not allow for the flow of water, rendering the water inaccessible and unsuitable for abstraction.

In the same way that topography forms surface water divides, geological structures form groundwater divides. In most cases, the topography is determined by the geology wherein more competent units form the mountains and topographically high-lying areas and the less competent units form the valleys and shallow-lying areas. For this reason, the groundwater divides often coincide with the surface water divides. Investigation of the geological structures in the subsurface and the distribution of folds reveal any deviations from this pattern.

Faults can act as natural boundaries to groundwater flow. This is however highly dependent on the nature of the fault and the displacement of correlating units on either side of the fault plane. In some cases, displacement is insufficient to fully sever a water-bearing unit, allowing leakage of water across the fault.

Faults themselves are capable of acting as conduits for groundwater flow. In the event that the faults have not been fully precipitated, spaces remain wherein water can flow. Physical flow principles govern that any water flow in the faults will preferentially remain there as opposed to travelling from a higher-lying aquifer unit, along a fault plane and into a lower fault plane.

5.2 DELINEATION AND CLASSIFICATION OF THE IWRM DOMAINS

Using the parameters mentioned in the section above, the Berg WAAS Project study area has been subdivided into 15 Integrated Water Resource Management (IWRM) domains (**Table 5-1** and **Figure 5-1**). The IWRM domains are classified according to three categories based on the water storage and conductivity capability of the main lithologies that exist in the IWRM domain areas. The three categories are:

1 FR Fractured rock Aquifers (Peninsula and Nardouw aquifers)

2 IG Intergranular Aquifers (Quaternary sediments)

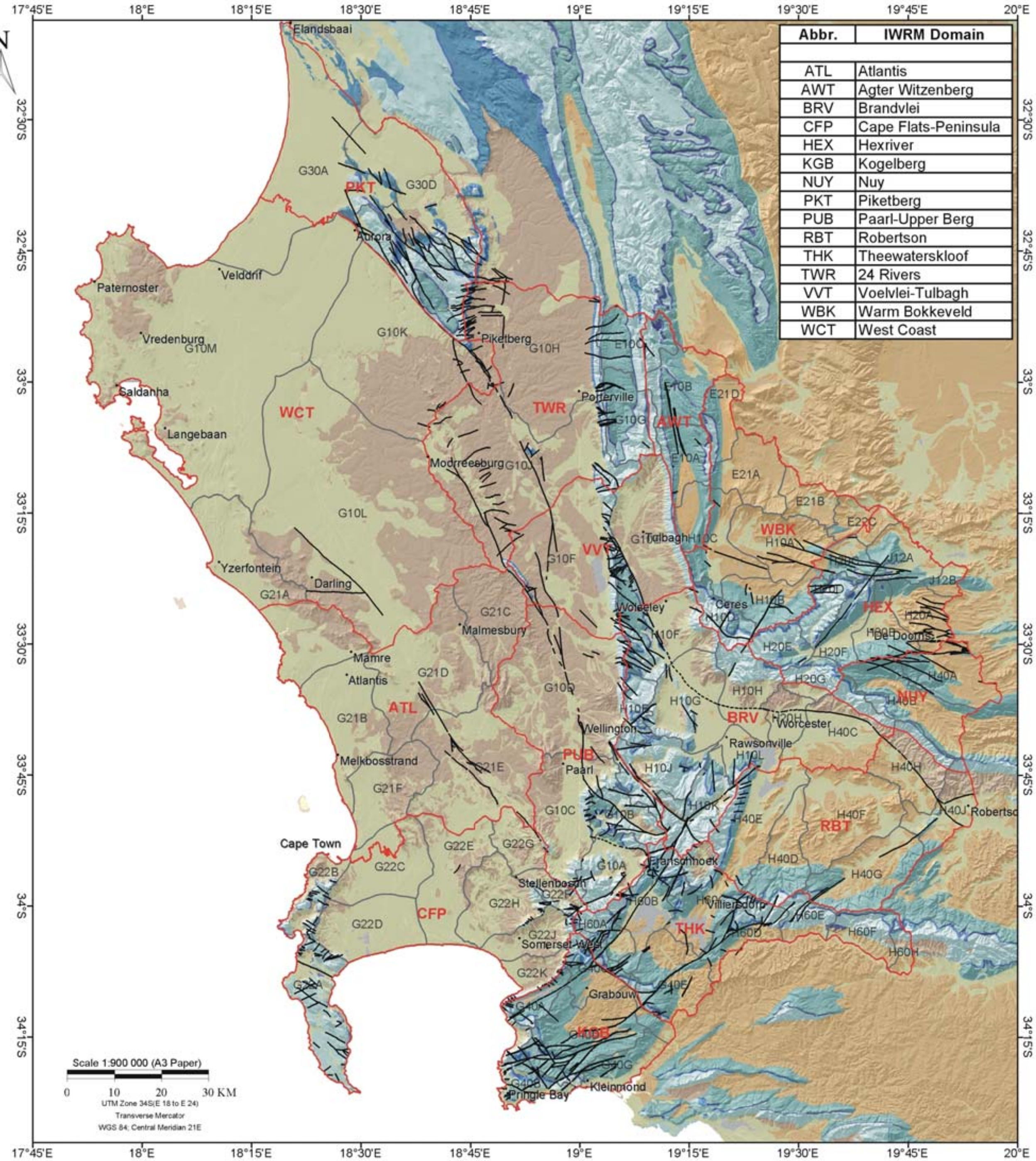
3 FR+IG A combination of Primary and Fractured rock aquifers that are mutually dependent on one another.

The choice of classification depended on the dominant geology, the primary point of focus and the surface water presence. In some instances, large portions of the IWRM Domains are dominated by "fractured and weathered" or "regolith" aquitards. These aquitards are not considered in the classification scheme outlined above.

Of the 15 IWRM domains, 9 are classified as "FR", 3 are classified as "IG", and 3 are classified as "FR+IG" (**Table 5-1**).

Table 5-1 IWRM Domain Classification

ID	Abbr.	IWRM Domain	Category	Area (km^2)
1	PKT	Piketberg	FR+IG	1 303.42
2	ATL	Atlantis	IG	2 092.50
3	CFP	Cape Flats-Peninsula	IG	1 685.19
4	KGB	Kogelberg	FR	767.06
5	THK	Theewaterskloof	FR	1 138.52
6	RBT	Robertson	FR+IG	1 385.42
7	PUB	Paarl-Upper Berg	FR	1 356.25
8	NUY	Nuy	FR	516.04
9	HEX	Hex River	FR	921.31
10	WBK	Warm Bokkeveld	FR	1 105.56
11	AWT	Agter Witzenberg	FR	498.23
12	TWR	24 Rivers	FR	1 839.88
13	WCT	West Coast	IG	5 113.90
14	VVT	Voëlvlei-Tulbagh	FR	933.20
15	BRV	Brandvlei	FR+IG	1 582.03



Abbr.	IWRM Domain
ATL	Atlantis
AWT	Agter Witzenberg
BRV	Brandvlei
CFP	Cape Flats-Peninsula
HEX	Hexriver
KGB	Kogelberg
NUY	Nuy
PKT	Piketberg
PUB	Paarl-Upper Berg
RBT	Robertson
THK	Theewaterskloof
TWR	24 Rivers
VVT	Voelvlei-Tulbagh
WBK	Warm Bokkeveld
WCT	West Coast

LEGEND

- Towns
- Faults
- Quaternary Catchment
- IWRM Domains

SIMPLIFIED LITHOLOGY

- Quaternary
- Pre_Cape
- Nardouw Group
- Cedarberg Formation
- Pakhuis Formation
- Peninsula Formation
- Piekenierskloof Formation
- Graafwater Formation
- Post_TMG
- Dam

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

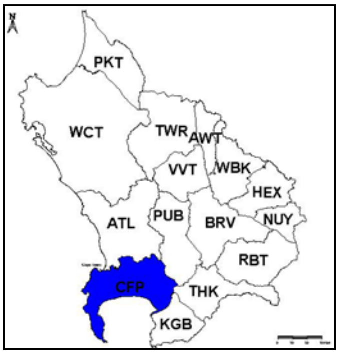
INTEGRATED WATER RESOURSE MAGEMENT (IWRM) DOMAINS

FIGURE 5.1

The parameters used for delineating the IWRM domain boundaries included the following factors:

- Surface water divides on a quaternary and quinery level
- Groundwater divides on a 1:50 000 scale
- Topography on a 20 x 20 m scale
- Formation lithologies,
- Geological structures and
- Fault systems.

In addition, there is recognition that each IWRM domain is defined around a potential water-resource development scheme that integrates the local surface-water resource with one or more components of the groundwater system in that area. They generally combine between two and ten quaternary catchments, and therefore constitute conjunctive management units of appropriately large scale for groundwater schemes at the wellfield and aquifer-basin level. This IWRM-Domain scale contrasts with the definition of “groundwater management units” based around fifth-order (quinery) or higher-order catchment subdivisions (West Coast District Municipality, 2003), which are appropriate only to the management of subsurface water alone at the single-borehole, or at most small well-field, scale.

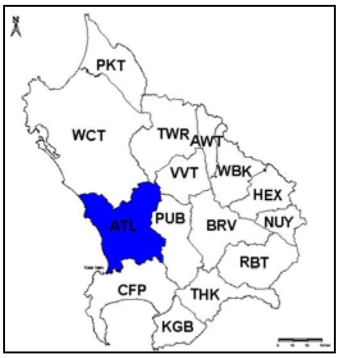


Cape Flats-Peninsula (CFP)

The Cape Flats-Peninsula IWRM domain (CFP) is situated in the far southwestern corner of the Berg WAAS area. The CFP has a total area of 1 685.19 km^2 (**Table 5-1** and **Figure 5-1**) and incorporates the Cape Peninsula, Table Mountain and the Cape Flats that encircle False Bay. Coastlines largely bound the CFP with the Atlantic Ocean on the west and the False Bay on the south. The northern and eastern boundaries follow the G22 quaternary catchment boundaries and enclose the CFP within the G22 catchment. The IWRM boundary deviates from the quaternary boundary in the NW corner of the CFP. A local high in the bedrock occurs inland to the east of Table Bay. The boundary instead follows the best-fitting quintenary boundary that overlies this basement high.

The CFP comprises predominantly wind-blown sediments in the form of coastal dunes and quaternary sediments that overlie basement Malmesbury in the region of the Cape Flats and Cape Granite Suite rocks on the eastern and western margins of this flat central basin. The primary groundwater interest lies in the Cape Flats Primary Aquifer, which flows toward the south along a central, north-south orientated palaeo channel. Topographic highs in the north grading to coastal plains in the south send surface water flow in the same direction as is evident by the south-flowing Kuils River.

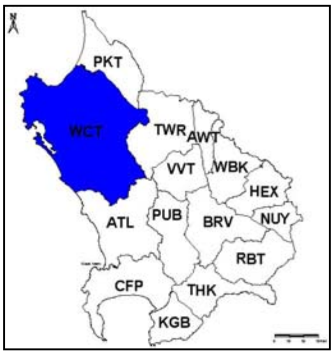
Rock of the lower TMG suite, predominantly Peninsula Formation, outcrop to the west and form the Cape Peninsula, as well as in the Stellenbosch and Jonkershoek mountains in the east. The Peninsula Aquifer is unconfined in the CFP. Run-off and seepage from the eastern mountains and the eastern part of the Cape Peninsula serve as a recharge zone to the Cape Flats Primary Aquifer. The CFP is classified as an IG-IWRM Domain, because the key ground and surface-water scheme development in this domain will be based around the Cape Flats Aquifer.



Atlantis (ATL)

The Atlantis IWRM Domain (ATL) is situated in the southwestern corner of the Berg WAAS area along the West Coast. The ATL is the second largest IWRM Domain in the study area with a total area of 2 092.50 km^2 (**Table 5-1** and **Figure 5-1**), and covers the Atlantis/Malmesbury area. The ATL boundary is made up of the Atlantic coastline and the quaternary catchments that enclose the G21 catchment. The G21A catchment is, however, split where the boundary deviates to accommodate a basement high between the Darling Granite Pluton and Dassen Island, just off the west coast.

The ATL comprises primarily wind-blown sediments in the Atlantis dune fields and Quaternary sediments that overlie the Malmesbury and Cape Granite basement. The area of interest includes the Witsand and Langebaan Formation sediments that outcrop in the north-western quadrant of the ATL and constitute a primary aquifer. Groundwater flow occurs from NE to SW along preferred palaeo channels. Surface water flow occurs in the headwaters of the north-flowing Groen and south-west-flowing Diep rivers. Some surface flow sheds off the weathered surface of the Malmesbury rocks. The ATL is classified as an IG-IWRM Domain, because the key ground- and surface-water scheme development is already based on the Atlantis Aquifer.

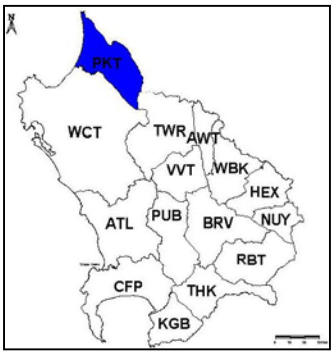


West Coast (WCT)

The West Coast IWRM Domain (WCT) is situated in the western part of the Berg WAAS area along the West Coast. The WCT is the largest of the 15 IWRM Domains and has a total area of 5 113.90 km^2 **(Table 5-1** and **Figure 5-1**). It covers the area between Darling, Vredenburg, Piketberg and Morreesburg. The WCT is bounded on the West Coast by the Atlantic Ocean and by the ATL in the south. The northern and eastern boundaries follow the quaternary catchment boundaries of the Lower Berg River including the G10M, G10K and G10L catchments. The boundary in the north-eastern corner follows the Piketberg-Aurora Megafault as opposed to the catchment boundary so as to exclude the rocks of the TMG in the Piketberg area.

The main surface water in the WCT IWRM Domain occurs in the Lower Berg River and the Groen and Sout rivers, main tributaries to the former. In addition, water sheds off the weathered portions of the Saldanha and Darling Granite Plutons in the north-west and south respectively and the Malmesbury rocks in the east.

A sediment corridor comprising the Witsand, Langebaan and Springfontein Formations transects the WCT from Aurora in the northeast to Langebaan in the southwest, covering the palaeo channels of the proto-Berg and Groen rivers. While surface-water flow is directed toward the north-west, groundwater flow is directed toward the south-west, recharged by the overlying rivers. The WCT is classified an IG-IWRM domain, because the key ground and surface-water scheme development in this domain is based around the Langebaan Road and the Geelbek aquifer systems.

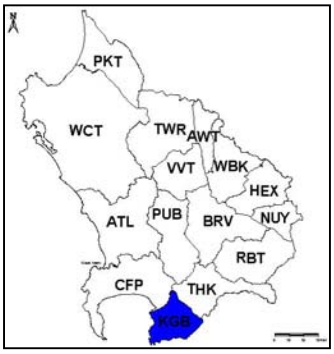


Piketberg (PKT)

The Piketberg IWRM Domain (PKT) is situated in the north-western part of the Berg WAAS area. It is a relatively small domain with a total area of 1 303.42 km^2 (**Table 5-1** and **Figure 5-1**). The PKT is bounded by the Atlantic Ocean on the West Coast and the WCT to the south. The northern boundary follows the Berg WAAS study area boundary, a combination of both quaternary and quinternary boundaries. The eastern boundary follows the TMG-Malmesbury contact that roughly parallels the northern segment of the quaternary catchment boundary separating the G10H and G10K. Surface-water flow occurs from the highlying Piketberg Mountains of the TMG outcrop in the southeast by means of the Verlorenvlei River, through the coastal dunes to the Atlantic Ocean in the northwest.

The PKT comprises both Lower TMG rocks inland and quaternary sediments of the Springfontein and Langebaan Formations with wind-blown dune sands bordering the coast. These sediments are underlain by Malmesbury basement in the northern half of the PKT and southwest of the Piketberg-Aurora Fault extension. It is highly likely that the Peninsula Formation extends along strike below the quaternary sediments towards the coast. Groundwater flow occurs in the Peninsula Aquifer from the southeast toward the sea, recharging the Sandveld Aquifer that extends NE-SW along the Verlorenvlei palaeo channel.

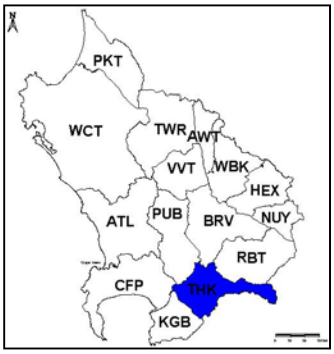
The PKT is classified as a FR+IG-IWRM Domain, because future integrated ground and surface-water scheme development in this area will be based around the TMG aquifers in the Piketberg range and the postulated palaeo channel linking the Velorenvlei drainage to the coastal plain south of Elands Bay.



Kogelberg (KGB)

The Kogelberg IWRM Domain (KGB) is located in the far southern corner of the Berg WAAS area on the South Coast. It has a total area of 767.06 km^2 (**Table 5-1** and **Figure 5-1**). Its southern half is bounded by the Atlantic Ocean with False Bay in the West. The G40 catchment boundary bounds the north-western part of the KGB, while the Groenlandberg Fault bounds the north-eastern part. The south-eastern boundary follows the Bot River, which also bounds the Berg WAAS domain. This IWRM boundary on the north side is chosen to follow a natural compartment formed by the above-mentioned faults.

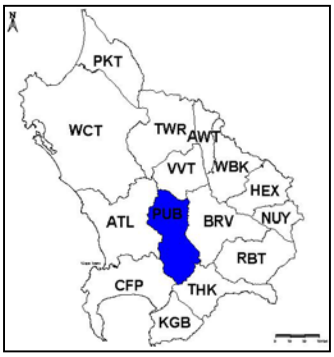
The KGB contains rocks from both the Table Mountain and Bokkeveld Groups. A broad zone of fault splays transects the southern part of the KGB. Groundwater flow occurs in the Peninsula and Nardouw aquifers. Inland surface water flows to the north-east toward the Theewaterskloof Dam, while surface water in the mountains bordering the coast, flows toward the sea. The KGB is classified as a FR-IWRM Domain, because the key ground- and surface-water scheme development will in future be based around the TMG aquifer system (Nardouw and Peninsula) in the region around the Steenbras reservoir.



Theewaterskloof (THK)

The Theewaterskloof IWRM Domain (THK) is located in the south-eastern part of the Berg WAAS area, and contains the Theewaterskloof Dam, the largest dam in the study area. The THK has a total area of 1 138.52 km^2 (**Table 5-1** and **Figure 5-1**). The overall Berg groundwater study area bounds the south-east and the KGB along the Groenlandberg Fault bounds the south. The northern boundary follows the quaternary catchment boundaries that enclose the H60 catchment.

Surface water flow of the Riviersonderend River, Bot River, Du Toits River and Wildevyebooms River is directed toward the Theewaterskloof Dam, located in a fault-bounded Bokkeveld basin. Groundwater flow occurs in both the Peninsula and Nardouw aquifers, channelled by the Steenbras-Brandvlei Megafault (SBM; see **Section 3.2.2)** in the north-west and the Robertson-Rooiels Megafault (RRM, see **Section 3.2.2**) in the south-east. The THK is classified as a FR-IWRM Domain, because the key ground and surface-water scheme development will be based around the TMG aquifers and the region around the Theewaterskloof reservoir.



Paarl – Upper Berg (PUB)

The Paarl–Upper Berg IWRM Domain (PUB) is located in the central part of the Berg WAAS area. It has a total area of 1 356.25 km^2 (**Table 5-1** and **Figure 5-1**). It is bounded by the ATL and CFP in the east and the THK in the south. The south-eastern boundary follows the quaternary catchment boundaries of the upper G10 catchment except at the head of the Franschhoek Valley where the TMG-alluvium contact is favoured. The eastern contact follows the Du Toits Fault to the TMG-Malmesbury contact, which it then follows to the northern boundary on the divide between the G10D and G10F catchments.

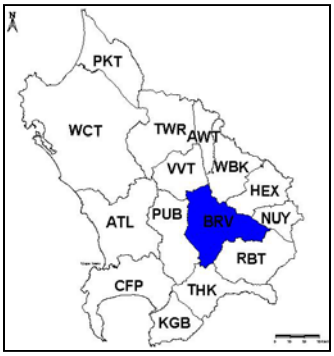
Surface water flows in the Klein- and Groot-Drakenstein mountains, and Franschhoek mountains to the south form the headwaters of the Upper Berg River. Groundwater flow occurs in the Peninsula Formation and along a series of transecting, north-west south-east orientated faults with short orthogonal crosscutting faults into the surface water flow of the Upper Berg River. This IWRM Domain may be classified as a FR-IWRM Domain, because of the dominance of the TMG in this area. However, the base of the TMG is at a generally high elevation, and groundwater scheme development is, for most part, neither technically nor environmentally feasible.

Robertson (RBT)

The Robertson IWRM Domain (RBT) is located in the eastern portion of the Berg WAAS study area. It has a total area of 1 385.42 km^2 (**Table 5-1** and **Figure 5-1**). The THK in the south and the overall Berg groundwater study area in the east bound the RBT. The northern boundary follows the contact between the rocks of the Malmesbury basement and the overlying Peninsula Formation becoming the quaternary boundary enclosing the H40D, -E, -F and –H quaternary catchments.

The Breede River flows from west to east through the RBT, into which surface water from the Waboomsberge in the west and the Riviersonderend Mountains in the south is drawn. The RBT hosts rocks of the Witteberg, Ecca and Uitenhage Groups, with rocks of the Malmesbury on the northern side of the southward down-thrown extensional Worcester Fault. Quaternary sediments overlie these rocks and alluvium borders the Breede River. Groundwater flow occurs in the Peninsula and Nardouw Aquifers into deep confinement below the rocks of the Bokkeveld and Witteberg in the Villiersdorp Syncline (see Section **3.2.1**). It is believed that this circulating deep-confined water may be the source for the Brandvlei Hot Spring.

Groundwater from the TMG aquifers is mainly accessible along the western and southern margins of the RBT. However, for the most part, it is groundwater in the alluvium bounding the Breede River that is mainly used. The RBT is therefore classified as a FR+IG- IWRM Domain, but is not of particular interest to this study, except insofar as deep groundwater circulation in the TMG beneath this domain may provide an explanation for the high temperatures of the Brandvlei Hot Spring.

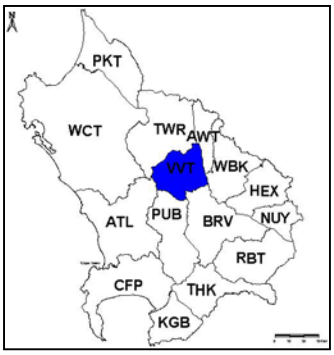


Brandvlei (BRV)

The Brandvlei IWRM Domain (BRV) is located in the central eastern portion of the Berg WAAS area. It has a total area of 1 582.03 km ^{2} (**Table 5-1** and **Figure 5-1**). The PUB, THK and RBT bound the BRV in the south. The northern boundary follows the northern H10F quaternary boundary, deviates along the Peninsula Malmesbury contact to the northern H10H quaternary boundary before returning to the contact.

The BRV consists of rocks of the Table Mountain Group with inliers of Malmesbury and Granite basement in the bounding mountains, and quaternary sediments of the Bredasdorp Group in addition to alluvium bounding the Upper Breede River basin. The quaternary sediments are underlain by the Malmesbury Group north of the transecting Worcester Fault and by the upper TMG sequence and Bokkeveld Group south of the Worcester Fault.

Surface water drains from the bounding watersheds toward the Breede River and toward the east. The Jan Du Toits River feeds the Breede River from the north while the Molenaars River and Holsloot River feed it from the south. The rivers supply water to the Breede River alluvial aquifer, which is also fed by groundwater flow from the Peninsula Aquifer that makes up the bounding mountains. The BRV is classified as a FR+IG-IWRM Domain, because the key surface- and groundwater scheme development in this domain will likely be centred around the Breede River alluvial aquifer in the Rawsonville area, which however, has significant lateral recharge inputs from TMG aquifers along the western IWRM boundary.

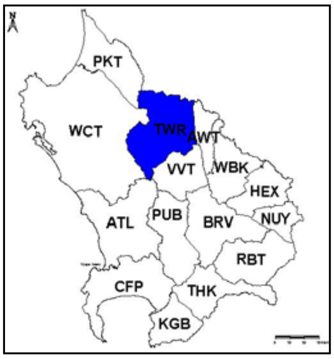


Voëlvlei - Tulbagh (VVT)

The Voëlvlei-Tulbagh IWRM Domain (VVT) is located in the central part of the Berg WAAS area. It has a total area of 933.20 km^{2} (**Table 5-1** and **Figure 5-1**). The VVT is bounded in the south by the ATL, PUB and BRV. The northern boundary follows the northern part of the G10E and –F quaternary catchments. The contact between the Peninsula Formation and the Malmesbury Group forms the eastern boundary of the VVT. The VVT includes the Tulbagh Valley consisting of quaternary sediments of the Bredasdorp Group and Strandveld Formation, underlain by the Malmesbury Group and north-south trending dolerite and greenstone dykes, Elandskloof Mountains and the Malmesbury basin surrounding the Voëlvlei Dam.

The Elandskloof Mountains consist of rocks of the Table Mountain Group that are displaced by a sequence of north-west-south-east-orientated faults. Surface water flow occurs in the Klein Berg River, starting in the Tulbagh Valley, through the (and supplemented by the) Elandskloof Mountains and into the Berg River in the west. Groundwater flows along the axis of the Waterkloof Syncline (see **Section 3.2.1** above) and exits as springs into surface water flow.

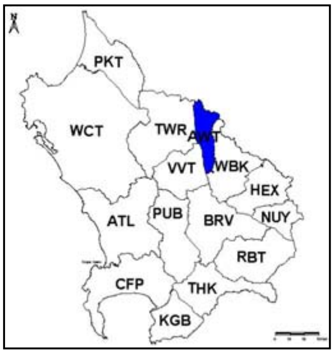
The VVT is classified as a FR-IWRM Domain, because the key surface and groundwater scheme development in this domain will likely be based around the TMG aquifers in the Waterval Syncline and possible future pumped-storage links with the Voëlvlei reservoir.



24 Rivers (TWR)

The 24 Rivers IWRM Domain (TWR) is located in the central northern part of the Berg WAAS area. It has a total area of 1 839.88 km^2 (**Table 5-1** and **Figure 5-1**). The TWR is bounded by the PKT and WCT in the west, the ATL, and VVT in the south and the overall Berg groundwater study area in the north. The western boundary follows the axis of the Koue Bokkeveld Anticline (see **Section 3.2.1**) along the best-fitting quaternary boundaries. The TWR consists of rocks of the Table Mountain Group in the mountains in the east and the Malmesbury Group in the west. Surface water flow occurs along the Olifants River Syncline and in the 24 Rivers region over the Malmesbury bedrock. Groundwater in the Nardouw Aquifer flows northward into the Olifants River Syncline. Groundwater in the Peninsula Formation flows both into the Olifants River Syncline and southward into the Tulbagh-Ceres Valley.

The TWR is classified as a FR-IWRM Domain, because the only significant ground- and surface-water scheme development in this domain is likely to be based around the TMG aquifers in the southern part of the Olifants River Syncline, linked by canal to the Voëlvlei reservoir in the VVT domain.



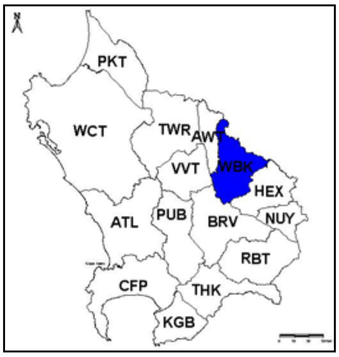
Agter Witzenberg (AWT)

The Agter Witzenberg IWRM Domain (AWT) is located in the central northern part of the Berg WAAS area. It is the smallest of the IWRM Domains with a total area of 498.23 km^2 (**Table 5-1** and **Figure 5-1**). It is bounded by the TWR and VVT in the west and the overall Berg groundwater study area to the north. The eastern boundary follows the axis of the Hansiesberg Anticline (see **Section 3.2.1** above) along the best-fitting quinternary catchment boundaries.

Surface water flows along the axis of the Agter Witzenberg Syncline (see **Section 3.2.1** above). Groundwater flow occurs from the east and the west into the center of the AWT toward the Agter Witzenberg Syncline axis. Groundwater in the Peninsula Aquifer flows toward the south and flows to the north in the Nardouw Aquifer.

The AWT is classified as a FR-IWRM Domain, because the key ground- and surface-water scheme development in this domain is likely to be based around the TMG aquifers in the Agter-

Witzenberg Syncline, possibly linked to the greater Ceres basin in the adjacent WBK domain (see below).

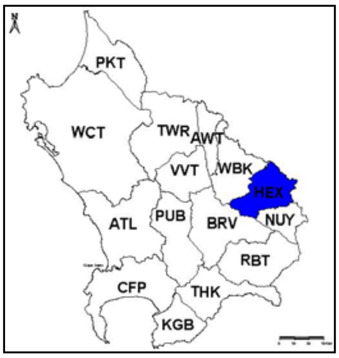


Warm Bokkeveld (WBK)

The Warm Bokkeveld IWRM Domain (WBK) is located in the central northern part of the Berg WAAS area. It has a total area of 1 105.56 km^2 (**Table 5-1** and **Figure 5-1**). The AWT in the west, the BRV in the south, and the overall Berg groundwater study area in the north bound it. The eastern boundary follows the quaternary catchment boundaries enclosing the H10 catchment.

The WBK contains the southern portion of the Warm Bokkeveld. Surface water flow drains from the bounding mountain ranges into the Warm Bokkeveld and out through the Mitchell's Pass in the southwestern corner. Groundwater flow in the Nardouw Aquifer occurs from the higher lying Table Mountain Group rocks in the bounding mountains into the lower lying valley where it is confined below the Bokkeveld Group. Groundwater flow in the Peninsula Aquifer flows toward the Hex River Mountains in the east.

The WBK is classified a FR-IWRM Domain, because the key ground- and surface-water scheme development in this domain is likely to be based on the TMG aquifers underlying its western and southern borders.

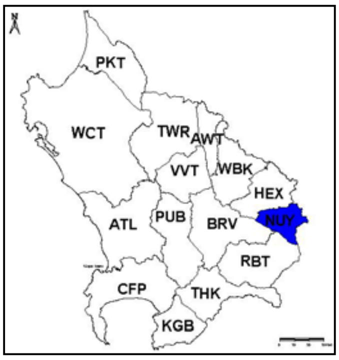


Hex River (HEX)

The Hex River IWRM Domain (HEX) is located in the north-eastern portion of the Berg WAAS area. It has a total area of 921.31 km^2 (**Table 5-1** and **Figure 5-1**). The WBK in the northwest, the BRV in the south, and the overall Berg groundwater study area in the north bound it. The eastern boundary follows the quaternary catchment boundaries that enclose the H20 catchment. The boundaries contain the Hex River Valley, bounded by the TMG-dominated Hex River Mountains and the Kwadouwsberge.

Surface water drains into the Hex River Valley and flows to the south-west via the Hex River into the Breede River. Some surface water is caught up in the quaternary sediments and alluvium bounding the Hex River. Groundwater flow in the Peninsula Aquifer exits as springs and feeds the surface water run-off into the Hex River, while groundwater in the Nardouw Aquifer flows into confined storage in the center of the valley.

Although both surface water and groundwater flow are of interest in this IWRM Domain, the rocks of the TMG predominate over the alluvium in terms of water capacity and as such the HEX is classified a FR-IWRM Domain. The future development of the deeper Peninsula Aquifer along the northern limb of the Hex River Syncline presents a significant potential.



Nuy (NUY)

The Nuy IWRM Domain (NUY) is located in the eastern portion of the Berg WAAS area. It is the second smallest IWRM Domain and has a total area of 516.04 km^2 (**Table 5-1** and **Figure 5-1**). It is bounded by the HEX in the north and west, the BRV and RBT in the south and the overall Berg groundwater study area in the east. Surface water flow occurs southward toward the Breede River by means of the Nuy River and eastward out of the study area into the Koo Valley. Groundwater flow in the Nardouw Aquifer feeds the Nuy River while flow in the Peninsula Formation enters confinement in the Koo Valley.

The NUY is classified a FR-IWRM Domain, because the TMG aquifer systems at the western end of the Koo Valley Syncline are likely to constitute the key basis of a future ground and surface-water scheme development.

6. DETAILED MODEL DOMAINS

During the Phase 1 of the Berg WAAS Study, nine areas were chosen as additional model domains for groundwater evaluation modelling (DWAF, 2005. Figure 1.2). It was recommended in the Inception Report that additional numerical models should be developed in specific domains within the TMG Aquifer where extensive groundwater use and current or proposed surface water use might result in conflicting use during the compulsory licensing process (DWAF, 2005). The areas were identified and tasked according to **Table 6-1.**

Table 6-1 Detailed Model Domains recommended in the Inception Report

Task	Aquifer Type	Model Domain (Region)
Task 13	Intergranular	Cape Flats Aquifer
Task 14a	Sandveld - Intergranular	Langebaan – Die Vlei
Task 15a	Sandveld – Intergranular & TMG – Fractured	Worcester – Breede Valley
Task 15b	TMG – Fractured	Tulbagh – Ceres Area
Task 15c	TMG – Fractured	Hex River Mountains Area
Task 15d	TMG - Fractured	Piketberg Area

The conceptual model for each of these detailed model domains (**Table 6-1**) is considered here in preparation for the model development, the results of which will be documented in the individual Model Reports that form part of the deliverables of this study. In each of these detailed model domains, the common Integrated Water Resource (IWR) modelling agreements are:

- First order reconciliation of
  - Storage capacity
  - Recharge
  - Natural aquifer discharge taking into account both surface and groundwater
  - Run-off
  - Rain volumes (inverse mass balance solution)
  - Potential Yield
- Identification of areas of potential high impact of aquifer abstraction on stream flow
- Identification of key data gaps and uncertainties in quaternary scale resource evaluation.

In order to achieve the IWR agreement, the following parameters are taken into account in the delineation of the detailed model domains:

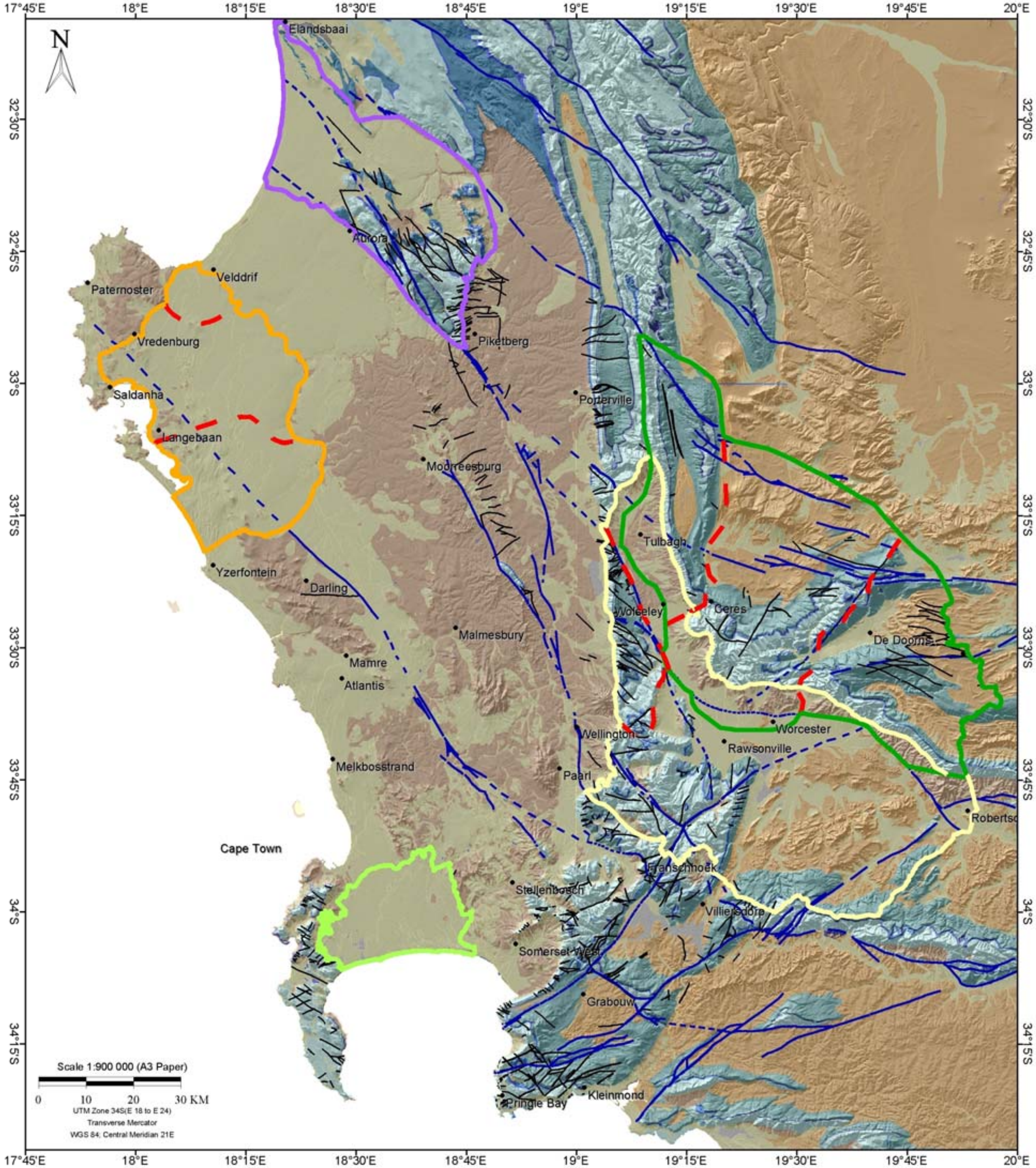
- Surface and bedrock topography
- Surface water drainage and spring occurrences
- High precipitation areas
- Geological contacts, formations and lithological composition
- Fold structures, fault displacements
- Aquifer types, outcrop location and area
- Subsurface aquifer/aquitard geometry

- Groundwater flow paths
- Possible interbasin transfers of both surface water and groundwater.

Interbasin transfers of both surface water and groundwater between the Tulbagh – Ceres and Hex River Mountains detailed model domain areas, require that these areas be modelled in parallel as a single model. The conceptual model retains the individual subdomains separating areas of recharge and discharge for the three aquifers of interest respectively. Similarly, the exchange of groundwater and surface water between the Breede Alluvium and the TMG Aquifer in the Worcester – Breede River Valley requires that modelling of the two systems is done co-jointly. The revised detailed model domains (See **Table 6-2** below) are illustrated in **Figure 6-1.**

Table 6-2 Revised Detailed Model Domains

Task	Aquifer Type	Model Domain (Region)
Task 13	Intergranular	Cape Flats Aquifer
Task 14a	Sandveld - Intergranular	Langebaan Road – Geelbek Aquifer
Task 15a	Sandveld – Intergranular & TMG – Fractured	Worcester – Breede River Valley, Du Toits and Riviersonderend Mountains (Breede River Alluvium)
Task 15b&c	TMG – Fractured	Winterhoek – Koo Valley (Witzenberg-Nuy)
Task 15d	TMG – Fractured & Sandveld – Intergranular	Piketberg Area towards the coast



LEGEND

- Towns
- Faults
- Hydrotects

MODEL DOMAINS

- Piketberg
- Langebaan
- Cape Flats
- Breede Alluvium
- Witzenberg - Nuy
- Model Sub-domain

(Refer to Figure 5.1 for geology legend)

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

DETAILED MODEL DOMAINS

FIGURE 6.1

6.1 CAPE FLATS AQUIFER

This study aims to add value to the previous work done in the Cape Flats area in order to assess the aquifer as a bulk water source for the City of Cape Town (DWAF, 2005). Previous work done in the Cape Flats area has been repeatedly reviewed in the past ten to fifteen years and includes amongst others those works listed in **Table 6-3**.

Table 6-3 Previous studies done in the Cape Flats Area

Source	Year	Study
DWAF	1980's	Comprehensive pumping tests on the Cape Flats Aquifer
Rogers, J.	1980	Aquifer structure in the form of a transmissivity distribution map that conflates hydraulic conductivity and thickness into a single parameter
Rogers, J.	1980	Database of information on the total thickness of the Sandveld Group, and the subsurface geomorphology of the basement-Sandveld unconformity, relative to present mean sea level
Hay, E.R.	1981	Cross-sectional information on the thickness and geometry of the main Sandveld units within the proto-Kuils River palaeovalley
CSIR (Fraser and Weaver)	2000	"Groundwater Impact Scoping for the Cape Flats Aquifer"
CSIR (Fraser and Weaver)	2000	"The Cape Flats Aquifer: Bulk Water for Cape Town now"
City of Cape Town	2001	IWRM study indicating the cost of utilizing water from the Cape Flats Aquifer; (R162 million with R10 million annual operating costs)

6.1.1 Motivation

During the late 1980's and 90's increasing informal settlement and expansion of the urban and industrial base has increased the threat to the aquifer from human and industrial waste as well as created a flood management problem in the township and informal settlement areas. Floods result from a high groundwater table during winter that is exacerbated due to increased stormwater runoff and ponding in topographic lows.

The decentralized development of this aquifer lends itself to solving both the social and the natural hazard described above. The active over abstraction of water in the summer for irrigation of sports fields and green open spaces, possible use as non-potable supply to flush toilets, fight fires, create artificial wetlands or recreation areas in natural lows *inter alia* can contribute to the holistic solution of water resource management.

6.1.2 Conceptual Model

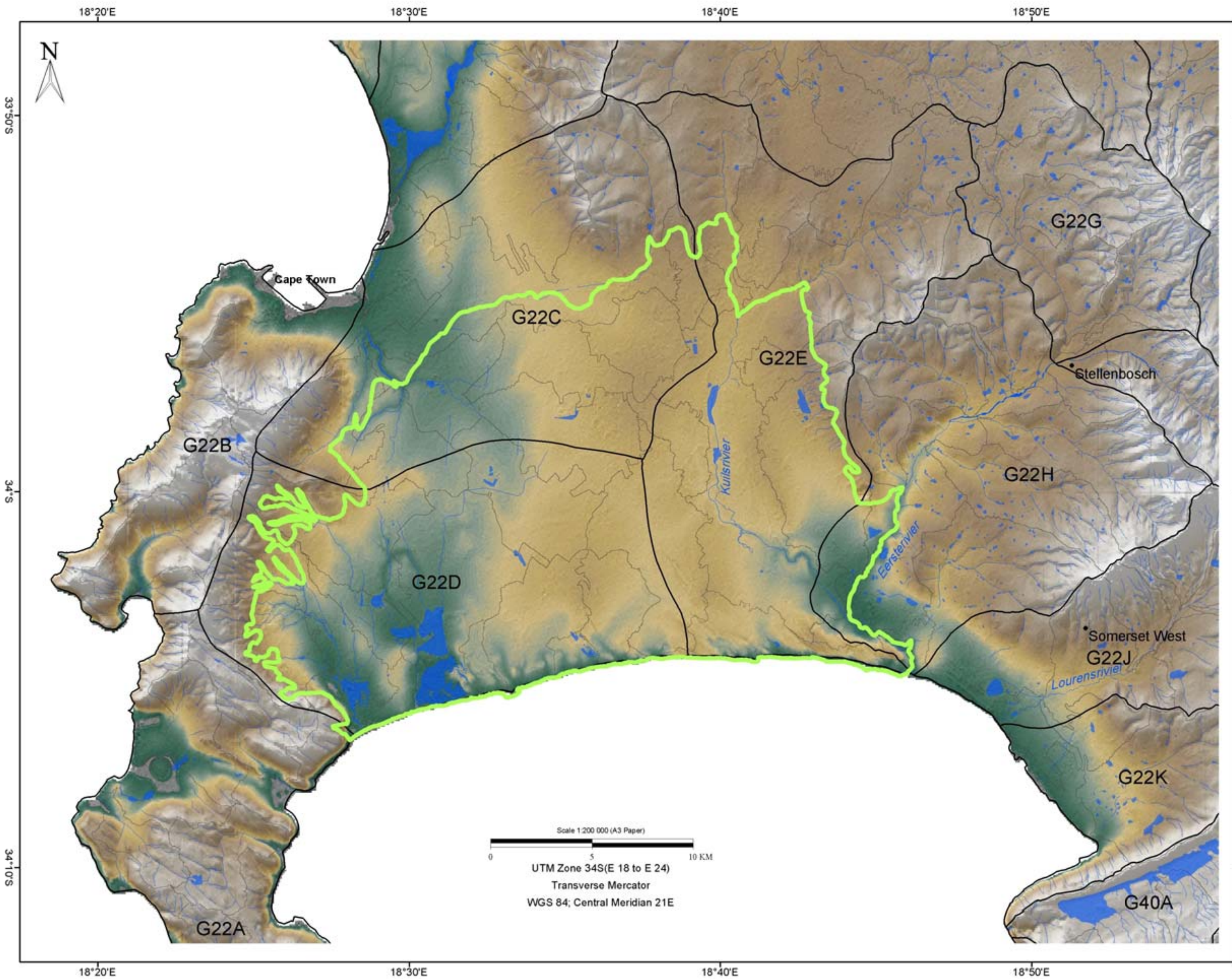
The Cape Flats covers a large area in excess of 400 km^2 (Hay, 1981, DWAF, 2005), extending from False Bay in the south to the Tygerberg Hills in the northeast and Milnerton in the northwest (See **Figure 6-2**). It is bounded by Table Mountain in the west and the hills of Kanonkop at Brackenfell in the east. As the name suggests, the topography is relatively flat with elevations ranging from 0 mamsl in the south to only 110 mamsl in the northeast. The Cape Flats area is largely urbanised as part of the greater Cape Town Metropolitan Area and is traversed by an extensive road and railway network, including the N1 that heads in the direction of Paarl, and the N2 that heads in the direction of Somerset West.

Surface water flow is controlled by the surface topography and trends north to south across the Cape Flats Model Domain (See **Figure 6-2**). Higher rainfall occurs in the mountains bounding the Cape Flats Model Domain including Table Mountain in the west, the Hottentots Holland and Stellenbosch environs to the east, and the Durbanville Hills to the north-east, which have the highest rainfall. The Kuils River is sourced in the Durbanville/Tygerberg Hills in the eastern part of the area and flows southward till it joins with the Eerste River, which flows from the Jonkershoek Mountains east of the area to the coast in False Bay. The Lotus rivers (Little and Big) are sourced from within the Cape Flats and drain into Zeekoevlei. The Diep River also sources from within the Cape Flats aquifer to the west of the Lotus and Zeekoevlei, and runs approximately north-south towards its discharge point at the ocean. The Elsieskraal River has its origin in the Tygerberg Hills to the north-east of the study area, and drains in a west-south-west direction. Near the intersection of the N2 and the 'Cape Town southern line' railway line, the Elsieskraal joins the east-flowing Vyekraal River, the source of which is within the Cape Flats area, and then these join the north flowing Swart River. The Swart River then flows north-west and drains to Table Bay.

The steep, bounding mountains to the east and west of the Cape Flats are built from resistant quartzititc sandstones belonging to the Peninsula Formation of the Table Mountain Group (see **Figure 6-3**). Weathered rocks of the Malmesbury Group and the Cape Granite Suite, forming an undulating, hilly terrain, largely covered by vineyards, dominate the northern part of the area. The central part of the Cape Flats is a narrow low-lying coastal plain covered by un-vegetated dunes with older vegetated dunes further inland and on the flanks.

Water-level information points are clustered in the central portion of the Cape Flats area with some scattered points in the north and on the eastern and western flanks (See **Figure 6-4**). The piezometric map developed from these data points illustrates that the water level relative to mean annual sea level is higher in areas of raised topography around the Durbanville/Tygerberg Hills, Stellenbosch Mountains and environs. Water levels are higher in the footslopes of mountains to the east of the Cape Flats than in the footslopes of Table Mountain to the west. On the Cape Flats themselves, where the topography is relatively even, the water levels decrease toward the coast.

Groundwater flow occurs in the relatively thin Cape Flats Aquifer, which straddles a poorly defined quaternary boundary between the G22C (Table Bay) and G22D (western False Bay) catchments, and overlies aquiclude clays above the weathered Malmesbury and granite basement rocks. The near-surface groundwater-flow direction parallels the surface water drainage, which flows directly on top of the aquifer. Groundwater flows generally from the higher lying outcrops of basement Malmesbury shales in the north-east near Durbanville, branching around the G22C/D divide toward Table Bay to the NW and the False Bay coast to the south (see **Figure 6-5**). Studies of the basement topography reveal what is suspected to be a palaeo channel of the Kuils River aligned N/S roughly in the center of the model domain (See **Figure 6-5**). Coarser-grained deposits of fluvial sands and gravels within the axis of this palaeo channel provide a preferred flow-path southwards across the G22C/D divide, for some proportion of the groundwater recharge along the northern boundary of the model domain.



LEGEND

- Towns
- Rivers
- Dams
- Cape Flats Model area
- Quatenary Catchments
- Standars basins

Elevation (mamsl)

- 1 - 30
- 30 - 55
- 55 - 85
- 85 - 195
- 195 - 305
- 305 - 550
- 550 - 1380

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

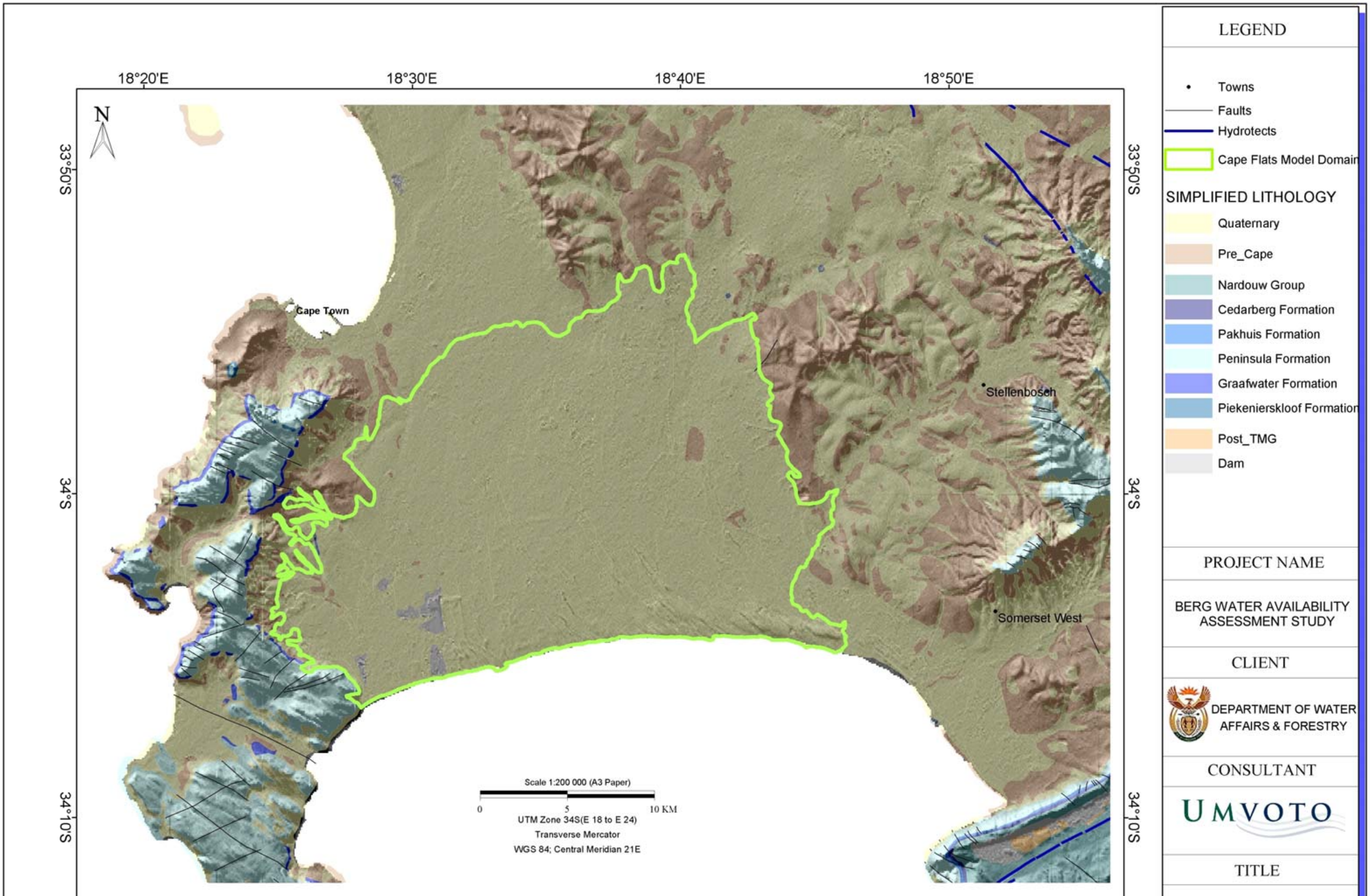
CONSULTANT

UMVOTO

TITLE

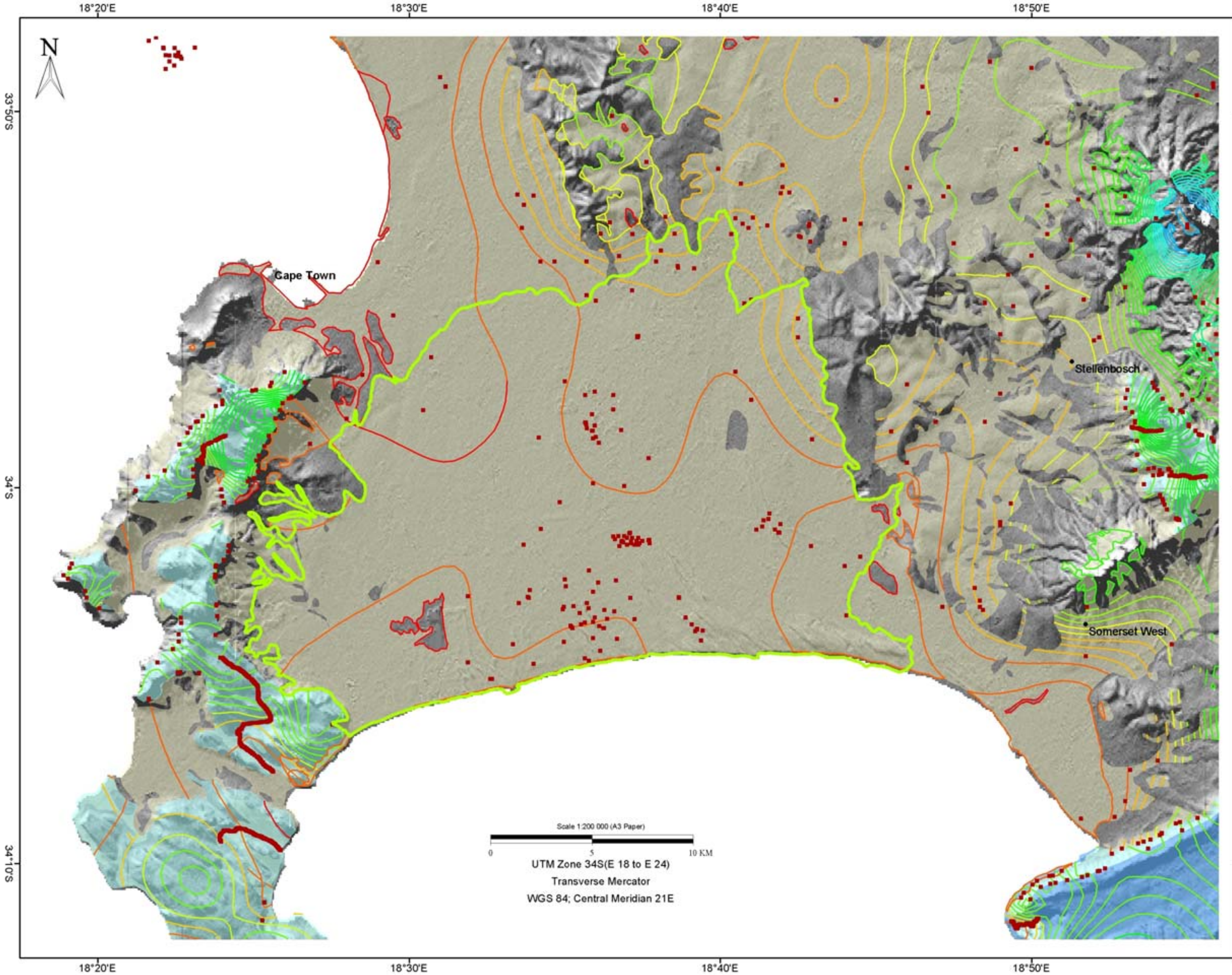
LOCALITY AND DRAINAGE CAPE FLATS

FIGURE 6.2



GEOLOGY OF THE CAPE FLATS AREA

FIGURE 6.3



LEGEND

Towns
Water Level Points
Cape Flats Model Domain
Sandveld Outcrop
Peninsula Outcrop
Peninsula Suboutcrop

Water Level (mamsl)

-243. - 0
0 - 50
50 - 100
100 - 150
150 - 500
500 - 600
600 - 700
700 - 800
800 - 1017

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

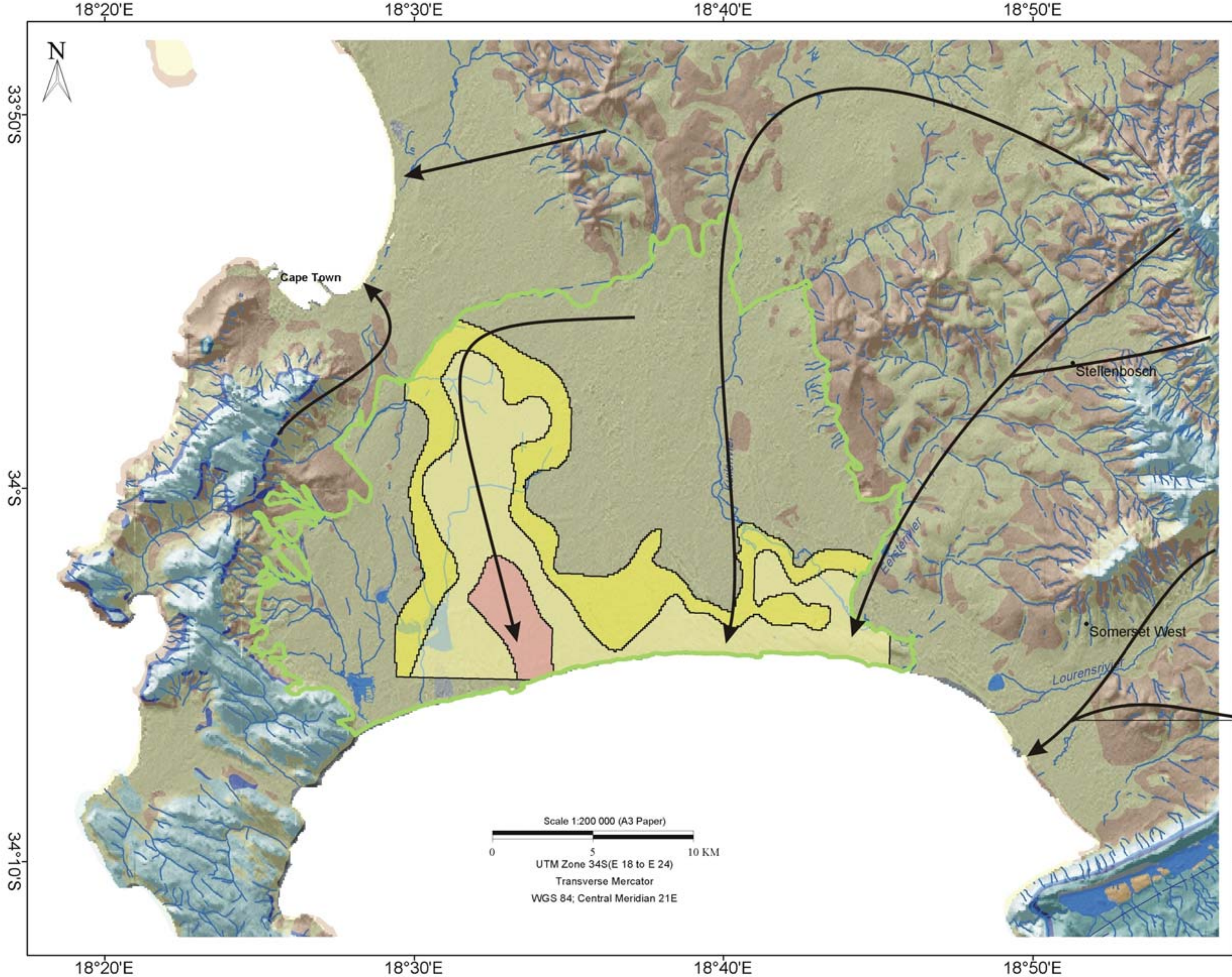
CONSULTANT

UMVOTO

TITLE

WATER LEVEL DATA AND PIEZOMETRIC MAP IN THE CAPE FLATS

FIGURE 6.4



LEGEND

- Towns
- Rivers
- Hydrotects
- Cape Flats Model area

Bedrock Elevation (mamsl)

- -20_-30
- 0_-20
- 10_0

(For geology legend Figure 5.1)

- Flow paths

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

CONCEPTUAL MODEL OF CAPE FLATS

FIGURE 6.5

The Cape Flats Aquifer has been extensively studied by various different individuals (See **Table 6-3). Figure 6-6** illustrates a vertical section through the Cape Flats after Hay, (1981), wherein Hay describes the 5 distinct different units that make up the sediments overlying the basement. However the lateral continuity of the Cape Flats sediments is questionable, and varying geological interpretations have been suggested (Henzen, 1973, Wessels and Greef, 1980).

Since the rivers flow on the aquifer there is direct interaction between surface-water and groundwater flow. In winter, elevated rainfall and surface water run-off recharges the groundwater in the aquifer. The water table rises as winter continues and as summer approaches a reversal of the flow direction takes place. By this time, the water table is sufficiently high for the groundwater in the aquifer to recharge the overlying rivers. The main rivers flow through the Cape Metropolitan Area and have in part been channelized and lined with concrete. These areas will have implications during the modelling process in terms of surface water/ groundwater interaction.

This direct interaction between surface water flow in the rivers and groundwater flow in the aquifer has significant implications with regard to contamination of the aquifer by pollution in the form of industrial and urban waste in the rivers.

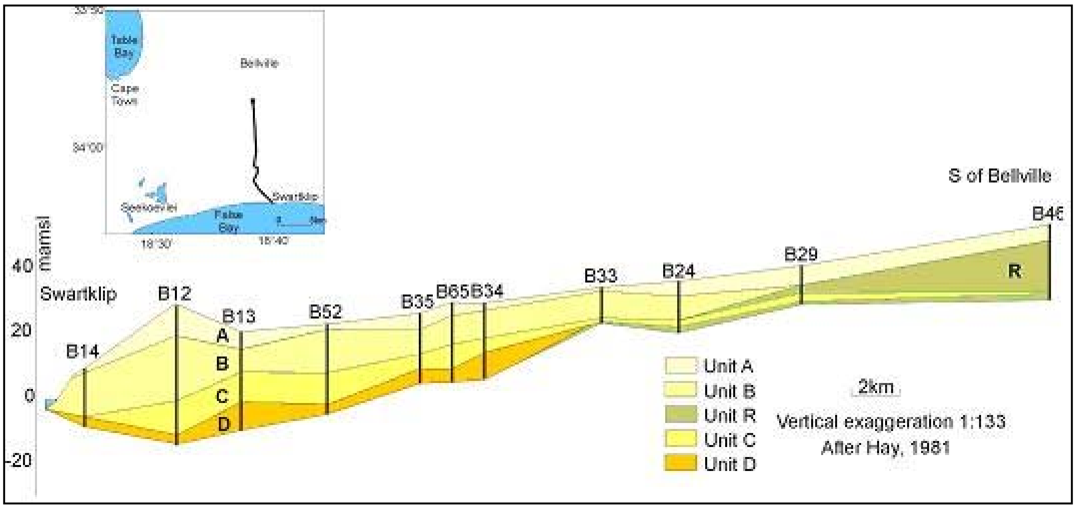


Figure 6-6 Vertical section of the Cape Flats (after Hay, 1981) illustrating the different units making up the Cape Flats Aquifer,

D= basal marine unit (angular to well rounded, poorly sorted slightly muddy gravely Sand to slightly muddy sandy Gravel), A, B, C = overlying Aeolian units (A= recently wind-blown surficial moderately to moderately well-sorted medium to fine sands, B= calcrete layers in close association with calcareous clayey horizon, C=clean quartzose, well sorted fine to medium sand), R = fluvial unit (medium to coarse, gravely, angular sand plus minor feldspar overlain by fine sandy mud, clay and peat).

6.2 LANGEBAAN ROAD AQUIFER SYSTEM – ELANDSFONTEIN AQUIFER SYSTEM

The area is predominantly rural, with elevated population levels in the coastal towns that support the industrial areas around the Saldanha Harbour facilities (see **Figure 6-7**). The coast is well connected by a network of tarred (R27, N7) and dirt (farm) roads.

Previous work done in the area covered by the Langebaan Road Aquifer detailed Model Domain is tabled in **Table 6-4**.

Table 6-4 Langebaan Road Reports

Source	Year	Study
Weaver	1973	Drilling results around the future Saldanha Steel Project site
De La Cruz	1978	Geological report providing background information on the Langebaan Road Aquifer
Schreuder	1979	Regional hydrogeological investigations into the coastal Sandveld region around the mouth of the Berg River mostly postdate a first hydrocensus investigation (Schreuder, 1979), carried out to obtain an overview of the groundwater potential in the area between the Berg and Olifants rivers This initial study was followed by a regional geophysical investigation of the primary aquifers, which was restricted in its geographic scope to the area between Elands Bay, Lamberts Bay and Graafwater, north of the present study area
Vandoolaeghe	1982	Technical report
Rogers	1982	Geological report providing background information on the Elandsfontyn Aquifer
DWAF departmental report and a PhD thesis by Timmerman, Timmerman and Vandoolaeghe (1985)	1985 1987 1985	The primary documentary sources for the Langebaan Road Aquifer and related well-field proposal

6.2.1 Motivation

The West Coast Aquifers were recently investigated as part of the DWAF project, “Pre-Feasibility Study of Potential Water Resources for the area served by the West Coast District Municipality”. The associated assessment of the groundwater potential (Woodford et al., 2003) is critically reviewed as part of this present investigation.

The conceptual model for the area around the Lower Berg River depends upon the hydrostratigraphic re-interpretation of the high permeability units at the base of the Sandveld Group, in the context of the Late Cenozoic evolution of the palaeodrainage systems of the Berg and its southern tributary, the Sout River. The present conceptual model for the Langebaan Road and Elandsfontein Aquifer Systems (SRK, 2003, Fig. 15) is based upon a pattern of bed-rock elevation (op. cit., Fig. 16) that is not readily explained by any common geomorphological process, and overlooks the potential for lateral recharge via up-gradient connections to surface-water sources in the lower Berg and Sout-Groen river channels.

The actual extent and 3D geometry of the aquifer therefore requires critical re-examination, since it is likely to be larger than currently thought, and the lateral recharge relationships along the eastern boundary are probably more complex than previously considered. The impact of these revisions on resource planning or optimisation using Artificial Recharge and Storage Recovery will be significant, especially since it is known that the mean annual recharge of the West Coast Aquifers is low relative to their typical storativity.

6.2.2 Conceptual Model

The Langebaan – Geelbek area is located on the West Coast dominated by wave-cut terraces overlain by aeolian dunes. Intrusive granitic plutons are responsible for the raised areas in the regions surrounding Vredenburg in the west and Darling in the south.

The drainage networks in the Langebaan area are predominantly non-perennial in character. The Sout and Groen rivers drain toward the north into the Lower Berg River (see **Figure 6-7**). These perennial river reaches mark the eastern and northern boundary of the Langebaan-Geelbek area. The rivers themselves are sourced in the high-lying areas to the south and the east, and are supplemented by water shedding off the Malmesbury outcrops, the formation that underlies the whole Langebaan-Geelbek area except where the granitic plutons have intruded (see **Figure 6-8**).

The Langebaan-Geelbek area has a well-spread distribution of water-level data points (see **Figure 6-9**). The piezometric map drawn from these data points reveals that the water levels relative to mean annual sea level are higher in the areas immediately adjacent to the intrusive Granite plutons as well as the Malmesbury outcrop basins to the east. The water levels become lower toward the coast. The piezometric map also indicates the existence of a channel of lower water levels traversing the Langebaan-Geelbek area north-east to south-west from the Berg River to Saldanha Bay at the entrance of the Langebaan Lagoon. This low in water levels is located in the region of the Langebaan Road Aquifer palaeo channel of the "proto-Berg" River (Hendey, 1982; Umvoto, 1997).

In the current scheme (Woodford et al., 2003), the two larger Sandveld aquifer systems situated in palaeo-drainage channels south of the Berg River are designated as (1) the "Langebaan Road Aquifer System" (op. cit., p.38-43; henceforward LRAS) and the "Elandsfontein Aquifer System" (op. cit., p. 43-46). The latter aquifer system is named after the farm Elandsfontyn 349, as a modernized form of the archaic Dutch name. During an exploratory phase to delineate this aquifer, DWAF drilled a number of boreholes (more than 12 on Elandsfontyn alone), which penetrated the maximum thickness of gravel and clay units of the Elandsfontyn Formation (Rogers, 1982).

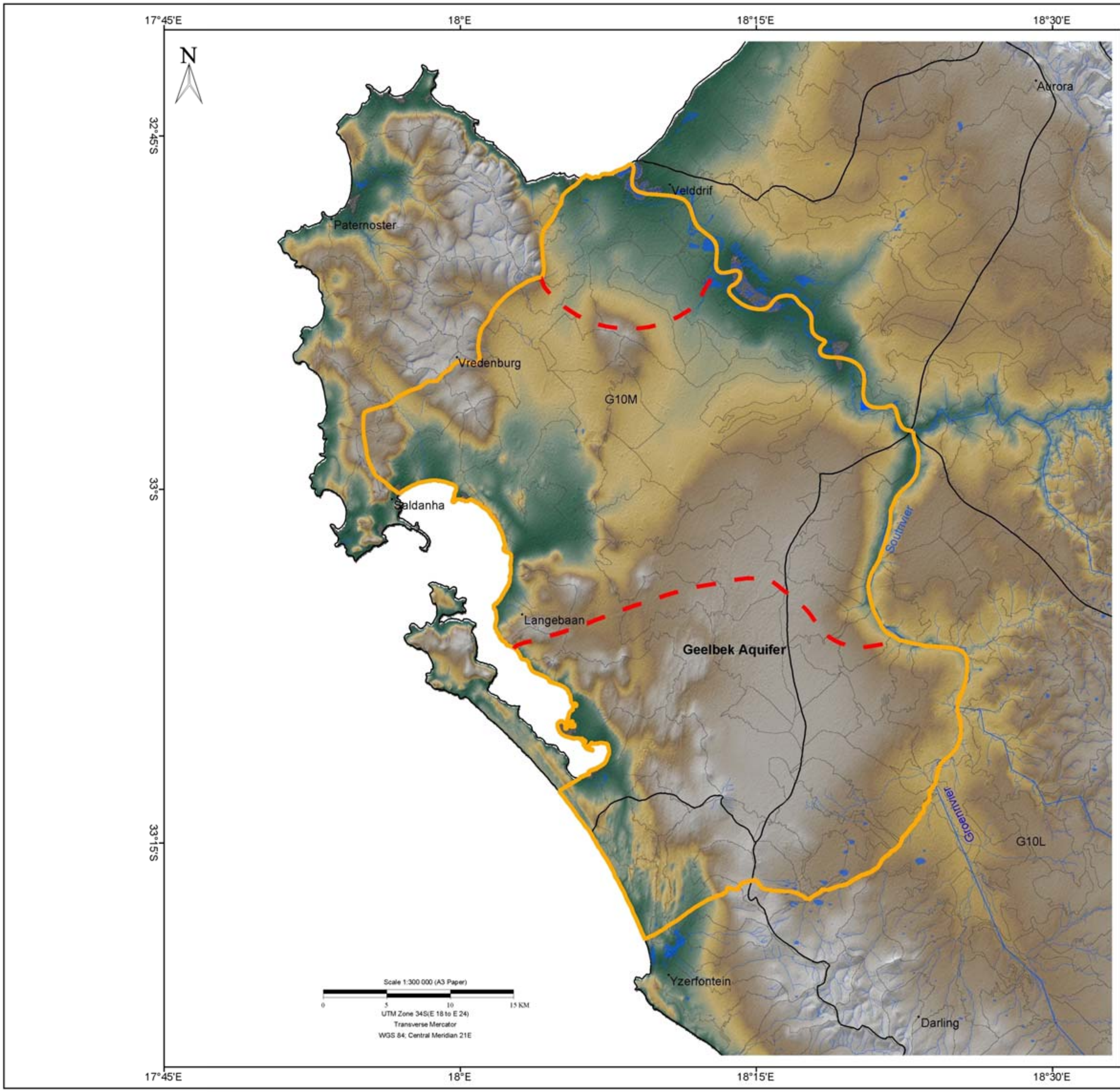
There is a potential for confusion between the Elandsfontein Aquifer System (henceforward EFAS, see **Figure 6-10)** and the Elandsfontyn Formation, which is a basal primary aquifer unit, and therefore a distinctive element of the Sandveld hydrostratigraphy, in both the Langebaan Road and Elandsfontein aquifer systems. Accordingly, it was proposed to rename the southern palaeo channel system as the "Geelbek Aquifer System", following an earlier critical review (Umvoto, 1997). However, the term Geelbek Aquifer may instead apply to only a local portion of the Elandsfontein Aquifer down-gradient along of this palaeodrainage zone, now being investigated by the CSIR at the farm Geelbek (H. van Kleef, personal written communication, March 2007).

In the current interpretation of hydrocensus data, geophysical and drilling data, and groundwater quality data, the direction of flow in the LRAS is towards the 'present' Berg River, i.e., opposite to that indicated in **Figure 6.10**. On the southern side of the Berg River plain, a number of flowing springs are found, which may be supplied from the "proto-Berg" aquifers along the LRAS. Along the present day Sout River, Malmesbury Group strata, with steep dips and N to NE strike directions, crop out along a "fault system" on the farms Jantjesfontein B 140 and Hazekraal 141, close to the confluence of the Sout and Berg rivers. It is possible that recent (late Tertiary to Quaternary) faulting has shifted the course of the Berg River in the direction that it flows today (H. van Kleef, personal communication, 2007). The present lower (estuary) end of the Berg River follows the eroded/weathered portion of the contact zone of the Malmesbury Group and the Cape Granites.

It is also possible that the aquifer palaeodrainage configuration around the LRAS has a palaeoclimatic rather than a neotectonic explanation. Between about 15.6 and 12.5 million years ago (Middle Miocene time), one of the largest shifts in global climate produced dramatic global cooling and reorganization of ocean-circulation patterns, recorded as a shift in the isotopic composition of oxygen in the oceans. This dramatic and permanent shift set the stage for modern oceanic and atmospheric circulation and ushered in the bipolar ice ages that have dominated climate records for the last 2.5 million years. The Pliocene-Pleistocene development of aeolian landforms along the coastal plain of the Western Cape produced significant changes in the surface hydrology of the river systems, by damming and diverting their lower courses.

In relation to the Elandsfontein fossil and archaeological site, it has been noted that: "Wind is a powerful scouring agent and wind erosion continually exposes bones and artefacts in the swales between the dunes. Where erosion reaches the water table – the limit for wind erosion – standing pools of water form. It is around such water holes that animal and human activities have been concentrated in the past" (Deacon and Deacon, 1999, p. 83). The Elandsfontein excavations reveal a Middle Pleistocene (400 to 800 ka) fauna of impressive diversity, especially in grazers, which would not be supported by the present, grass-poor vegetation: "Perhaps the best modern analogue for the vegetation of the Middle Pleistocene is the ribbon of strandveld, a thicket vegetation, growing on shelly alkaline sands along the coast today. In contrast to the fynbos it is capable of supporting a high animal biomass and possibly attracting herds of grazers seasonally" (op. cit., p. 85).

This change from processes dominated by fluviatile erosion and degradation in the coastal plain to aggradational aeolian processes dominated by dune-migration of fine carbonate-rich sands may be linked to intensification of the Benguela Upwelling. Establishment of the deep thermohaline circulation and the surface Benguela Current is related to a significant increase in upwelling along the south-west African continental margin. The onset of the Benguela upwelling is in turn related to the genesis of phosphate-bearing deposits (phosphorites) within the marine sedimentary strata. Increased oceanic circulation associated with the early Miocene transition from a "greenhouse" to an "icehouse" Earth resulted in a removal of phosphorus from the deep ocean by cold, oxygenated waters and its delivery as a nutrient to a rich shallow-water marine life.



LEGEND

Towns
Rivers
Dams
Model Sub-domain
Langbaan Model Domain
Standard basins
Quaternary Catchments

Elevation (mamsl)

1050
111
56
1

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

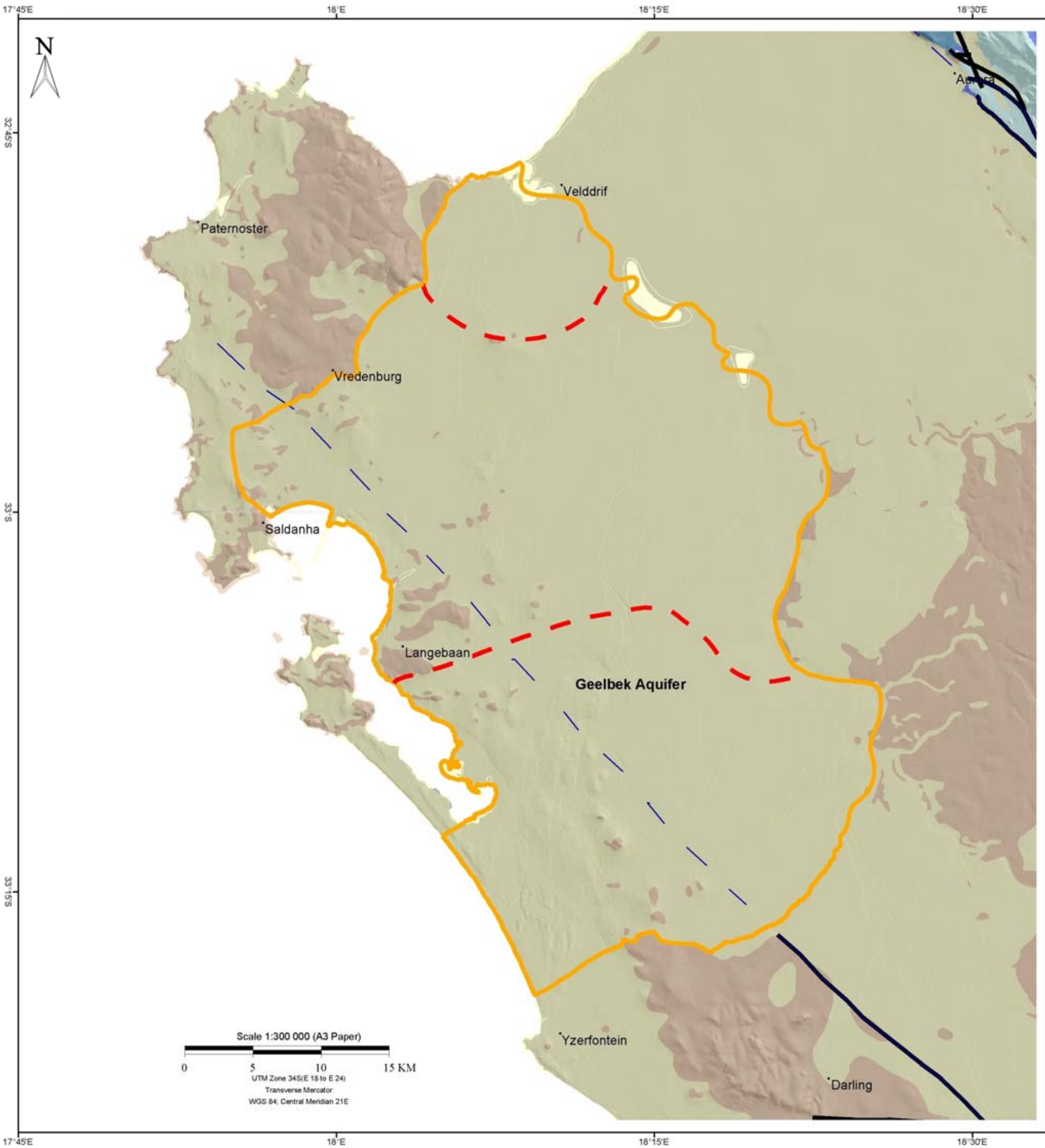
CONSULTANT

UMVOTO

TITLE

LOCALITY AND DRAINAGE IN THE LANGEBAAN ROAD-GEELBEK AREA

FIGURE 6.7



LEGEND

Towns
Faults
Hydrotects
Model Sub-domain
Langebaan Model Domain

SIMPLIFIED LITHOLOGY

Quaternary
Pre_Cape
Nardouw Group
Cedarberg Formation
Pakhuis Formation
Peninsula Formation
Graafwater Formation
Piekenierskloof Formation
Post_TMG
Dam

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

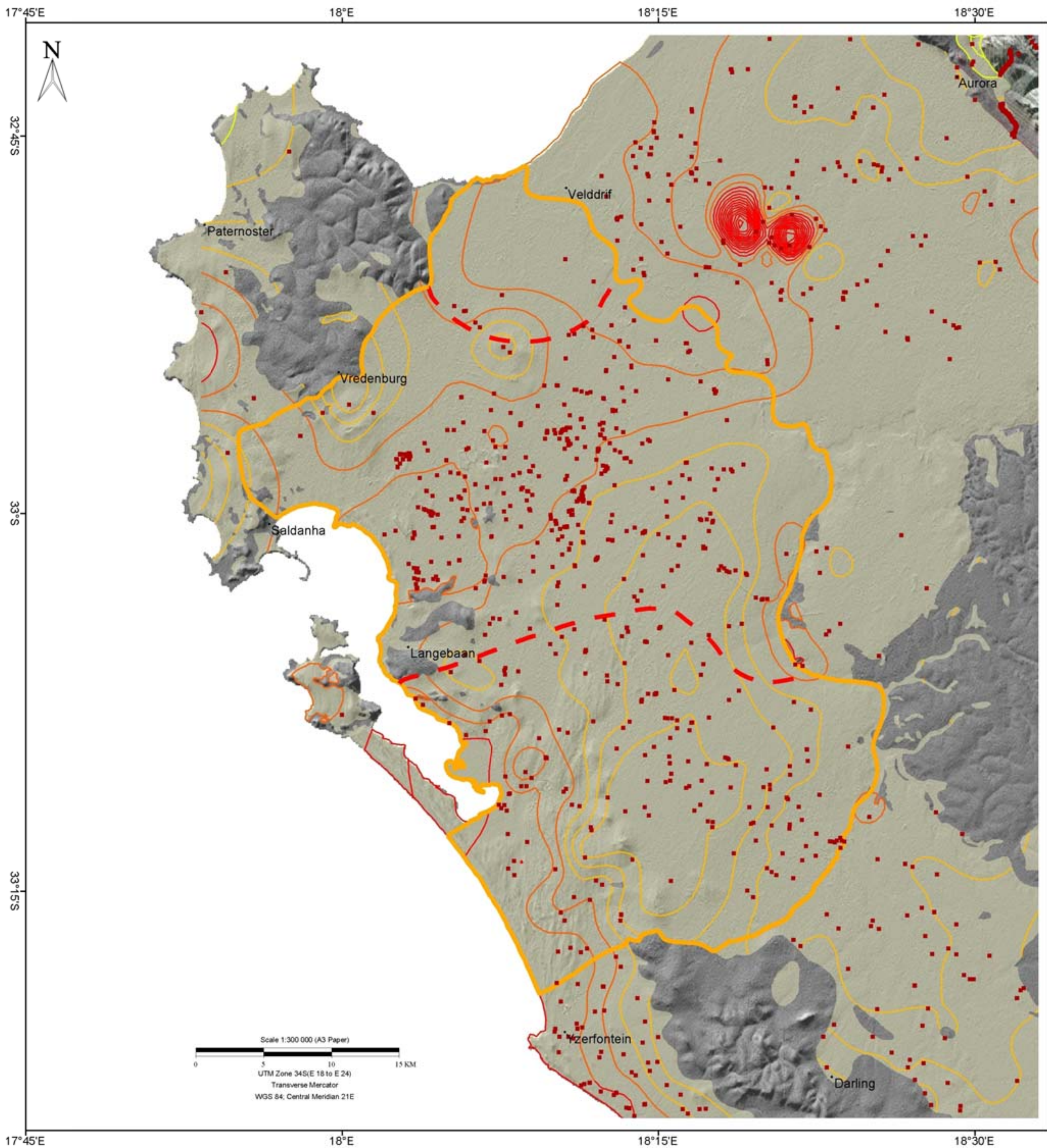
CONSULTANT

UMVOTO

TITLE

GEOLOGY IN THE LANGEBAAN ROAD-GEELBEK

FIGURE 6.8



LEGEND

- Towns
- Water Level Points
- Model Sub-domain
- Langebaan Model Domain
- Sandveld Outcrop

Water Level (mamsl)

- -243 - 0
- 0 - 50
- 50 - 100
- 100 - 150
- 200 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 1017

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

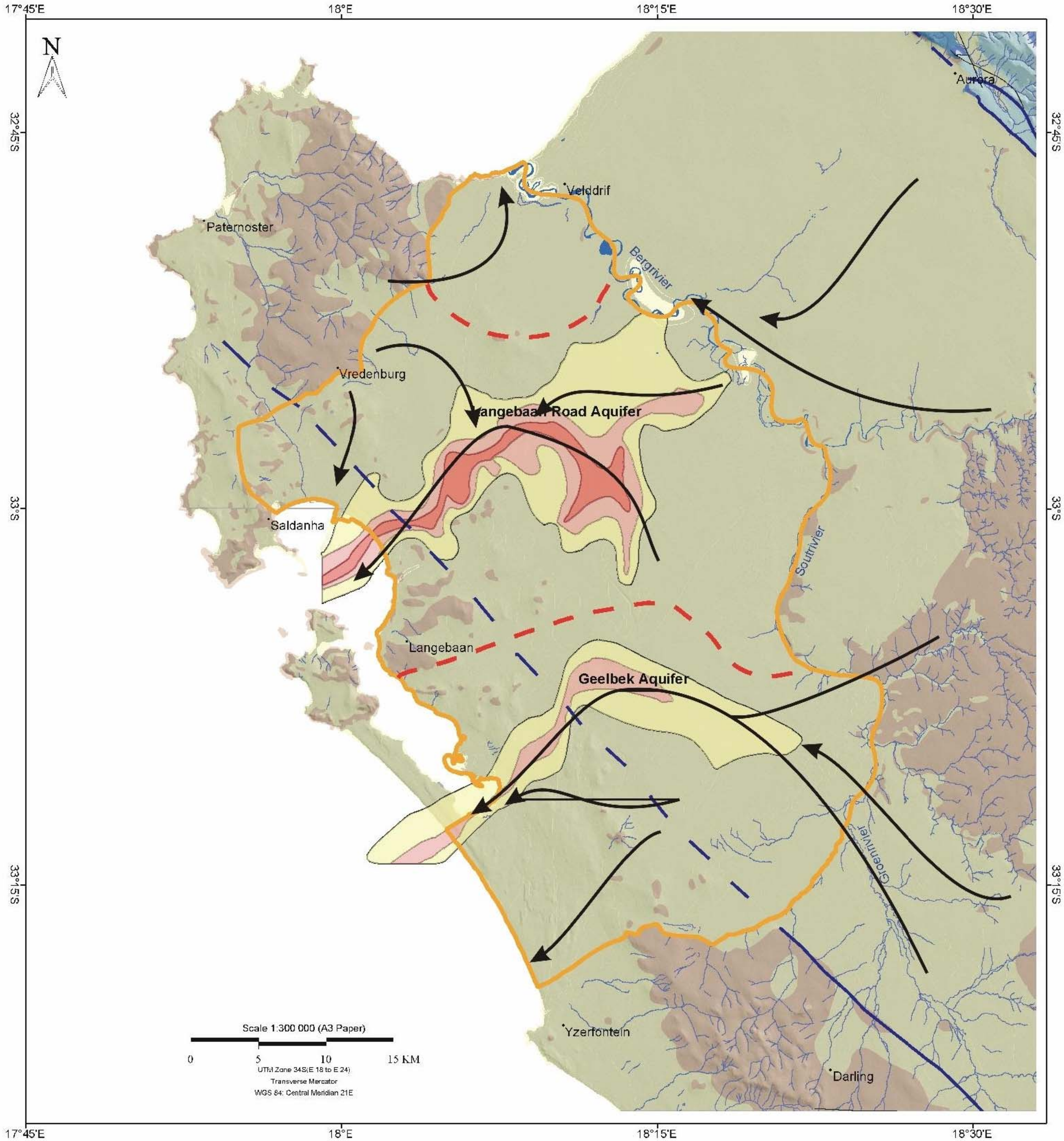
CONSULTANT

UMVOTO

TITLE

WATER LEVEL DATA AND PIEZOMETRIC MAP IN THE LANGEBAAN ROAD-GEELBEK

FIGURE 6.9



LEGEND

Towns
Rivers
Faults
Hydrotects
Langebaan Model Domain
Model Sub-domain

Bedrock Elevation (mamsl)

<-40
-20_ -40
0 _-20

(For geology legend, refer to figure 5.1)

Flow paths

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

CONCEPTUAL MODEL OF GROUNDWATER FLOW IN THE LANGEBAAN ROAD-GEELBEK

FIGURE 6.10

Rapid desiccation in Namibia at 2.2 Ma is associated with increasing upwelling and decreasing sea- surface temperatures along the coast, producing changes in climate and onland vegetation that correspond to the Matuyama diatom maximum of the Namibian upwelling system (DuPont et al., 2005). It is this sudden 2.2 Ma transition to a dryer and windier environment that changed the geomorphology of the near-coastal fringe of south-western Africa, from a river and stream-dominated Sandveld system to a dune-dominated one, marked by the onland deposition of the late Pliocene-Pleistocene Bredasdorp Group calc-arenite formations.

The 3D geometry, facies continuity and hydraulic properties of variably sorted, aquifer sandstones and gravels in the fluvial Sandveld depositional system is bound to differ substantially from the finer, well-sorted calcareous sands in the overlying Bredasdorp depositional system, with the latter being much less favourable from a hydrogeological perspective. Conceptual and numerical models of the LRAS and EFAS have to take this difference into account.

A schematic geological cross-section (**Figure 6-11**) across the main Sandveld aquifer systems is drawn between the Vredenburg hills in the NW and the valley of the Groen River in the SE. The key feature of this section is the separation of the sequences within the two palaeo channel aquifer systems, into

(1) a lower part fluvial-marine of Miocene-Pliocene age (~25-5 Ma), consisting of the Elandsfontyn, Saldanha and Varswater Formations (Rogers, 1982), and
(2) an upper part consisting of various members of the Bredasdorp Group (**Table 3-1**), which is mainly aeolianite of windblown, dune-sand origin.

Langebaan Road Aquifer System (LRAS)

The LRAS is located between the lower Berg River and Saldanha Bay, the geomorphological origins of which are related to deep fluviatile incision of bedrock by a "proto-Berg" River (Umvoto, 1997) during Miocene or pre-Miocene times, as revealed by marine geological and geophysical investigations in Saldanha Bay (De la Cruz, 1978; and references cited therein, which – surprisingly - seem never to have been properly correlated with onland depth-to-bedrock investigations). "The fact that the bedrock is deep close to the north-eastern coast of the Bay suggests that it continues at a considerable depth under the adjacent onland dunes in the region" (op. cit., p. 27). Despite this indication, however, Rogers (1982, Fig. 3.21) inferred a bedrock depth of only -20 m to 0 m elevation along the Saldanha Bay coastline, and drew a low (< +20 m elevation above mean sea level) palaeodrainage divide roughly midway between the coastline and Langebaan Road.

In our view, the LRAS palaeo channel displays greater axial continuity and a consistent westerly slope. Particularly in the west between Lynch Point (Club Mykonos) and the Saldanha Steel site, its bedrock base is inferred to be substantially greater in depth than indicated on existing maps (cf. Woodford et al., 2003, Fig. 16). Furthermore, the deeper (semi-)confined part of the LRAS, which is located along the axis of the “proto-Berg” palaeo channel, is not limited on the west by a bedrock ridge. Its westerly extension toward and beneath the Spreeuwal dunefield (Witzand Formation) may therefore be much larger than presently conceived (see **Figure 6-10**). Recent geotechnical investigations related to extensions of the harbour at Saldanha Bay appear to confirm this view, and it is possible that new drilling data from this area can be made available to inform the numerical modelling of the LRAS (D van Rooyen, personal oral communication, 19 December 2006).

Under particular hydraulic conditions, the lower Berg River may receive an inflow of groundwater from the upper, unconfined portion of the LRAS on its southern bank. Timmerman (1987) indicated that a direct hydraulic connection exists between the Berg River and both the upper (semi-) unconfined aquifer D as well as the lower (semi-) confined aquifers A, B, C of the LRAS along different reaches of the river.

The (semi-) confined lower LRAS is capped by relatively impermeable clays of the uppermost Elandsfontyn Formation (E6 member), which are shown to underlie a wide area around the lower course of the Berg River (Timmerman, 1987, Map 3.8). The upper parts of the Elandsfontyn Formation have, however, been eroded along the lower course of the Berg River, as shown by lithostratigraphic profiles (e.g., Timmerman, 1987, Illustrations 3.72 and 3.77), so that the permeable aquifer units (E3 and E5 members) locally sub-outcrop beneath only a thin cover of younger aeolian sands.

Geelbek Aquifer System (GBAS)

The GBAS palaeo channel, which evidently contained the Miocene (~24-5 Ma) palaeodrainage of the Groen River and possibly also the Sout River, also contains the Elandsfontyn Aquifer in its lower part. Timmerman (1987, p. 90ff) records that groundwater in the Elandsfontyn catchment area is recharged at the foot of the granitic hills near Darling, and flows northwards to the property Elandsfontyn before turning westwards towards Langebaan Lagoon (see **Figure 6-10**). There is a localised discharge zone on the western part of Elandsfontyn (op. cit., p. 92), formed by flow concentration where permeable strata were deposited in the Geelbek palaeo channel. It is separated from the discharge zone east of Langebaan Lagoon by a local water-table divide.

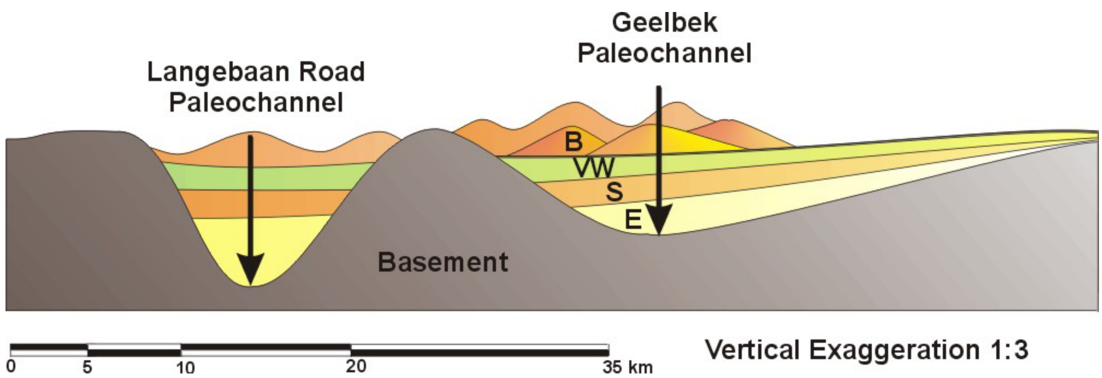


Figure 6-11 Vertical section through Langebaan

Schematic section across the main Sandveld aquifer system between the Vredenburg hills in the NW (left) and the valley of the Groen River in the SW (right) in which, B=Bredasdorp Group, VW = Varswater, S = Saldanha, E = Elandsfontyn Formations.

6.3 TMG PIKETBERG

The Piketberg Model Domain is located in the north-western corner of the study area. It includes the area above the westerly extension of the Saron-Aurora Megafault Zone from the coast below Elandsbaai as far as the Peninsula Formations contact with the Malmesbury shales east of Piketberg. The northern boundary of the Model Domain extends to the overall study boundary at the Verlorenvlei River.

6.3.1 Motivation

The Piketberg Model is a requirement under Task 15 of the Berg WAAS as detailed in the Inception Report, (DWAF, 2005). Over the past five years there has been increasing agricultural use of TMG groundwater in the Piketberg area, both because of expanding development as well as the poor rains over the past few seasons.

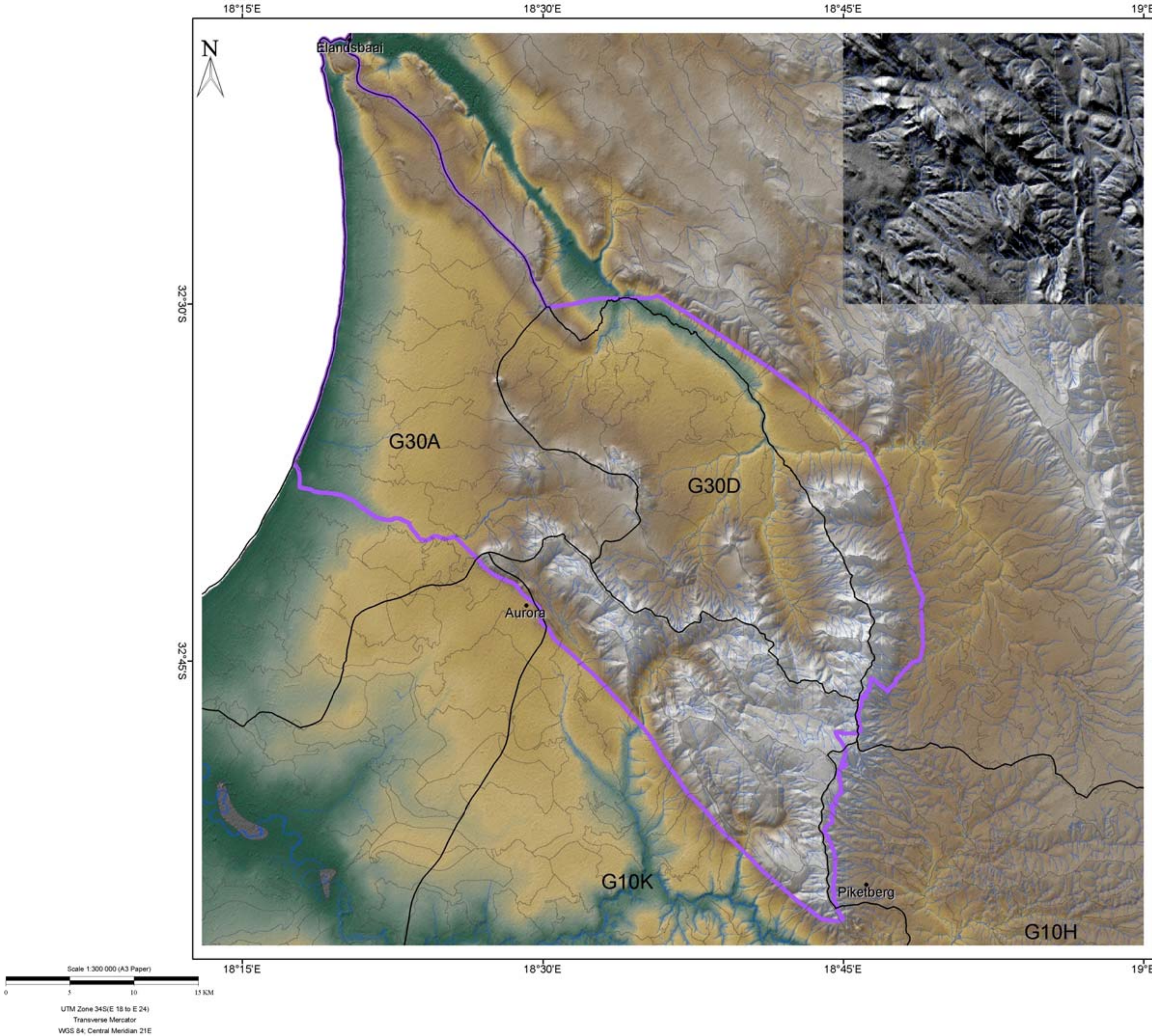
6.3.2 Conceptual Model

The Piketberg area is predominantly rural with a very small population compared to the remainder of the Berg WAAS area. The ~800 to ~1400 m high Piketberg Mountains in the south-eastern corner give way to coastal dunes to the west before meeting the ocean in Elands Bay. The surface-water run-off is controlled by this surface topography, draining westward toward the coast by means of the Krom Antonies River and Verlorenvlei River (see **Figure 6-12**). Surface-water flow also drains southward into the Lower Berg River by means of the Boesmans and Platkloof rivers.

The Piketberg Mountains are made up of the Lower TMG sequence including the Graafwater and Piekenierskloof formations forming the base overlain by the Peninsula and Nardouw Formations (See **Figure 6-13**). Several outcrops of basement Malmesbury Formation occur in the north-eastern part of the Piketberg area, and this basement underlies the coastal dunes in the west. It is suspected that the Peninsula Aquifer that outcrops in the Piketberg Mountains also extends north-west along a strike below the Sandveld Aquifer although it is unknown to what extent.

The Piketberg area has a relatively sparse, but regular distribution of water-level data points (See **Figure 6-14**). The piezometric map developed from these water points illustrate that the water levels relative to the mean annual sea level are highest in the valleys opening out of the Piketberg Mountains in the southeast corner, decreasing toward the coast. It is noted here that the water levels also decrease toward the Berg River toward the south.

The main groundwater resource of interest in the Piketberg region is the Peninsula Aquifer, which straddles the divide between the Berg River drainage and the south-western part of the Olifants-Doorn WMA, i.e. the Verlorenvlei drainage system. Within the Piketberg, there are also zones where the Skurweberg Aquifer is locally significant. Along the western faulted margin of the Piketberg range, springs emerging from the TMG aquifers in the Piketberg feed streams and groundwater in palaeo channels towards the lower Berg River, and together with boreholes are the sole supply to the small settlements along the south-western slopes of the mountain, e.g. the village of Aurora (See **Figure 6-14**). The fractured rock groundwater is recharged in the mountains of Piketberg and discharged at sea beyond Elands Bay (See **Figure 6-16**). Groundwater flow in the Peninsula Aquifer is from south-east to north-west.



LEGEND

Towns
Rivers
Dams
Piketberg Model Domain
Standard basins
Quaternary Catchments

Elevation (mamsl)

1 - 50
50 - 100
100 - 195
195 - 485
485 - 630
630 - 730
730 - 1455

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

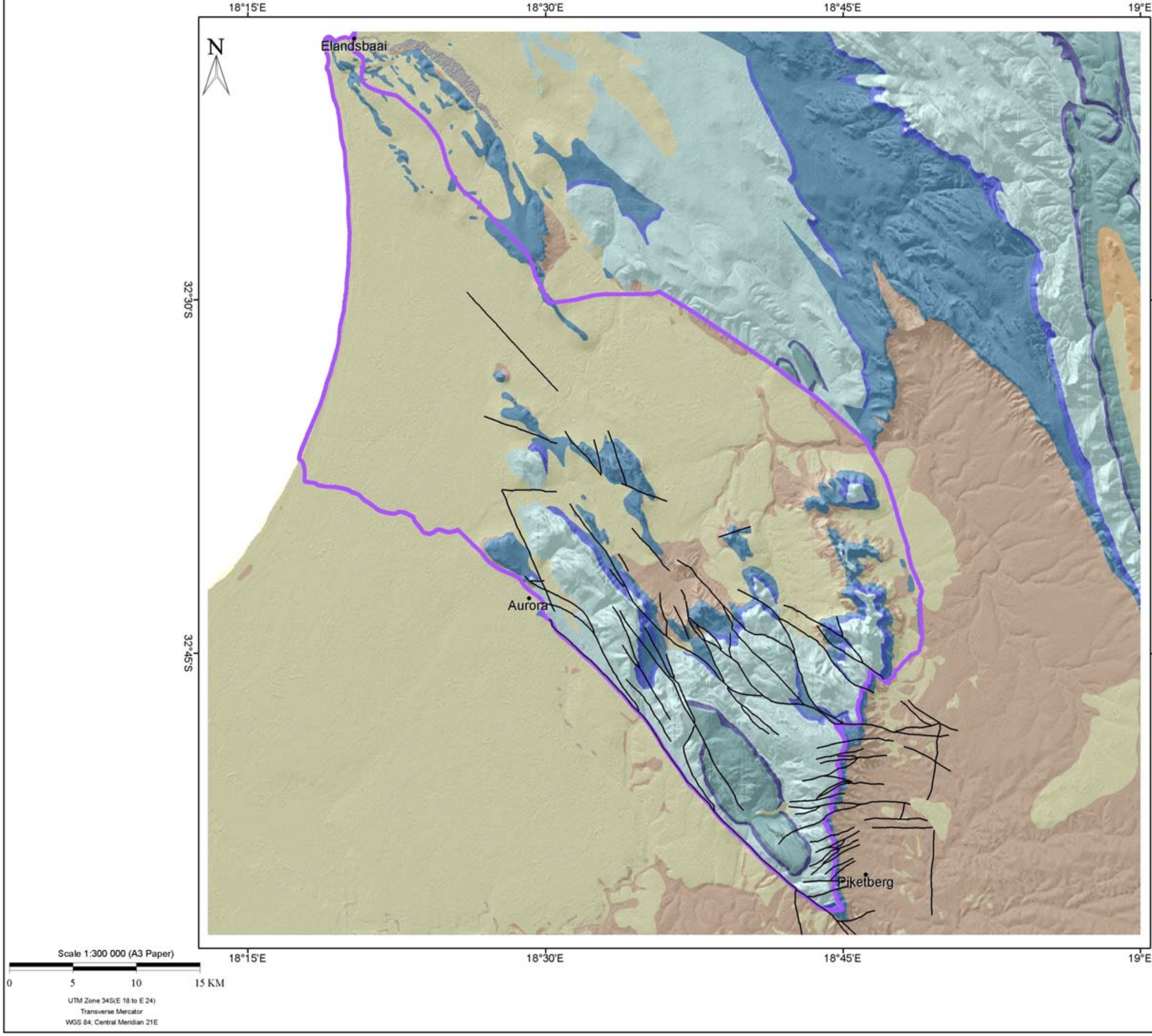
CONSULTANT

UMVOTO

TITLE

LOCALITY AND DRAINAGE IN THE PIKETBERG

FIGURE 6.12



LEGEND

- Towns
- Faults
- Piketberg Model Domain

SIMPLIFIED LITHOLOGY

- Quaternary Sediments
- Pre_Cape
- Nardouw Group
- Cedarberg Formation
- Pakhuis Formation
- Graafwater Formation
- Peninsula Formation
- Piekenierskloof Formation
- Post_TMG
- Dam

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

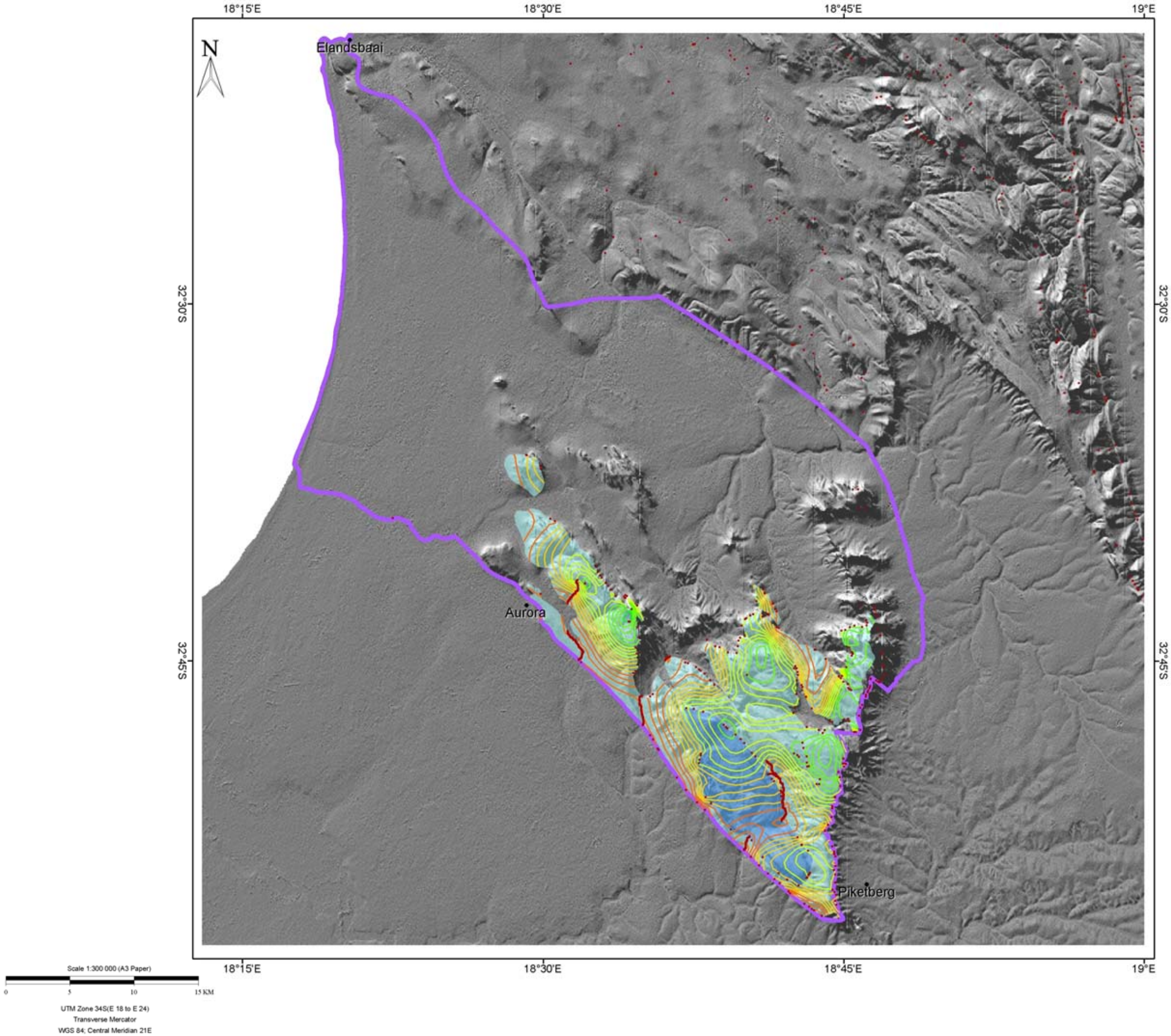
CONSULTANT

UMVOTO

TITLE

GEOLOGY IN THE PIKETBERG AREA

FIGURE 6.13



LEGEND

- Towns
- Water Level Points
- Langebaan Model Domain
- Peninsula Suboutcrop
- Peninsula Outcrop

Water Level (mamsl)

- -4 - 0
- 0 - 200
- 200 - 400
- 400 - 600
- 600 - 1200
- 1200 - 1400
- 1400 - 1600
- 1600 - 1800
- 1800 - 1946

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

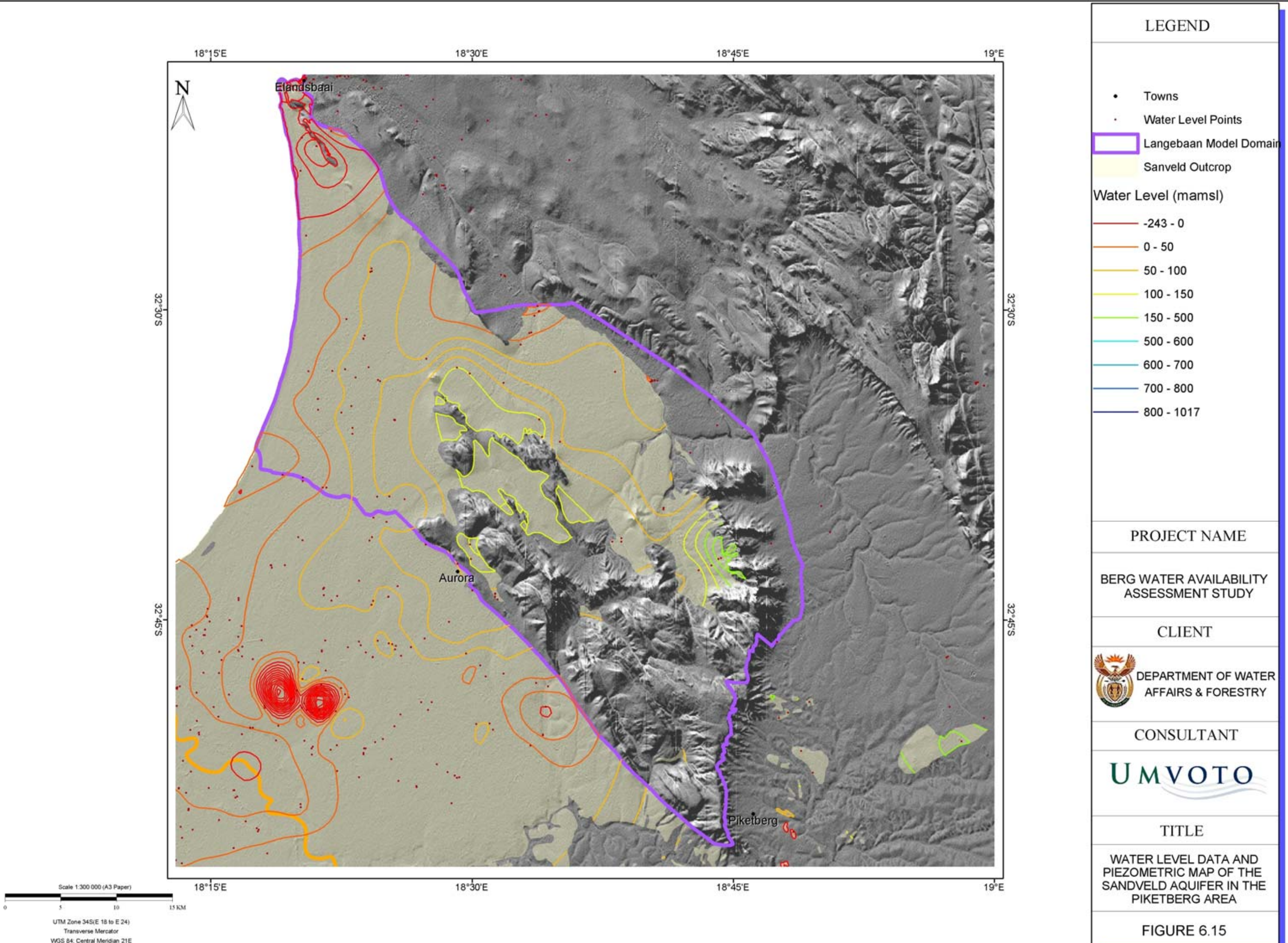
CONSULTANT

UMVOTO

TITLE

WATER LEVEL DATA AND PIEZOMETRIC MAP OF THE PENINSULA AQUIFER IN THE PIKETBERG AREA

FIGURE 6.14



PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

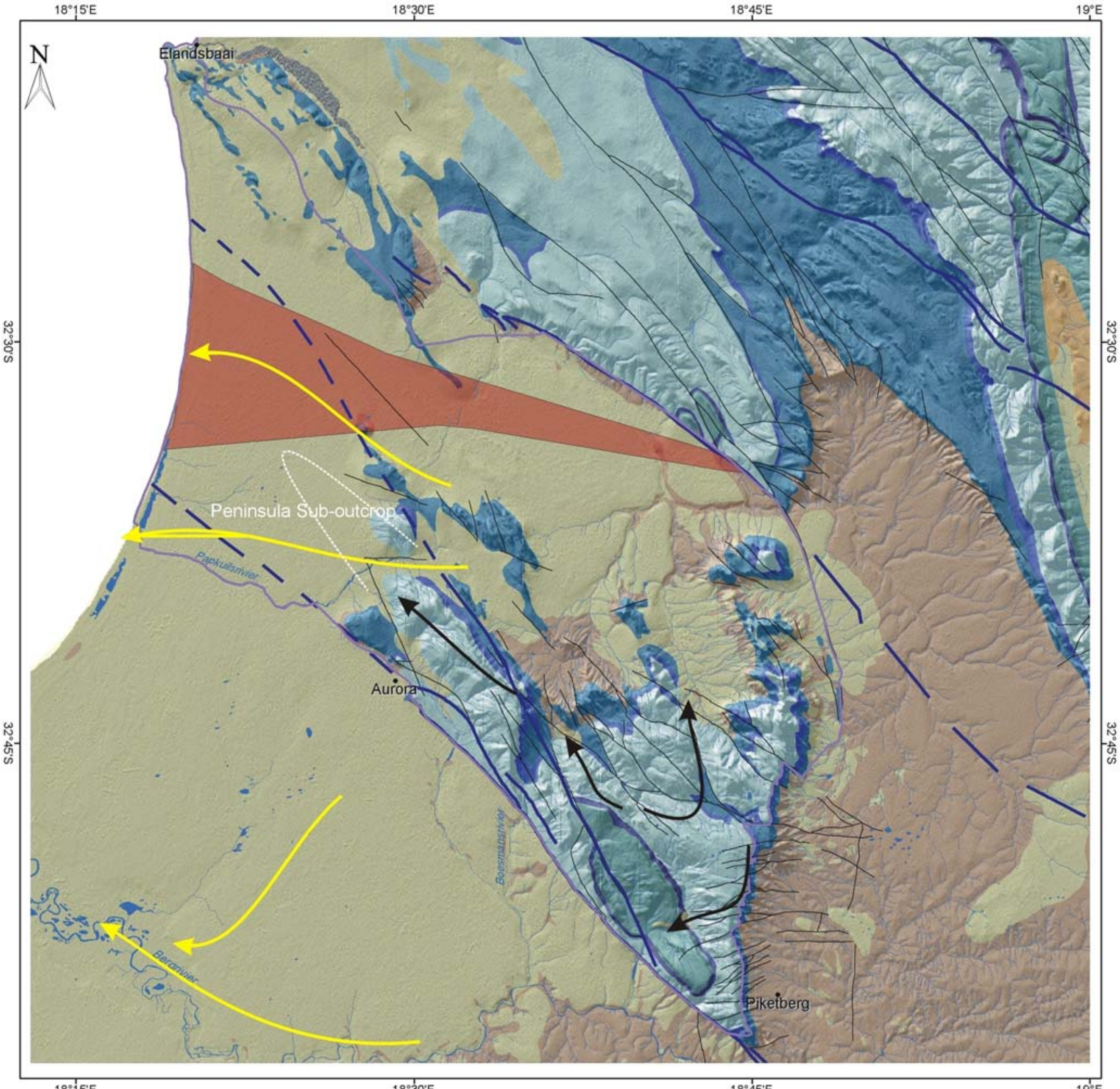
CONSULTANT

UMVOTO

TITLE

WATER LEVEL DATA AND PIEZOMETRIC MAP OF THE SANDVELD AQUIFER IN THE PIKETBERG AREA

FIGURE 6.15



Scale 1:300 000 (A3 Paper)

0 5 10 15 KM

UTM Zone 34S(E 18 to E 24)
Transverse Mercator
WGS 84; Central Meridian 21E

LEGEND

- Towns
- Rivers
- Faults
- Hydrotects
- Piketberg Model Domain
- De Duine Palaeochannel

(For geology legend refer Figure 5.1)

- Flow Paths (Peninsula)
- Flow Paths (Sandveld)

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

CONCEPTUAL MODEL OF GROUNDWATER FLOW IN THE PIKETBERG AREA

FIGURE 6.16

Sub-surface discharge probably also recharges the Sandveld aquifers on the western and northwestern slopes of the Piketberg, north of the Berg WMA boundary in the G30A catchment (see **Figure 6-16**). From 1998, drilling results around the farm Bottelfontein, relatively good quality groundwater (EC down to 61 mS/m) was discovered within one to four units of "quartzitic gravel" (TMG clasts?), interbedded with sands, clays and peats, within a dune-sand concealed palaeo channel overlying weathered Malmesbury bedrock at depths reaching ~49 m below sea level at a distance of ~3 km from the coastline (Umvoto, unpublished results for private client, see **Figure 6-17**). Groundwater flow in the intergranular aquifer drains from east to west. Water quality in this deeper aquifer is markedly better than in the overlying unconfined, fine sands, which indicates lateral recharge at depth.

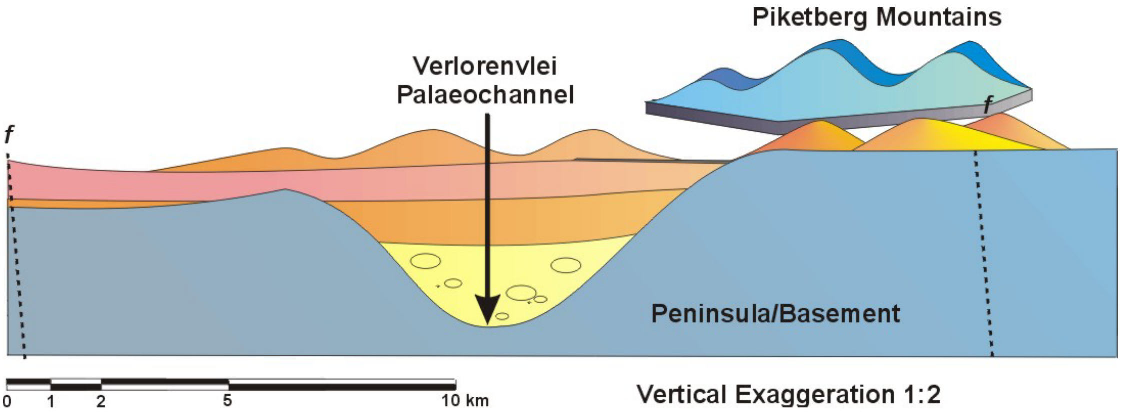


Figure 6-17 Vertical section illustrating the location of the Verlorenvlei Palaeo channel and Sandveld Aquifer deposits

6.4 WITZENBERG-NUY AREA

The Witzenberg-Nuy Domain is a combination of three subdomains, which include the Agter Witzenberg and the Tulbagh-Ceres Valley in the west, the Hex River area in the center and the Koo Valley east of De Doorns in the east.

The Tulbagh-Ceres area and the Hex River area were previously considered separate model areas belonging to the TMG Aquifer Conceptual and Water Balance Model requirement detailed in the Inception Report (DWAF, 2005). Preliminary investigations of the conceptual groundwater flow in the Peninsula and Skurweberg aquifers, as well as surface water flow are considerably different to one another. Conceptually, the groundwater flow in the various aquifers is not isolated to the originally defined domains of the Inception Report. Interbasin transfers translate to discharge of one subdomain being equivalent to recharge in the adjacent subdomain. From a modelling point of view, these subdomains cannot be considered individually. For this reason it was decided to join the Tulbagh-Ceres and Hex River model domains as well as include the area east of De Doorns.

6.4.1 Motivation

The TMG Aquifer is already heavily utilised for irrigation within the Hex River valley. The increased groundwater abstraction can result in stream-flow reduction and therefore in reduced water availability to downstream users, especially in the flood plain of the Breede River around Worcester. Since it is anticipated that the water demand and groundwater abstraction from the TMG Aquifer in the vicinity of the Hex River valley will increase further, it is important to understand and quantify the risk of stream flow reduction and the cascading effect on the possible future transfer scheme from the upper Breede River.

Similarly, the TMG Aquifer within the Tulbagh and Ceres area (i.e. Agter Witzenberg, Ceres valley) is also being utilized. It is envisaged to implement a transfer scheme from the Ceres valley towards the Berg River, and it is therefore important to understand and quantify the interaction between the TMG Aquifer and the surface water system in this area. The impacts could be similar to the Worcester area.

6.4.2 Conceptual Model

The Witzenberg-Nuy area is dominated by mountainous terrain resultant of its location in the syntaxis of the Cape Fold belt (See **Figure 6-18**). In the west, the north-south trending Agter Witzenberge and Skurweberge bound the Tulbagh-Ceres and Agter-Witzenberg Valleys. East of this lies the Kouebokkeveld bounded by the north-east-south-west arc of the Hex River Mountains in the south and east. Bordering the Hex River Valley is the Kwadousberge, adjacent to the Koo Valley. The east-west trending Langeberg separate the Koo Valley from the Worcester Valley that traverses the full-length of the southern margin of the Witzenberg-Nuy area.

Surface water flow is directed into the Klein Berg (Tulbagh-Ceres valley), Olifants (northern Agter Witzenberg valley), Hexrivier (Hex River valley) and Breede River (Worcester valley) basins (See **Figure 6-18**). The Koekedou River and the Modder River in the Agter Witzenberg valley flow southward to join the Klein Berg River through the Mitchell's Pass. These are fed by south-west flowing rivers in the Warm Bokkeveld including the Skaap River and the Titus River. The Hex River flows southwest through the Hex River Valley to join with the Breede River just south of Worcester. The Hex River Mountains form a large surface water divide shedding water into both the Warm Bokkeveld and the Hex River valley. The Kwadousberg sheds surface water into both the Hexriver valley and the Koo valley. The Langeberg in the south-west shed surface water into the Koo valley and the Breede River basin.

Basement Malmesbury rocks (Pre-Cape) with some inliers of the Cape Granite Suite underlie and outcrop in the Worcester valley (See **Figure 6-19**). The above-mentioned mountains comprise rocks of the full TMG suite from the Peninsula Formation to the Rietvlei Formation. North of the mountains, in the Kouebokkeveld and Koo valleys, the geology changes to that of the overlying Bokkeveld and Witteberg Formations.

The main aquifers of interest are the TMG Peninsula and Nardouw (Skurweberg) aquifers. The Peninsula Formation dominates the high mountain areas, while the valleys and their flanks are layered with rocks of the overlying stratigraphy. This is due in part to the competency of the Peninsula Formation and to the folding in the Cape Fold Belt. As a result the Peninsula Aquifer is unconfined in the mountainous areas and confined in the valleys. The Skurweberg Aquifer has a smaller outcropping area that is unconfined in the Agter Witzenberg valley and along the flanks of the mountain ranges, and is confined in the valleys.

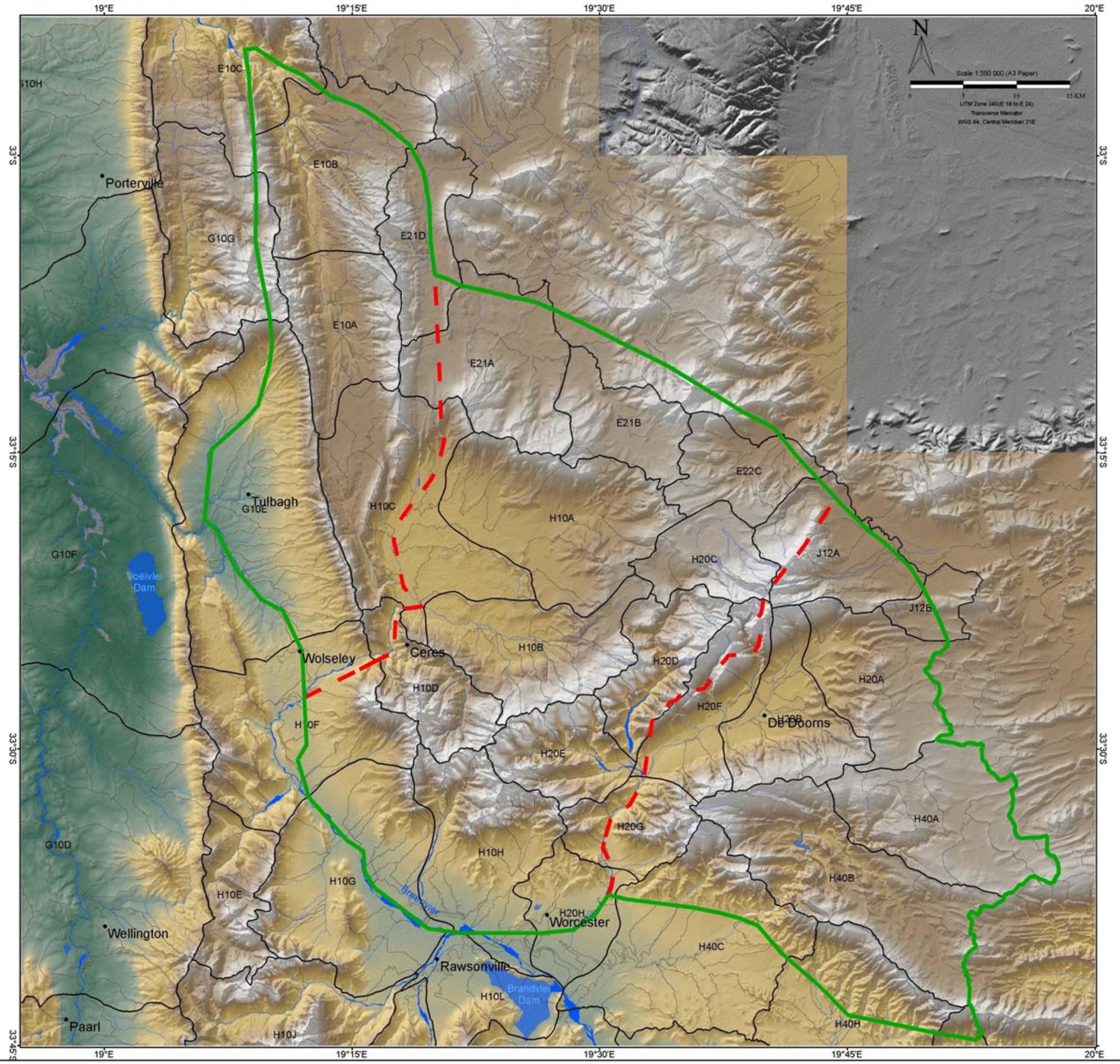
Water-level information was generated in the Witzenberg-Nuy area from all the points where the relevant aquifer's contact with an adjacent unit is crossed by a river. The assumption being that the topographic elevation of that point was equivalent to the water level relative to mean annual sea level. **Figure 6-20** and **Figure 6-21** show the piezometric maps for the Peninsula and Nardouw Aquifers respectively. Similarly to the piezometric maps generated in the Sandveld areas above, the water levels are higher in elevated topographic areas.

For the Peninsula Aquifer

- The highest water levels occur in the northwestern flanks of the Hex River Mountains.
- The high water levels in the Hex River Mountains are characterized by steep piezometric gradients to the Hex River Valley floor.
- Water levels lower from the Skurweberge in the west across the Koue Bokkeveld to the Hex River Mountains in the east.
- The water levels decrease to the north and south of a latitudinal high in the Olifants River and Agter Witzenberg Synclines.
- The lowest water levels occur along the Nuy River near the confluence with the Breede River in the Worcester valley.
- Water levels decrease eastward from the Kwadousberge.

For the Nardouw (Skurweberg) Aquifer

- The highest water levels occur on the northern flanks of the Hex River Mountains and along the Langeberge
- The water levels in the Kouebokkeveld decrease toward the center and are at their lowest in the Mitchell's Pass.
- The piezometric lines parallel the GVM hydrotects.
- The water levels decrease to the north and south of a latitudinal high in the Olifants River and Agter Witzenberg Synclines.
- The lowest water levels occur in the apex of the Hex River Valley.



LEGEND

- • Towns
- Rivers
- Dams
- Model Sub-domain
- Witzenberg-Nuy Model Domain
- Standard basins
- Quaternary Catchments

Elevation (mamsl)

- 33 - 115
- 116 - 198
- 199 - 280
- 281 - 529
- 530 - 777
- 778 - 1108
- 1109 - 1356
- 1357 - 1439
- 1440 - 1522
- 1523 - 2101

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

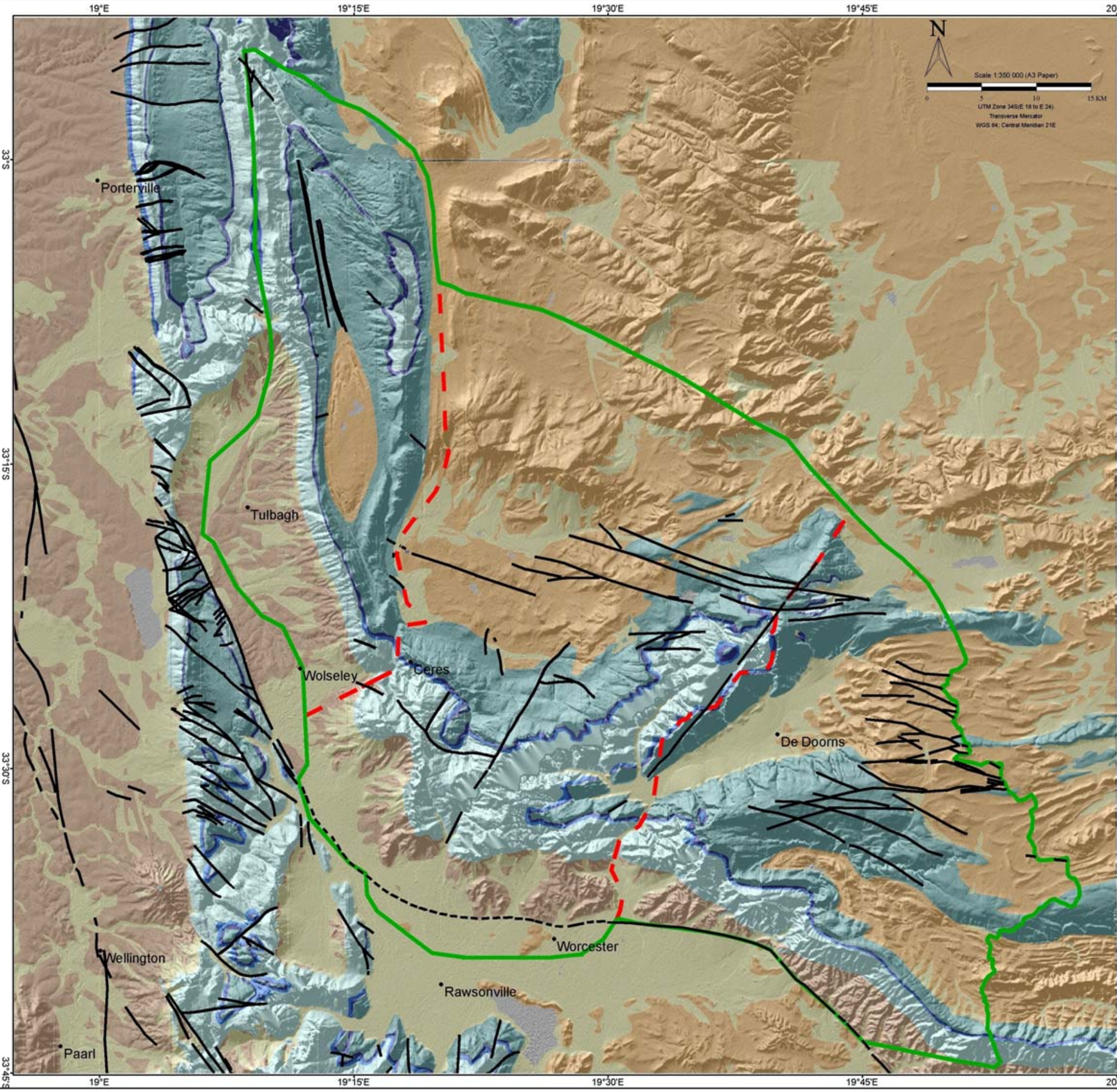
CONSULTANT

UMVOTO

TITLE

LOCALITY AND DRAINAGE IN THE WITZENBERG - NUY

FIGURE 6.18



LEGEND

- • Towns
- Faults
- Model Sub-domain
- Witzenberg-Nuy Model Domain

SIMPLIFIELD LITHOLOGY

- Quaternary Sediments
- Pre_Cape
- Nardouw Group
- Cedarberg Formation
- Pakhuis Formation
- Peninsula Formation
- Quaternary Catchments
- Graafwater Formation
- Piekenierskloof Formation
- Post_TMG
- Dam

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

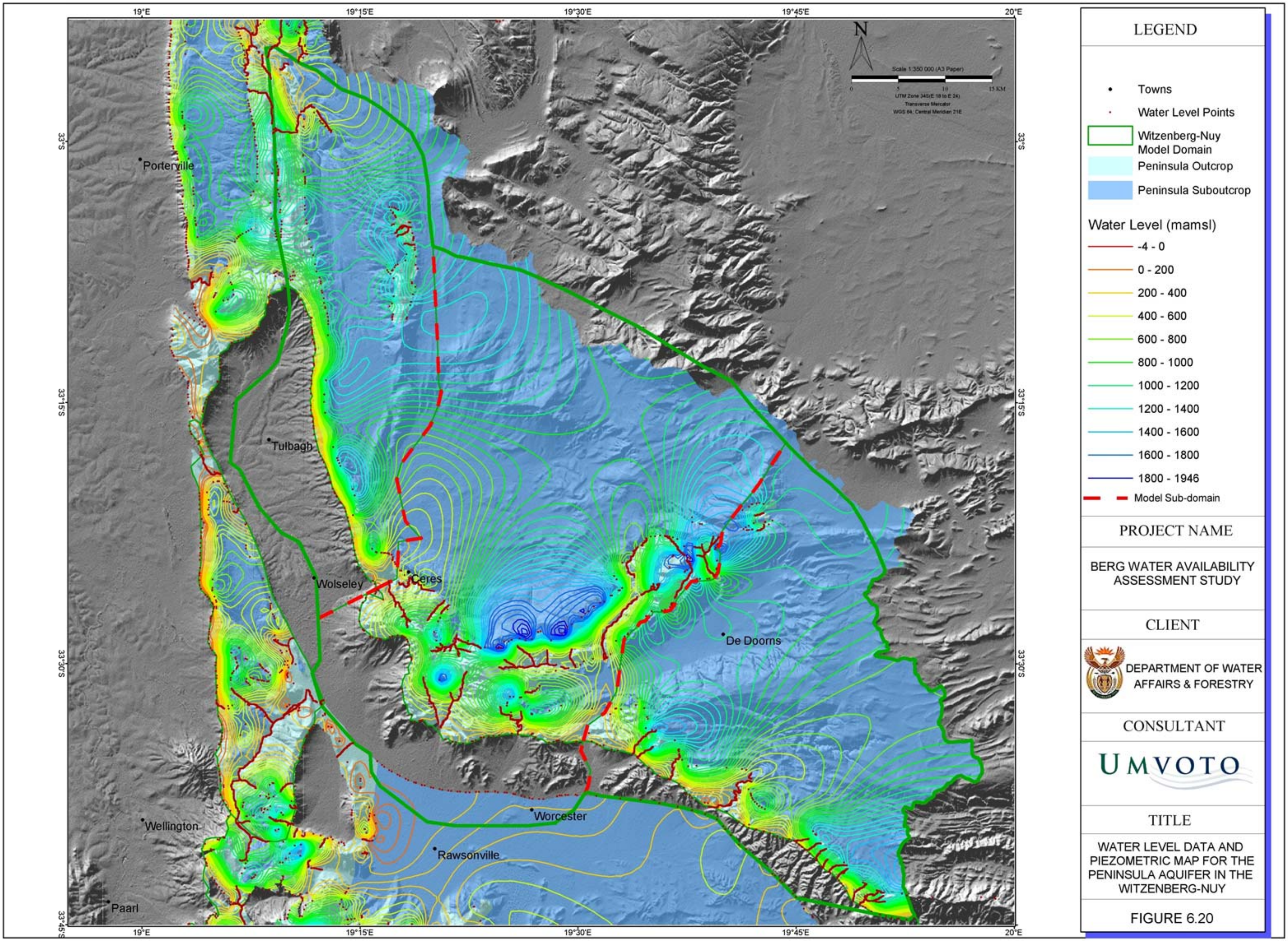
CONSULTANT

UMVOTO

TITLE

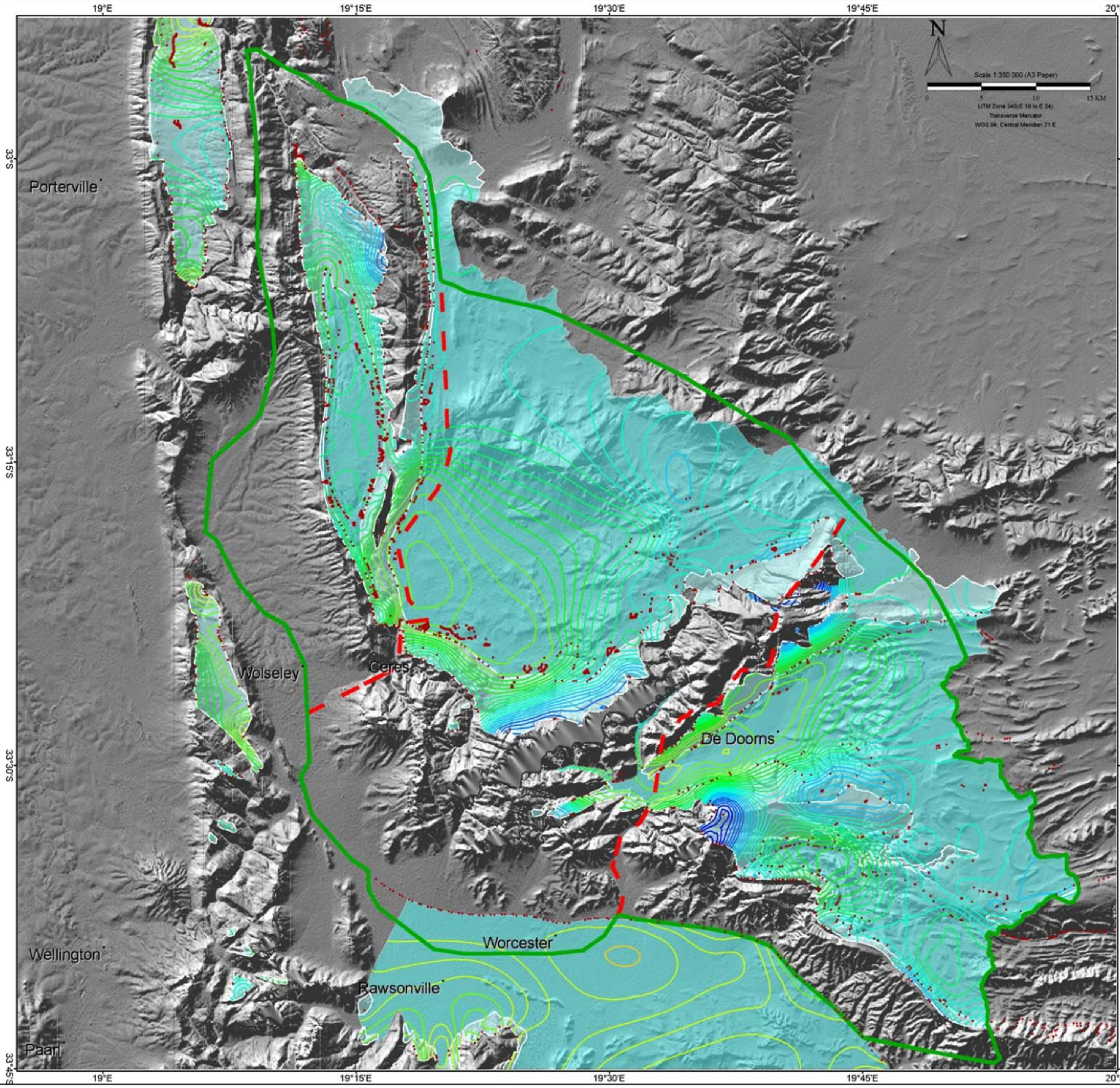
GEOLOGY IN THE WITZENBERG - NUY

FIGURE 6.19



WATER LEVEL DATA AND PIEZOMETRIC MAP FOR THE PENINSULA AQUIFER IN THE WITZENBERG-NUY

FIGURE 6.20



LEGEND

- Towns
- Water Level Points
- Witzenberg-Nuy Model Domain
- Model Sub-domain
- Skurweberg Outcrop
- Skurweberg Suboutcrop

Water Level (mamsl)

- -30 - 0
- 0 - 100
- 100 - 200
- 200 - 400
- 400 - 1000
- 1000 - 1200
- 1200 - 1400
- 1400 - 1600
- 1600 - 1870

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS

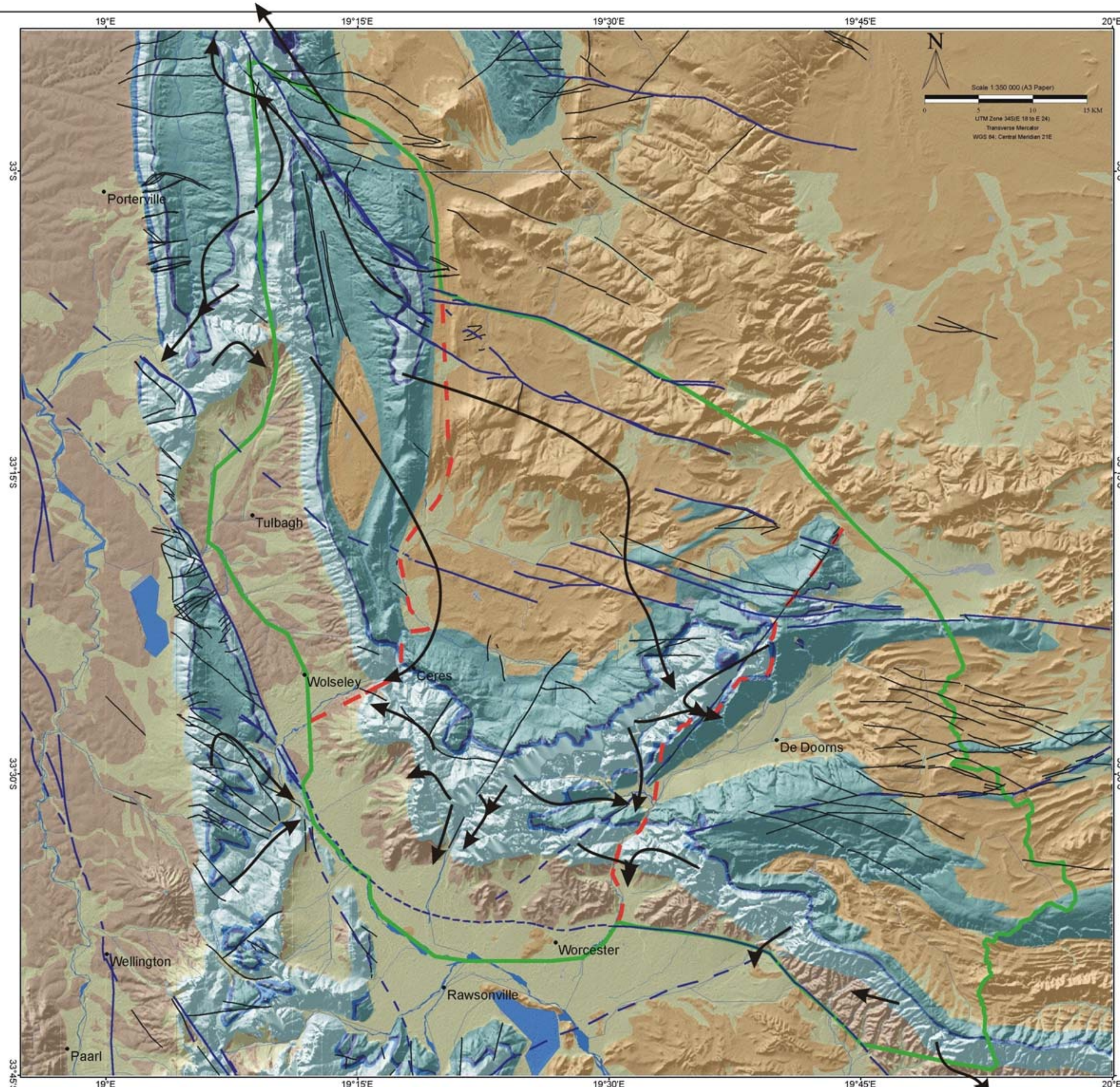
CONSULTANT

UMVOTO

TITLE

WATER LEVEL DATA AND PIEZOMETRIC MAP FOR THE SKURWEBERG/RIETVLEI AQUIFER IN THE WITZENBERG-NUY

FIGURE 6.21



LEGEND

- Towns
- Rivers
- Faults
- Hydrotects
- Model Sub-domain
- Witzenberg-Nuy Model Domain
- Flow paths

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

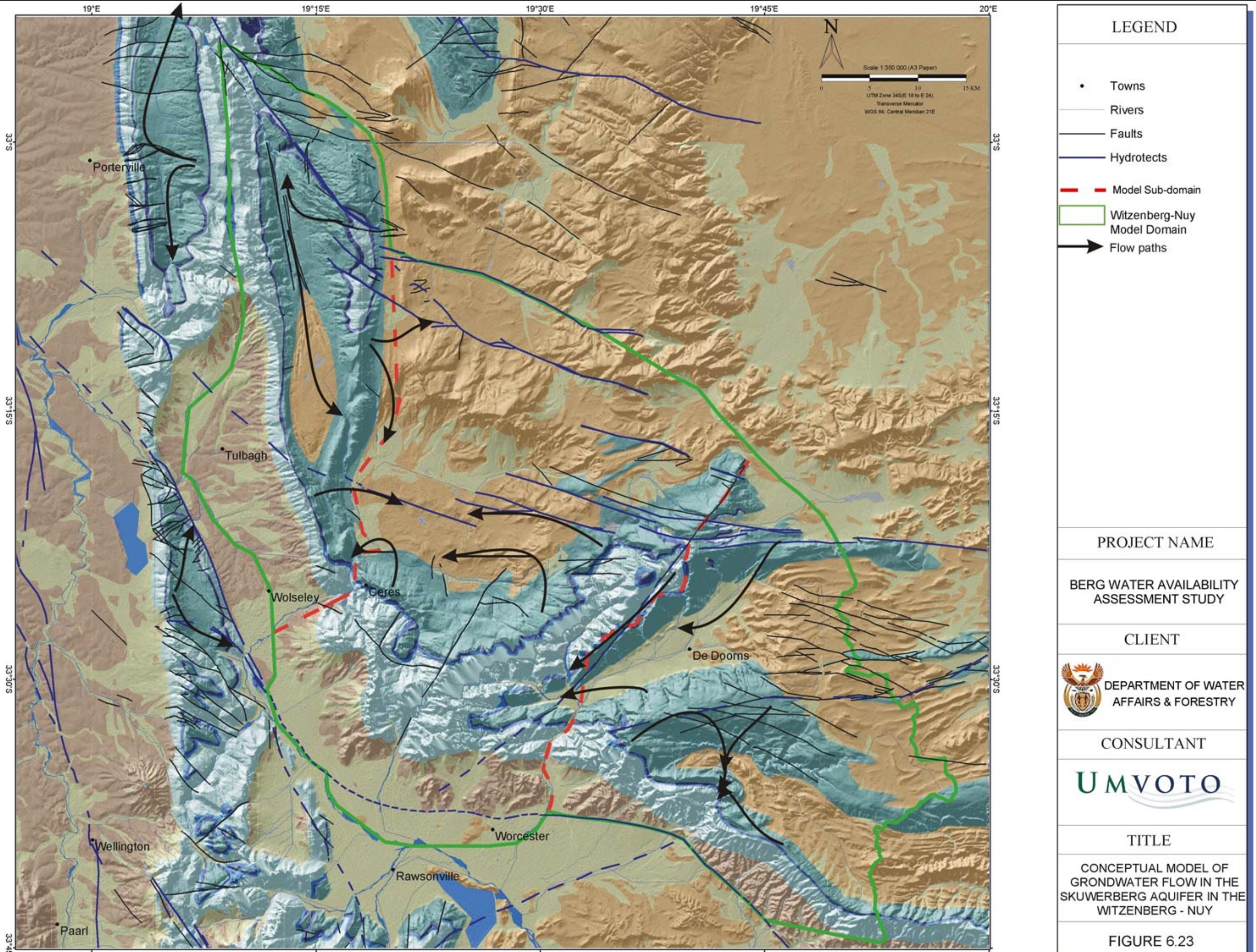
CONSULTANT

UMVOTO

TITLE

CONCEPTUAL MODEL OF GRONDWATER FLOW IN THE PENINSULA AQUIFER IN THE WITZENBERG - NUY

FIGURE 6.22



PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

CONCEPTUAL MODEL OF GRONDWATER FLOW IN THE SKUWERBERG AQUIFER IN THE WITZENBERG - NUY

FIGURE 6.23

High rainfall occurs in the high lying mountainous areas onto the unconfined Peninsula wherein the groundwater is recharged. The groundwater flow in the Peninsula aquifer from these high recharge areas, to the discharge areas is illustrated in **Figure 6-22** and **Figure 6-24**. Flow in the Agter Witzenberg valley is directed southward along the Agter Witzenberg Syncline and discharged in the Mitchell's Pass. Flow in the Hex River Mountains is recharged by confined groundwater below the Warm Bokkeveld as well as high rainfall in the southern extension of the Hex River Mountains. This groundwater flow in the Peninsula Formation is discharged into the Hex River surface water flow. Rainfall in the Waaihoekberge and environs is discharged via surface water and groundwater flow directly into the Breede River. Groundwater flow in the Kwadousberg joins the Hex River Valley and is discharged into the Breede River.

Groundwater flow in the overlying Skurweberg Aquifer differs from that of the Peninsula Aquifer. While groundwater flow in the Peninsula Aquifer flows west to east into the Hex River, groundwater flow in the Skurweberg Aquifer flows east to west away from the Hex River into the Warm Bokkeveld (See **Figure 6-23** and **Figure 6-25**).

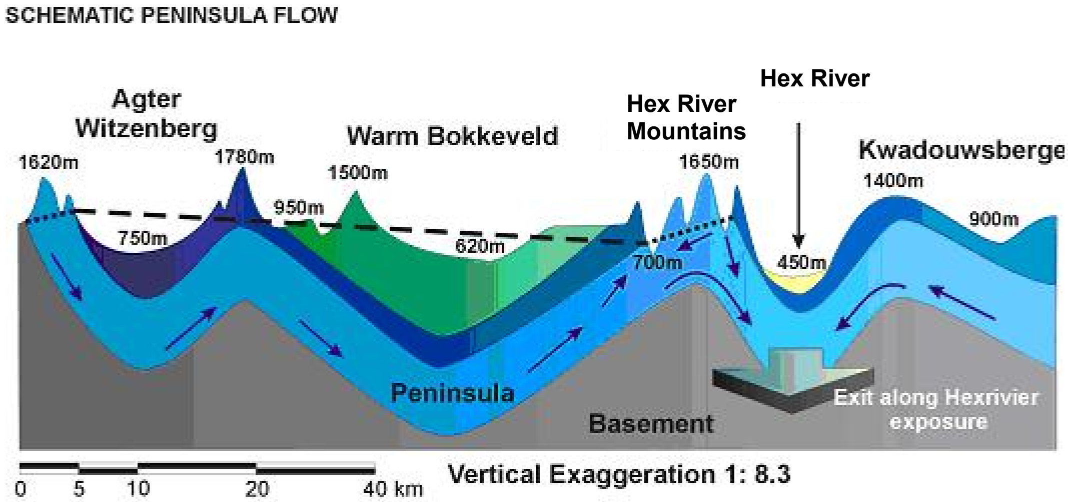


Figure 6-24 Vertical section illustrating the conceptual groundwater flow the Peninsula Aquifer in the Witzenberg-Nuy area

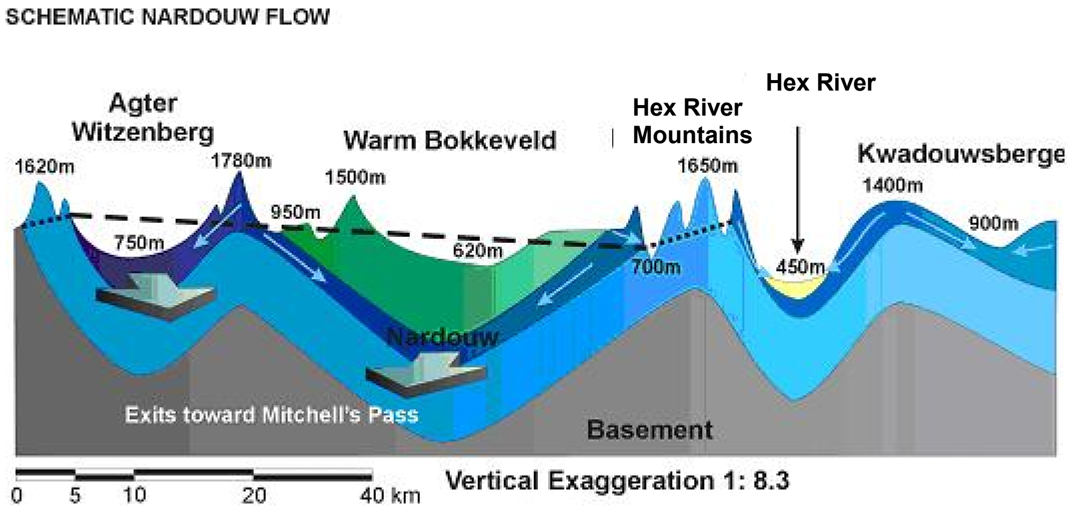


Figure 6-25 Vertical section illustrating conceptual groundwater flow in the Nardouw Aquifer in the Witzenberg-Nuy area

6.5 BREEDE RIVER ALLUVIUM – TMG

The Breede River Alluvium is located in the valley south of Worcester, adjacent to the Brandvlei Dam. This aquifer is recharged from several different directions including from surface water in the Breede River, and groundwater in the Peninsula Aquifer in the surrounding mountains to the south. The model boundary follows the contact between the Peninsula Formation and the Malmesbury sediments to the north and includes the WRS, RBT, DUT, MCG and ELA IWRM domains (See **Section 5**).

6.5.1 Motivation

The upper Breede River valley between Wolseley and Nuy is filled with sand and gravel deposits, which constitute an extensive aquifer (Van Zijl et al, 1981). The agricultural community in the valley utilises groundwater from this aquifer for irrigation as well as for domestic use in some of the towns. The upper Breede Riverand the existing dams (e.g. Brandvlei Dam) are considered for further augmentation of the Berg River WMA. Since the aquifer is already utilised, the water balance in this area and its split between surface water and groundwater needs to be reconciled. Additionally, the impact of further groundwater development on stream flow, the impact of river diversion on the groundwater level and quality, and the cumulative impact of both activities need to be simulated prior to decisions about upgrading of schemes.

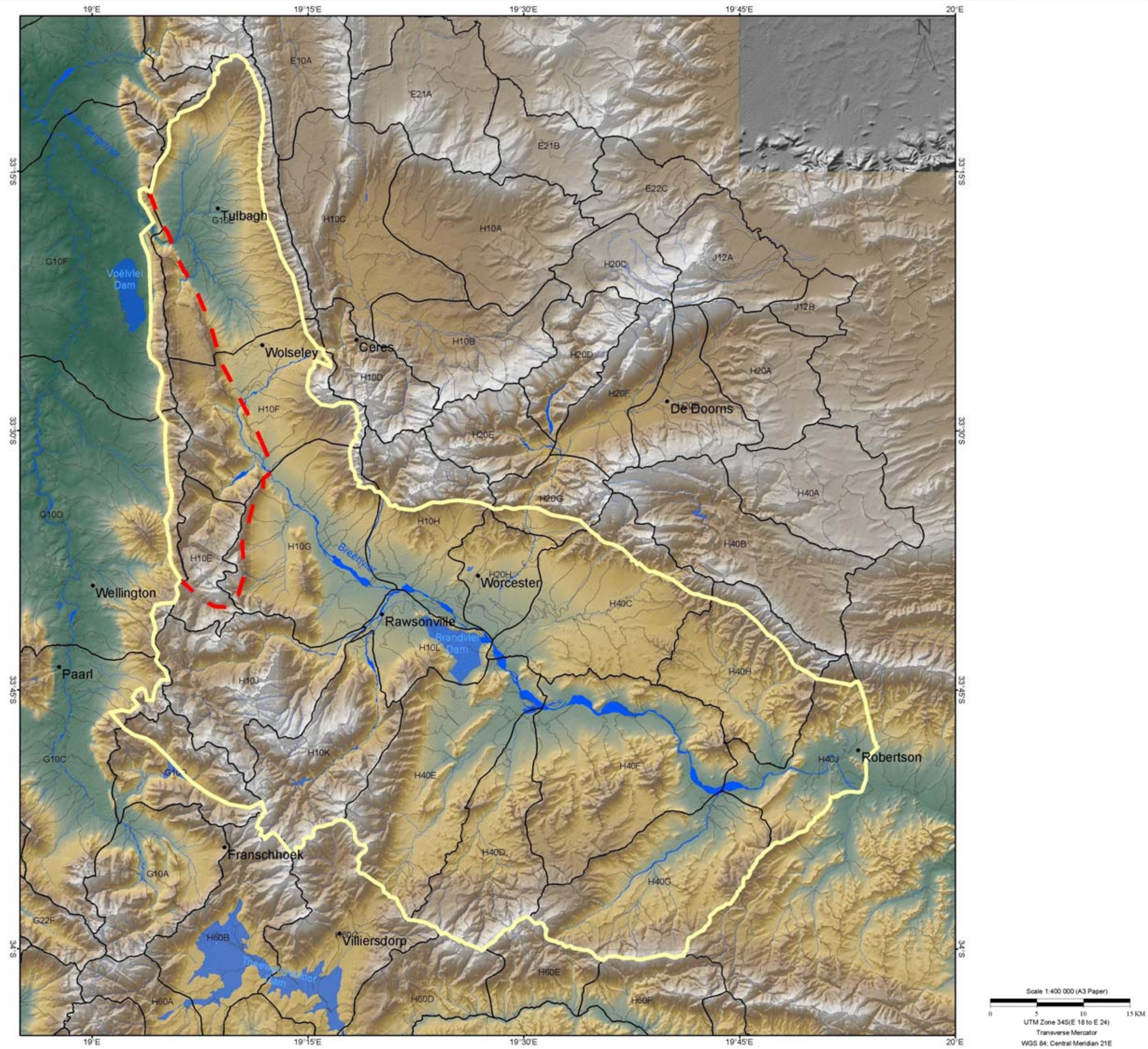
6.5.2 Conceptual Model

The north-eastern boundary of the model domain coincides with the south-western limit of the Winterhoek-Koo Model, such that the SW output boundary conditions for the latter become in input boundary condition for the former.

The southern part of the Breede Alluvium area is mountainous terrain that opens up into the broad Worcester Valley in the north (see **Figure 6-26**). Bounding the western margin are the Elandskloof, Watervals, Limiet and Slanghoek Mountains. The southwestern corner of the Domain is host to the high mountains of the Du Toits Mountains, with steep slopes and deeply incised kloofs. The Wabooms Mountains separate the Breede Alluvium in the center, with the Brandvlei Dam situated at their northern extension. The south-eastern corner is bounded by the Riviersonderend Mountains and the northeast extending Klipberge.

Surface water drains from the mountainous areas toward the Breede River (see **Figure 6-26**). The Wit River and Wabooms River enter the Breede River just south of the Tulbagh-Ceres Valley. The Slanghoek River enters into the Breede River north of the Badsberg. The Molenaars and Holsloot Rivers traverse the Breede Alluvium alluvial fan from the Du Toits mountains in the south, while the Jan Du Toits River enters the Breede River from the southern extension of the Hex River Mountains. The Hex River, Nuy and Doring River all enter the Breede River channel below the Brandvlei Dam and out of the immediate area of interest to the Breede Alluvium.

The Breede Alluvium area contains the full geological stratigraphy present in the Berg WAAS area (see **Figure 6-27**). The mountains to the south and west are made up of the resistant Table Mountain Group with local inliers of Malmesbury and Cape Granite Suite basement evident in the deep kloofs. The broad valley extending north-east from Villiersdorp to Robertson includes rocks of the Bokkeveld and Witteberg Groups and the tertiary sediments of the Karoo Supergroup. These are displaced by the large east-west trending Worcester Fault against further Malmesbury and Cape Granite Suite basement rocks in the northern part of the Worcester valley.



LEGEND

- Towns
- Rivers
- Dams
- Model Sub-domain
- Breede Model domain
- Standard basins
- Quaternary Catchments

Elevation (mamsl)

- 35 - 105
- 105 - 170
- 170 - 240
- 240 - 310
- 310 - 450
- 450 - 585
- 585 - 1000
- 1000 - 1140
- 1140 - 1480
- 1480 - 2101

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

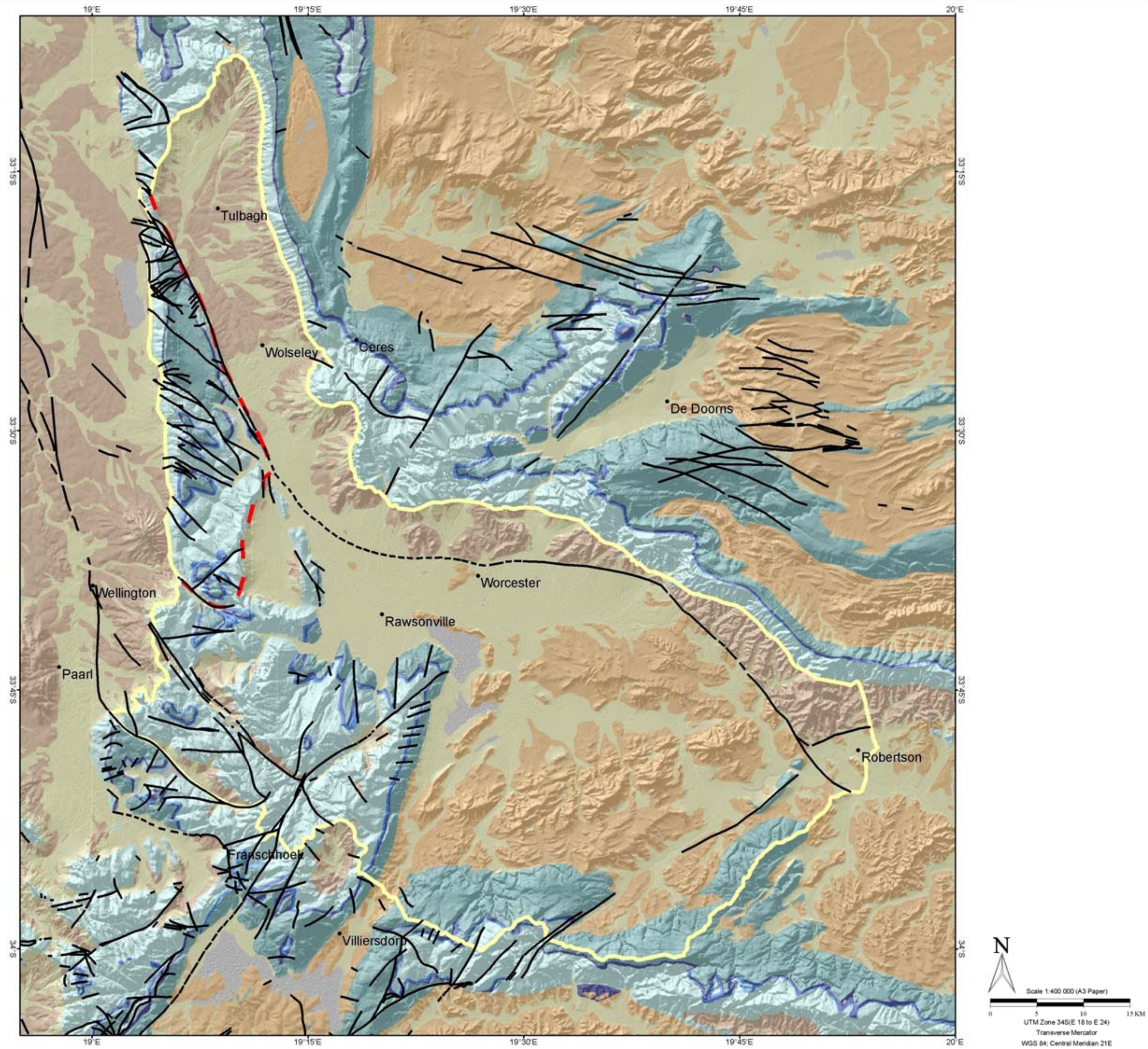
CONSULTANT

UMVOTO

TITLE

LOCALITY AND DRAINAGE IN THE BREEDE RIVER ALLUVIAL

FIGURE 6.26



LEGEND

- Towns
- Faults
- Model Sub-domain
- Breede River Alluvial Model Domain

SIMPLIFIED LITHOLOGY

- Quaternary
- Pre_Cape
- Nardouw Group
- Cedarberg Formation
- Pakhuis Formation
- Peninsula Formation
- Graafwater Formation
- Piekenierskloof Formation
- Post_TMG
- Dam

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

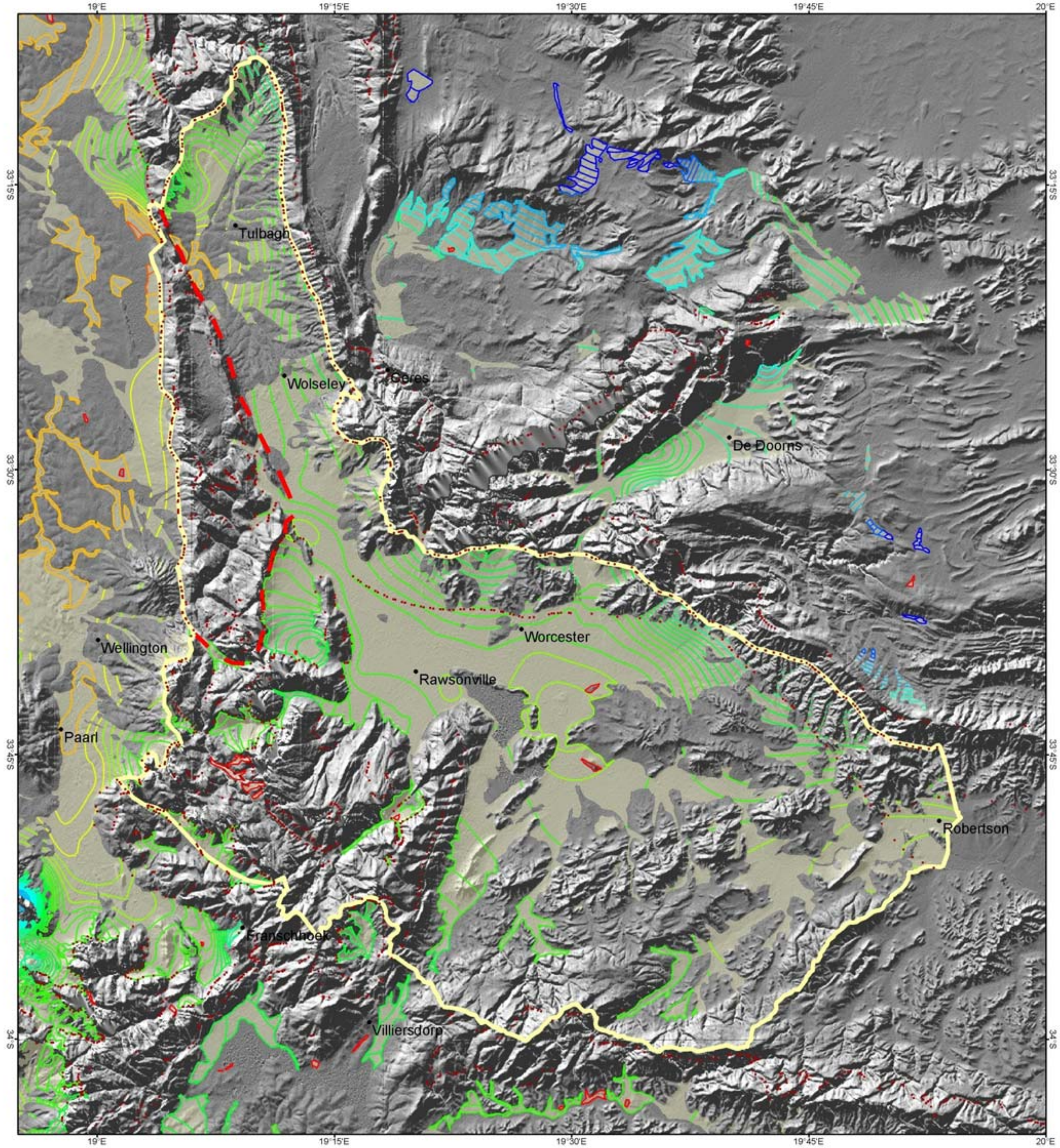
CONSULTANT

UMVOTO

TITLE

GEOLOGY IN THE BREEDE RIVER ALLUVIAL

FIGURE 6.27



N

Scale 1:400 000 (A3 Paper)

0 5 10 15 KM

UTM Zone 34S(E 18 to E 24)
Transverse Mercator
WGS 84; Central Meridian 21E

LEGEND

- Towns
- Water Level Points
- Model Sub-domain
- Breede River Alluvial Model Domain
- Sandvel Outcrop

Water Level (mamsl)

- -243 - 0
- 0 - 50
- 50 - 100
- 100 - 150
- 150 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 1017

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

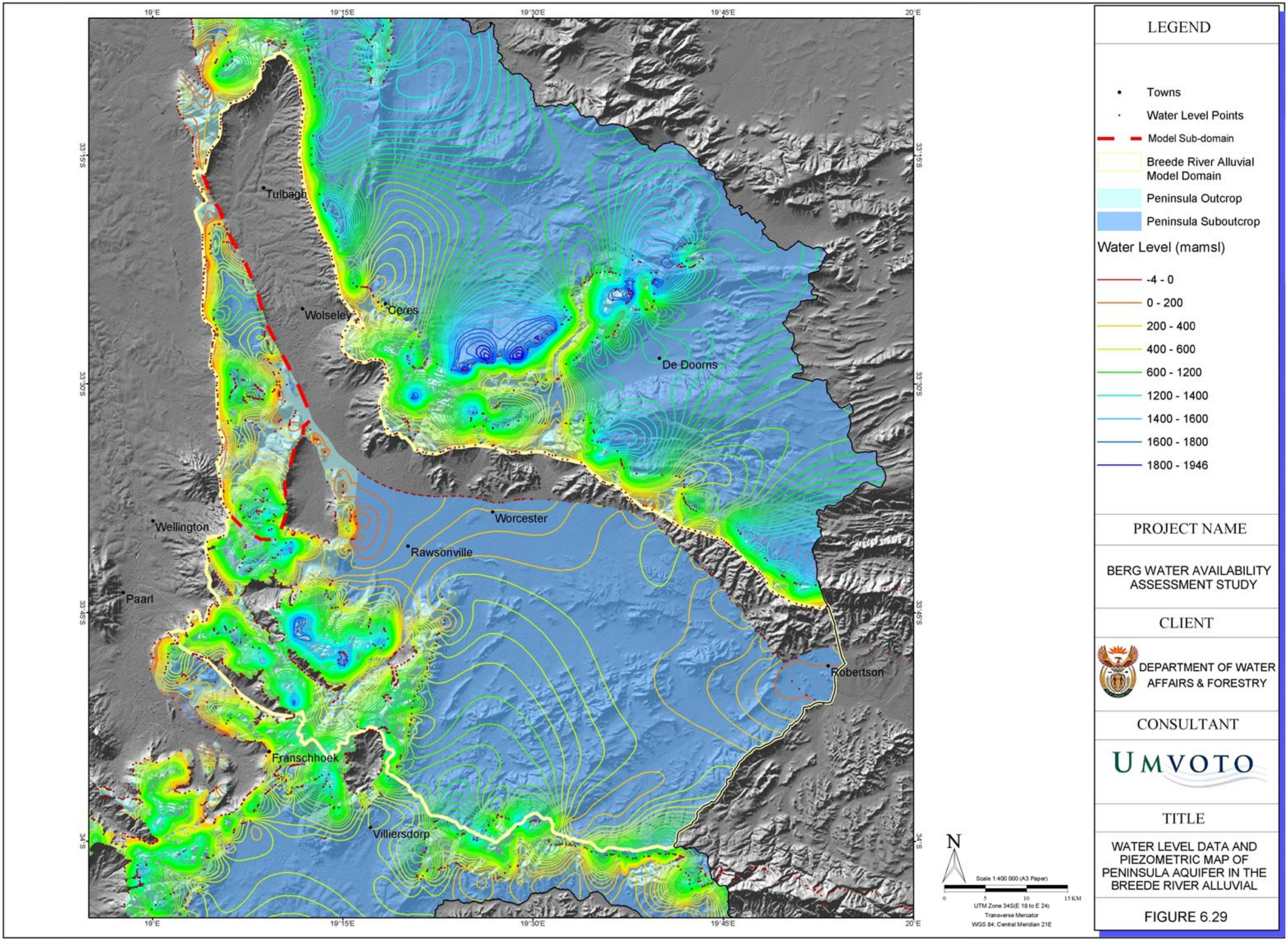
CONSULTANT

UMVOTO

TITLE

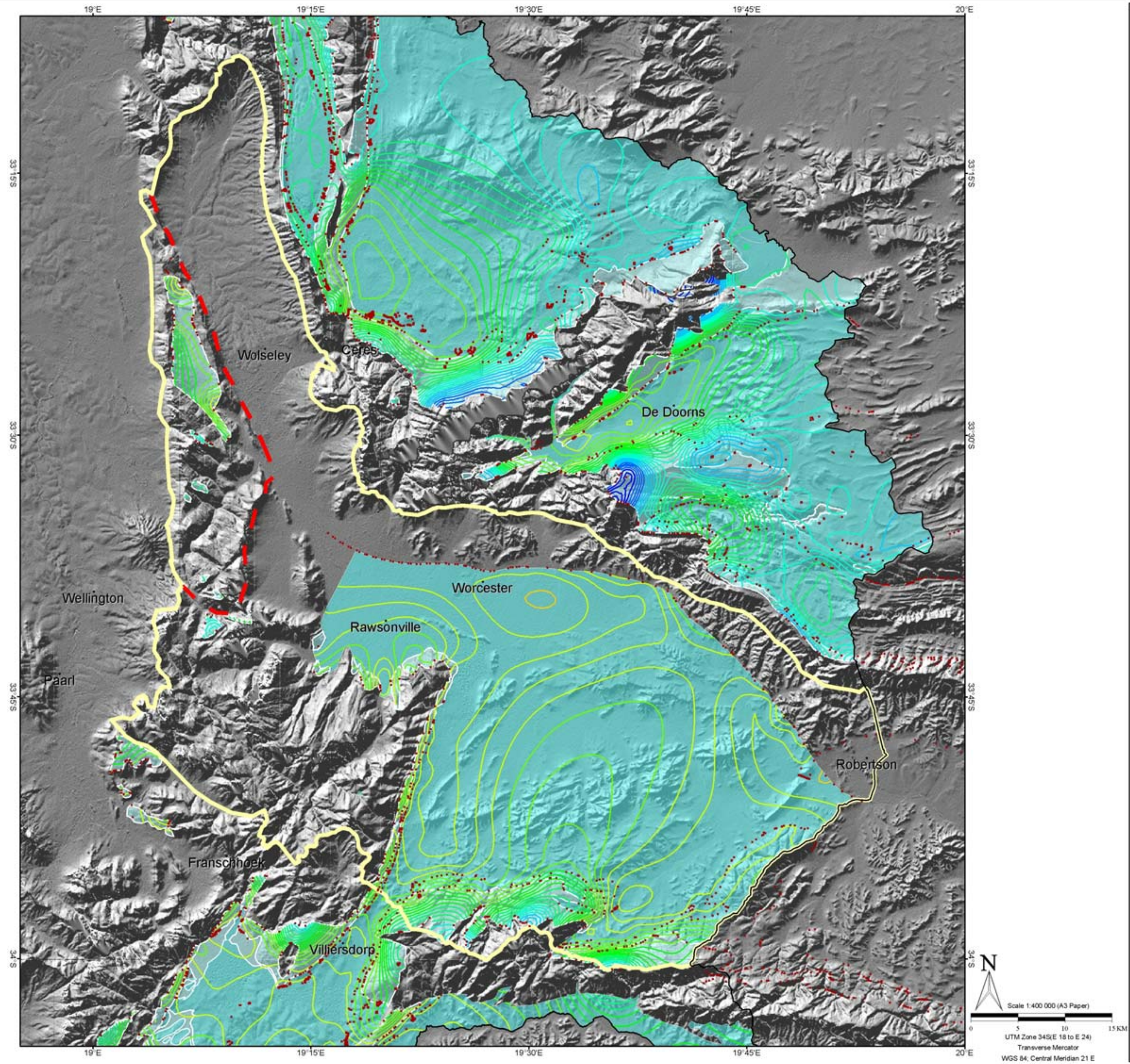
WATER LEVEL DATA AND PIEZOMETRIC MAP IN THE BREEDE RIVER ALLUVIAL AQUIFER

FIGURE 6.28



WATER LEVEL DATA AND PIEZOMETRIC MAP OF PENINSULA AQUIFER IN THE BREEDE RIVER ALLUVIAL

FIGURE 6.29



LEGEND

- Towns
- Water Level Points
- Breede River Alluvial Model Domain
- Model Sub-domain
- Skurweberg Outcrop
- Skurweberg Suboutcrop

Water Level (mamsl)

- -30 - 0
- 0 - 100
- 100 - 200
- 200 - 400
- 600 - 1000
- 1000 - 1200
- 1200 - 1400
- 1400 - 1600
- 1600 - 1870

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS

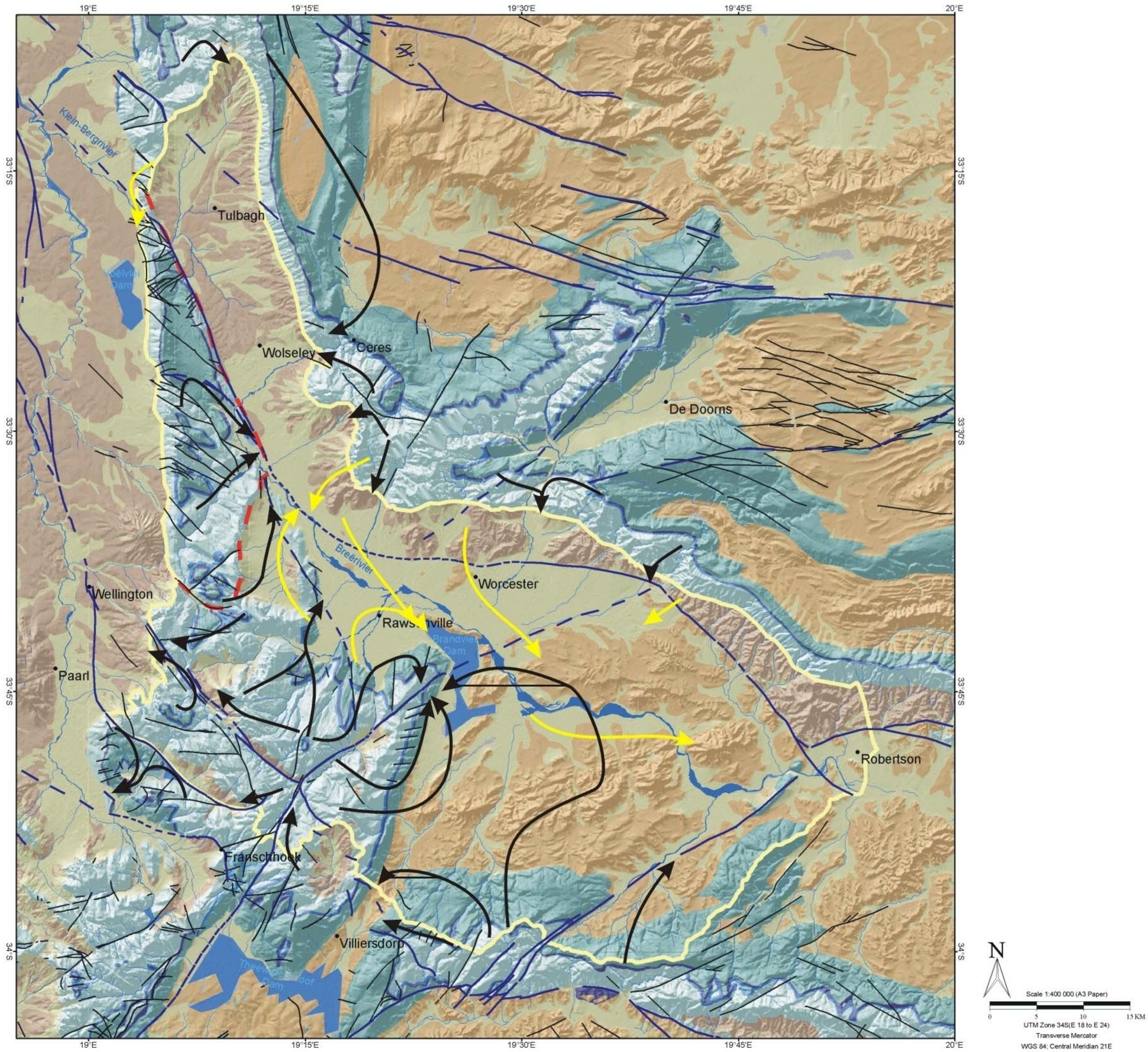
CONSULTANT

UMVOTO

TITLE

WATER LEVEL DATA AND PIEZOMETRIC MAP OF SKURWEBERG/RIETVLEI AQUIFER IN THE BREEDE RIVER ALLUVIAL

FIGURE 6.30



LEGEND

- Towns
- Rivers
- Dams
- Faults
- Hydrotects
- Model Sub-domain
- Breede Model Domain

(For geology legend refer Figure 5.1)

- Flow paths (Peninsula)
- Flow paths (Peninsula)

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

CONCEPTUAL MODEL OF GROUNDWATER FLOW IN THE BREEDE RIVER ALLUVIAL AQUIFER

FIGURE 6.31

Water level data points are sparse and irregularly spaced in the Breede Alluvium area. Water flow occurs from the high surrounding mountains into the Breede Alluvium.

Conceptually, the alluvial aquifers of the Breede River valley between Wolseley in the NW and the Nuy area in the east are recharged by surface-water flow from both the northern side (Hex River and Langeberg mountains) and the southern side (Du Toits Kloof and Stettynskloof ranges), and by flood recharge along the Breede channel itself (see **Figure 6-31**). Groundwater recharge to these aquifers may be related to overspill of “rejected recharge” from the Peninsula and Skurweberg aquifers around the northern slopes of the Du Toits Kloof Mountains, augmented by flow of deeper origin around the Goudini and Brandvlei hot springs.

Discharge from the alluvial system occurs in an easterly direction along the main channel of the Breede River, depending on the relative elevation of the water table with respect to river level (effluent or influent condition).

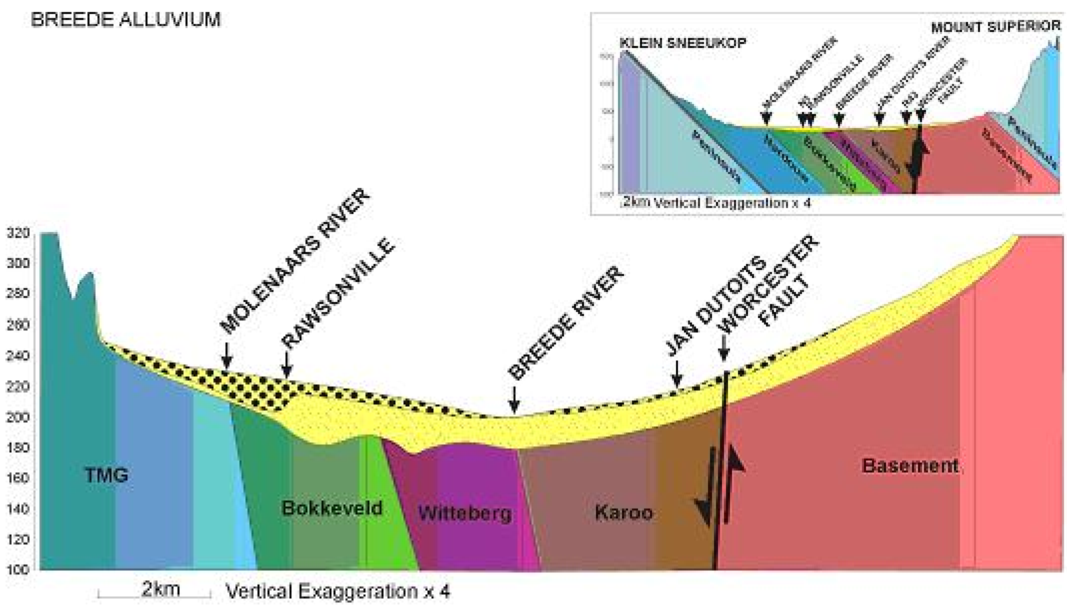


Figure 6-32 Vertical longitudinal section through the Worcester Valley

showing the Breede Alluvial Fan making up the Breede Alluvium Aquifer (Yellow, adapted from Meyer et al., 1981). The Breede Alluvium Aquifer is subdivided into an upper Boulder layer (yellow with black spots) and a lower Sand Layer (uniform yellow).

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The main conclusions that can be drawn from the conceptual modelling are:

- Recharge to the TMG aquifers occurs in the high lying mountainous ranges of the Cape Fold Belt, where the extensive outcrops of the Peninsula and Skurweberg Formations receive rainfall of up to 3400 mm/a.
- Recharge to the Sandveld aquifers occurs in the areas of aquifer exposure as well as through lateral and flood recharge. Due to the significantly lower amount of rain, the recharge volume and recharge percentage is expected to be lower than for the TMG aquifers.
- The groundwater from the different aquifers discharges either into rivers and streams via springs or along river reaches, or directly into the ocean.
- In some areas groundwater from the TMG discharges into the alluvium aquifers.
- Groundwater flow in the TMG aquifers follows structurally controlled preferred flow paths, called hydrotects.
- Groundwater flow in the Sandveld aquifers is controlled by the current surface topography and the bedrock topography, forming palaeo channels.

7.2 RECOMMENDATIONS

The recommendations below are suggested for implementation to verify model assumptions and hence to increase the confidence and, in case of hydraulic parameters, the certainty in the model outputs. It is therefore recommended to undertake the following additional data collection activities as part of a subsequent study:

- Spring hydrocensus
- Borehole hydrocensus
- Fracture mapping in TMG terrain
- Hydraulic testing in selected boreholes in both the Peninsula and Skurweberg aquifers
- Mapping of palaeochannels and bedrock topography in the West Coast and alluvium aquifers
- Hydrochemical sampling at specific river reaches
- Review and revise geological mapping in selected areas
- Review and revise monitoring network.

The following recommendations are made for the subsequent water balance model and the detailed groundwater flow models:

c) Extend the study area for the groundwater component at the northern boundary to reflect the results of the structural analysis and conceptual flow modelling in these areas.

d) Undertake the water balance modeling for the extended study area on an aquifer-specific basis.

e) Combine the proposed detailed models of Task 15b (TMG Tulbagh – Ceres) and Task 15c (TMG Hex River Mountains) into one model domain, called TMG Witzenberg – Nuy Valley.

f) Restrict the detailed modelling of the West Coast aquifers (Task 14a) to the Langebaan Road and Geelbek aquifers.

g) Extend the model domain for the detailed model of Task 15d (TMG Piketberg) towards the coast to include the interaction with the primary aquifer in the Verlorenvlei palaeo channel.

h) Set-up, configure and run the detailed groundwater flow models for the revised model domains:

- Cape Flats Aquifer
- Langebaan Road and Geelbek aquifers
- Piketberg TMG and Verlorenvlei palaeo channel aquifers
- Witzenberg – Nuy TMG aquifers
- Breede Alluvium.

8. REFERENCES

Al-Aswad, A.A. and Al-Bassam, A.M. (1997). Proposed hydrostratigraphical classification and nomenclature: application to the Palaeozoic in Saudi Arabia. J. Afr. Earth Sci. 24 (4), 497-510.

Anderson, M.P. and Woessner, W.W. (1992). Applied Groundwater Modeling. Academic Press, Inc., San Diego, CA., 381 p.

Bateman, M.D., Holmes, P.J., Carr, A.S. Horton, B.P. and Jaiswal, M.K. (2004). Aeolianite and barrier dune construction spanning the last two glacial-interglacial cycles from the southern Cape coast, South Africa. Quat. Sci. Rev., 23, 1681-1698.

Bidwell, V. (2003). Groundwater Management Tools: Analytical Procedure and Case Studies. New Zealand Ministry of Agriculture and Forestry Technical Paper No. 2003/06, 56 pp.

Birch, GF (1968). Some Eustatic Shorelines along the False Bay Coasts. Unpubl. BSc (hons) thesis, Univ. Cape Town, 99 pp.

Botha, L. (March 2007). Review of DWAF Project W8174/04

Braune, E. and Dziembowski, Z.M. (1997). Towards integrated groundwater and surface water management in South Africa; Paper presented at 8th South African National Hydrological Symposium, Pretoria, November 1997.

Broquet, C.A.M. (1992). The sedimentary record of the Cape Supergroup: A review. In De Wit, M.J. and Ransome, I.G.D. (eds). Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous Basin of Southern Africa. A.A. Balkema, Rotterdam, 159-183.

Clark, I.D. and Fritz P. (1997). *Environmental Isotopes in Hydrogeology*. Boca Raton, NY: Lewis Publishers.

Chamberlin, T.C. (1890). The method of multiple working hypotheses. Science, 15, p.92ff (reprinted in Science, 148, 754-759, 1965).

City of Cape Town (2001). Integrated Water Resource Planning Study. Ninham Shand and Arcus Gibb.

City of Cape Town (2004a). Hydrogeological Report. Prepared by the TMG Aquifer Alliance as part of the Preliminary Phase of the Table Mountain Group Aquifer Feasibility Study and Pilot Project.

City of Cape Town (2004b). Hydrocensus Report. Prepared by the TMG Aquifer Alliance as part of the Preliminary Phase of the Table Mountain Group Aquifer Feasibility Study and Pilot Project.

City of Cape Town (2004c). Wellfield Operation Report. Prepared by the TMG Aquifer Alliance as part of the Preliminary Phase of the Table Mountain Group Aquifer Feasibility Study and Pilot Project

City of Cape Town (2005a). CVA Report. Prepared by the TMG Aquifer Alliance as part of the Exploration Phase of the Table Mountain Group Aquifer Feasibility Study and Pilot Project.

City of Cape Town (2005b). Hydrocensus Report. Prepared by the TMG Aquifer Alliance as part of the Preliminary Phase of the Table Mountain Group Aquifer Feasibility Study and Pilot Project.

City of Cape Town (2006). Hydrocensus Report. Prepared by GEOSS as part of the Exploration Phase of the Table Mountain Group Aquifer Feasibility Study and Pilot Project.

Diamond, R.E. (1997). Stable isotopes of the thermal springs of the Cape Fold Belt. Unpubl. MSc thesis, Univ. of Cape Town, 82 pp.

Deacon, H.J. and Deacon, J. (1999). Huamn Beginnings in South Africa: Uncovering the secrets of the Stone Age. David Philip Publishers, Cape Town, 214 pp.

De La Cruz, M.A. (1978). Marine Geophysical and Geological Investigations in Saldanha Bay. Joint Geol. Surv./Univ. Cape Town Mar. Geosci. Group, Bull No. **9**, 115 pp.

Department of Water Affairs and Forestry (2000). Reconnaissance investigation into the development and utilisation of the Table Mountain Group artesian groundwater, using the E10 Catchment as a pilot study area: Final Report. Umvoto Africa cc and SRK Joint Venture. Cape Town. 2000

Department of Water Affairs and Forestry (2000). Hydrogeological Map Series 1:500 000 – Cape Town

Department of Water Affairs and Forestry (2003a). Berg River Baseline Monitoring Project: Description of Geohydrological Conditions, Groundwater Atlas. Parsons and Associations in association with SRK Consulting.

Department of Water Affairs and Forestry (2003b). Guidelines for Models to be Used for Water Resources Evaluations

Department of Water Affairs and Forestry (2003c). Berg Water Management Area: Overview of Water Resources Availability and Utilisation. Prepared by BKS (Pty) Ltd, on behalf of the Directorate: National Water Resource Planning. DWAF Report No. P WMA 19/000/00/0203

Department of Water Affairs and Forestry (2003d). Breede Water Management Area: Overview of Water Resources Availability and Utilisation. Prepared by BKS (Pty) Ltd, on behalf of the Directorate: National Water Resource Planning. DWAF Report No. P WMA 18/000/00/0203

Department of Water Affairs and Forestry (2004a). Berg Water Management Area: Internal Strategic Perspective. Prepared by Ninham Shand (Pty) Ltd in association with Jakoet and Associates, Umvoto Africa, FAT and Tlou and Matji, on behalf of the Directorate: National Water Resource Planning.

Department of Water Affairs and Forestry (2004b). Breede Water Management Area: Internal Strategic Perspective. Prepared by Ninham Shand (Pty) Ltd in association with Jakoet and Associates, Umvoto Africa, FAT and Tlou and Matji, on behalf of the Directorate: National Water Resource Planning.

Department of Water Affairs and Forestry (2004c). Groundwater Resource Assessment, Phase II Task 1 – Groundwater Quantification, Version 2.0 Final.

Department of Water Affairs and Forestry (2004d). Groundwater Resource Assessment, Phase II Task 2 – Planning Potential Map, Version 1.1.

Department of Water Affairs and Forestry (2004e). Groundwater Resource Assessment, Phase II Task 3a – Recharge Methodology, Version 1.0 Final.

Department of Water Affairs and Forestry (2004f). Groundwater Resource Assessment, Phase II Task 3b – Groundwater – surface water interactions, Version 1.

Department of Water Affairs and Forestry (2004g). Groundwater Resource Assessment, Phase II Task 5 – Groundwater Use, Version 1.0 Final.

Department of Water Affairs and Forestry, (2005). The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models: Inception Report, Final draft, September 2005 submitted by Ninham Shand in association with Umvoto Africa, Project No. W8147/04.

Department of Water Affairs and Forestry (2006a). The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models : Assessment of Flow Gauging Stations. Prepared by Ninham Shand (Pty) Ltd in association with Umvoto Africa (Pty) Ltd on behalf of the Directorate : National Water Resource Planning.

Department of Water Affairs and Forestry (2006b). Groundwater Dictionary. Developed by the Institute for Groundwater Studies (IGS).

Department of Water Affairs and Forestry (2006c). GRDM - Groundwater Resource Directed Measures, version 3. Software package developed by the Institute for Groundwater Studies (IGS).

Department of Water Affairs and Forestry (2006d). Groundwater Resource Evaluation Report. Prepared by ER Hay, CJH Hartnady, K Riemann, S Hartmann and L Groenewald of Umvoto Africa, as part of the Feasibility Study for the raising of Clanwilliam Dam in the Western Cape.

Department of Water Affairs and Forestry (2007). The Assessment of Water Availability in the Berg Catchment (WMA 19) by Means of Water Resource Related Models : Groundwater Model Report Volume 2 – Data Availability and Evaluation. Prepared by Umvoto Africa (Pty) Ltd in association with Ninham Shand (Pty) Ltd on behalf of the Directorate : National Water Resource Planning. DWAF Report No. P WMA 19/000/00/0407.

Department of Water Affairs and Forestry (2008). The Assessment of Water Availability in the Berg Catchment (WMA 19) by Means of Water Resource Related Models : Report 4 (Land Use and Water Requirements): Volume 3 (Water Use and Water Requirements). Prepared by Ninham Shand (Pty) Ltd in association with Umvoto Africa (Pty) Ltd on behalf of the Directorate : National Water Resource Planning. DWAF Report No. P WMA 19/000/00/0608.

Dupont, L.M. Donner, B. Vidal, L., Pérez, E.M., and Wefer, G. (2005). Linking desert evolution and coastal upwelling. Geology, 33, 461-464.

Freeze, R.A. and Cherry J.A. (1979). Groundwater. Prentice Hall. pp 604.

Gerber, A. (1980). Final Report on the geohydrology of the sand deposits in the Cape Flats; Report 620/9839/7, Water Research Commission, Pretoria.

Gresse, P.G. (Compiler) (1997). Sheet 3319 Worcester: 1:250 000 Geological Series. Council for Geoscience, Pretoria.

Gresse, P.G., and Theron, J.N. (1992). The Geology of the Worcester Area: Explanation of Sheet 3319, scale 1:250 000, by the Geological Survey for the Department of Mineral and Energy Affairs.

Government of South Africa. (1998). South African National Water Act, Act no. 36 of 1998.

Harris, C. and Talma A.S. (2002). The application of isotopes and hydro-chemistry as exploration and mangement tools. In: PIETERSEN K and PARSONS R (eds). A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy. WRC Report No TT 158/01, Water Research Commission Pretoria, p. 62-70.

Hartnady, C.J.H., Newton A.R. and Theron J.N. (1974). The stratigraphy and structure of the Malmesbury Group in the southwestern Cape. Bull. Precambr. Res. Unit, Univ. Cape Town, 15, 193-213.

Hartnady, C.J.H. and Curot, S. (2002). In situ borehole laboratory for TMG fractured rock hydrotectonics research. Blikhuis Experimental Deep Drilling (BEDD) Project, Table Mountain Group (TMG), Western Cape Province, South Africa.

Hartnady, C.J.H. (in prep.). Blikhuis Experimental Deep Drilling (BEDD) - Drilling and Geophysical Results. Final Report.

Hay E.R. (1981). A Stratigraphic and Sedimentological Analysis of Borehole Data from a Portion of the Cape Flats. Unpubl. BSc (Hons) thesis, Univ. Cape Town, 53 pp.

Hay, E.R., Hartnady, C.J.H., Goldberg, K., Jackson, C. Mlisa, A. and Riemann, K. (2004). Groundwater resource evaluation and management in a natural laboratory setting, in: Proceedings Finite element, Modflow and more 2004, Carlsbad, September 2004.

Haywood, I., Cornelius S. and Carver S. (2002). An Introduction to Geographic Information Systems. 2nd Edition. Prentice Hill.

Hendey, Q.B. (1982). Langebaanweg: A Record of Past Life. South African Museum, Cape Town, South Africa, 71 pp.

Henzen, M.R., (1973). Die Herwinning, Opberging en Onttrekking van Gesuiwerde Rioolwater in die Kaapse Skiereiland, Volume II. Nasionale Instituut vir Waternavorsing Suid-Afrikaanse Wetenskaplike en Nywerheidnavorsingsraad.

Hill, R.S. (1988). Quaternary faulting in the south-eastern Cape Province. S. Afr. J. Geol. 91 (3), 399-403.

Hiscock, K.M., (2005). Hydrogeology: Principles and Practise. Published by Blackwell Science Ltd. Australia. UK, pp 389.

http://www.geoafrica.co.za/REDDOG/groundwater/aquachem/aquachem.htm

Lowry, T., and Bright, J. (2002). Groundwater Management Tools: Draft Guidelines for Groundwater Allocation Management. Lincoln Environmental Report No. 4563/1 (Lincoln University, Canterbury, New Zealand).

Lowry, T., Bright, J., Robb, C., White, P.A., Cameron, S.G. and Close, M.E. (2001). Lincoln Environmental Report No. 4482/1 (Lincoln University, Canterbury, New Zealand), 30 pp.

Luger, M. and Hay E.R. (2002). Are Environmental Impact Assessments meeting the challenges of groundwater utilisation? Motivation for an alternative risk management approach. In: Proceedings: Tales of the hidden Treasure, Groundwater Division Western Cape Conference, Somerset West, 16 September 2002.

MacVicar, C.N., De Villiers J.M., Loxton R.F., Verster E., Lambrechts J.J.N., Merryweather F.R., Le Roux J., Van Rooyen T.H. and Von M. Harmse H.J. (1977). Soil Classification – A Binomial System for South Africa, The Soil and Irrigation Research Institute.

McKay, H.M. (1999). Water resources protection policy implementation. Resource directed measures for protection of water resources. Integrated manual. Department of Water Affairs and Forestry. Report No N/28/99.

Midgley, D.C., Pitman W.V., and Middleton B.J. (1994). Surface Water Resources of South Africa 1990: Book of Maps. Vol IV, First Edition. Water Research Commission. WRC Report No 298/4.2/94.

Mosala, T.C. (2006). A Study of the Hydrostratigraphy of the Table Mountain Group in the Oudtshoorn Area in the Western Cape. B.Tech Geology Thesis at Tshwane University of Technology, March 2006.

Murray, E.R., (1996). Guidelines for Assessing Single Borehole Yields in Secondary Aquifers, MSc Thesis, Rhodes University, Grahamstown, pp 138.

Newton, A.R. (1975). Structural applications of remote sensing in the Cape Province, and a new model for the evolution of the Cape Fold belt. PhD Thesis, unpublished, University of Cape Town. 86 pages, 16 Figures, 8 Plates and 8 Maps.

Parsons, R. (2001). Input into the Report "The evaluation of alternatives for the attenuation of phosphorous-rich groundwater discharging from the Cape Flats Waste Water Treatment Works into Zeekoeivlei", June 2002

Parsons, R. (2003). Berg River Baseline Monitoring Project, Description of Geohydrological Conditions – Groundwater Atlas.

Parsons, R. and Wentzel, J. (2005). Groundwater Resource Directed Measures: Assessment of the E10 Catchment, Pilot Study. Water Research Commission (WRC) Project No. K5/1427.

Reggiani, P., Sivapalan, M. and Hassanizadeh, S.M. (1998). A unifying framework for watershed thermodynamics: balance equations for mass, momentum, energy and entropy, and the second law of thermodynamics. Advances in Water Resources, 22:367-398.

Rust, I.C (1967). On the sedimentation of the Table Mountain Group in the Western Cape Province. Unpubl. DSc thesis, Univ. Stellenbosch.

Rogers, J. (1980). *First Report on the Cenozoic Sediments between Cape Town and Elands Bay.* Geological Survey of South Africa Open File Report No. 165.

Schulze, R.E., Maharaj, M., Lynch, S.D., Howe, B.J. and Melville-Thomson, B. (1997). South African Atlas of Agrohydrololgy and Climatology.

Smith, M.E., Clarke, S. and Cavé, L.C. (2002). Chemical evolution of Table Mountain Group groundwater and the source of iron. In: Tales of a Hidden Treasure. Regional groundwater conference. Ground Water Division, Geological Society of SA, Somerset West, Sept. 2002.

SRK (2003). Assessment of Development Potential of Groundwater Resources for the West Coast District Municipality, Report for the DWAF and the West Coast Municipality.

SRK (2004) Pre-feasibility Study: Elandsfontein and Adamboerskraal Aquifer Systems, Report for the DWAF and the West Coast Municipality.

Suppe, J. (1983). Geometry and Kinematics of Fault-bend Folding. American Journal of Science, Vol. 283, p. 684-721. September 1983.

Theron, J.N., Gresse, P.G., Siegfried, H.P., and Rogers, J. (1992). The Geology of the Cape Town Area: Explanation of Sheet 3318, scale 1:250 000, by the Geological Survey for the Department of Mineral and Energy Affairs.

Timmerman, L.R.A. (1987). Regional Hydrogeological Study of the Lower berg River Area, Cape Province - South Africa. Unpublished PhD thesis, State University Ghent, 236 pp. (3 Vols.)

Toerien, D.K. (1979). The geology of the Oudtshoorn area (Explanation to Sheet 3322, Scale 1:250 000) Geol. Surv. S. Afr., Pretoria, 13 pp.

Turc, L. (1954). "Le bilan d'eau sols. Relation entre les precipitation, l'évaporation et l'écoulement." Ann Agron., 5: 491-596; 6: 5-131.

Umvoto Africa (1997). Hydrogeology and Groundwater Resource Potential of the Olifants/Doring River Basin, Western and Northern Cape Provinces. Umvoto Africa CC report to Ninham Shand-BKS (September, 1997), 29 pp and 7 figs.

Umvoto Africa (2000). Citrusdal Artesian Groundwater Exploration (CAGE). Final report.

Umvoto Africa (2002). Greater Hermanus Area - Overstrand Municipality. Interim Report.

Umvoto Africa (2002). Boschkloof groundwater discovery. In: Pietersen, K. and Parsons, R. (eds). A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy. Water Research Commission Report TT158/01, 168-177.

Umvoto Africa (2005). Deep Artesian Groundwater for Oudtshoorn Municipal Supply: Target Generation & Borehole/Wellfield Siting using Structural Geology and Geophysical Methods (Phase D) Final Report. WRC Report No. K5/1254 Water Research Commission – chapter 3.

Vegter, J.R. (1995a). An Explanation of a set of National Groundwater Maps. Prepared for Water Research Commission report TT 74/95, 82 pp., Water Research Commission, Pretoria.

Vegter, J.R. (1995b). Groundwater Resources of the Republic of South Africa – Sheet 1 and Sheet 2. Maps published by the Water Research Commission, South Africa.

Vegter, J.R. (2001). Groundwater development in South Africa and an introduction to the hydrogeology of groundwater regions. Water Research Commission (WRC) Report No. TT 134/00,106 pp. 62.

Visser, H N. (1967). *Verspreiding en korrelasie van die Formasie Klipheuwel in die Swartland en die Strandveld*. Ann. Geol. Surv. S. Afr., 6, 31-38.

Visser, H.N., and Theron, J.N. (1973). 3218 Clanwilliam (1:250 000 Geological Series) Map & Explanatory Notes. South African Geological Survey, Pretoria.

Weaver, J.M.C, Talma, A.S., and Cavé, L.C., (1999). Geochemistry and isotopes for resource evaluation in the fractured rock aquifers of the Table Mountain Group, Vol. Water Research Commission (WRC) Report No. 481/1/99.

Wessels, W.P.J. and Greef, G.J. (1980). n Ondersoek na die optimale benutting van Eersterivierwater deur opberging in sandsafsettings of ander metodes; Department of Civil Engineering, University of Stellenbosch, Stellenbosch.

WRC (2003). Ecological and Environmental Impacts of Large-scale Groundwater Development in the Table Mountain Group (TMG) Aquifer System – Discussion Document for Scoping Phase. Report prepared by C. Brown, C. Colvin, C.J.H. Hartnady, E.R. Hay, D. le Maitre and K. Riemann. WRC Project K5/1327.

Zhang, G.P. and Savenije, H.H.G. (2005). Rainfall-runoff modelling in a catchment with a complex groundwater flow system: application of the Representative Elementary Watershed (REW) approach. Hydrology and Earth System Science, 9:243-261.

APPENDIX A

GEOLOGICAL HISTORY

APPENDIX A : OUTLINE OF THE GEOLOGICAL HISTORY

The geological history of the different, distinct geographic domains into which the study area is divided, is summarized below for the interest of the reader and because such knowledge informs the confidence associated with selected geological data sets and how they are used (see Volume 2 of this report (DWAF, 2007)). The history begins with the rifting of a former supercontinent and the opening of the Adamastor Ocean (see **Table A-1**) basin about 750 million years ago (750 Ma) and it continues today with the ongoing episode of seafloor spreading between the South American and African plates in the South Atlantic Ocean.

One of the most important geological episodes is the deposition of the Table Mountain Group (TMG) strata in an extensive basin on the margin of Gondwanaland (**Figure A-1**) in a setting not dissimilar (in scale or process) to that of the modern Amazon- or Ganges-type delta. The mature orthoquartzitic composition of the TMG sandstone testifies to intense chemical weathering under tropical to subtropical climates and to extensive transport by major fluviatile sedimentary systems arising in long mountain ranges with a high precipitation.

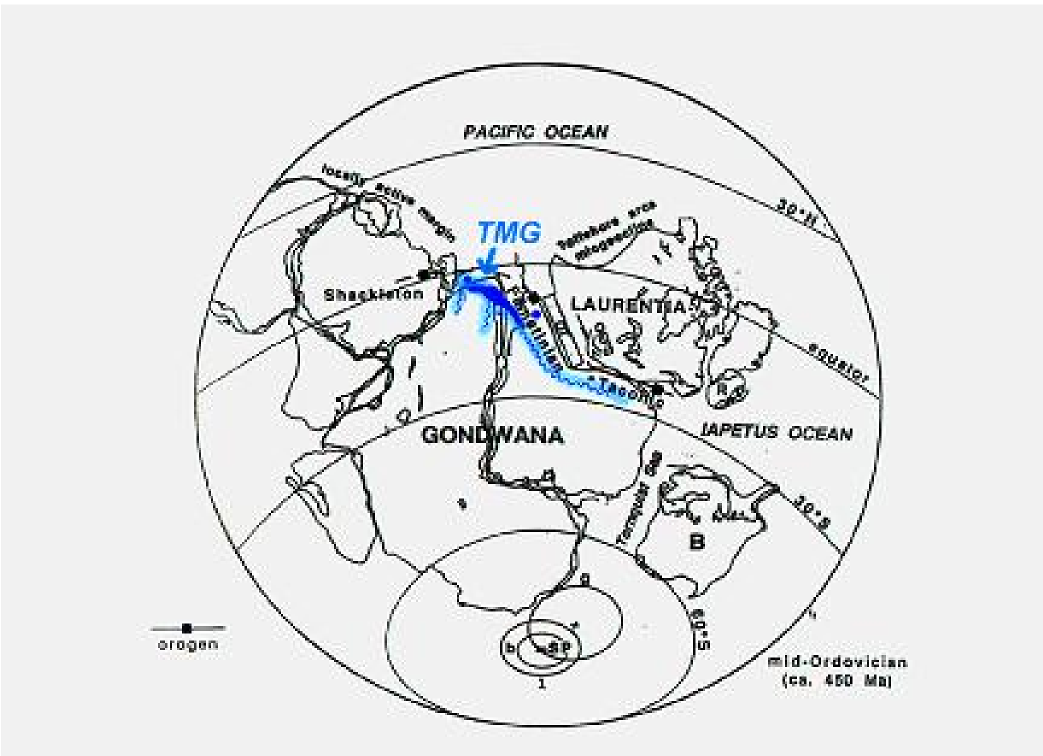


Figure A-1 Location of the TMG depositional basin in Gondwanaland, on the palaeo-pacific margin. Mature orthoquartzites formed from intense chemical weathering under tropical to subtropical climates and low latitude.

The warm palaeoclimatic conditions were very briefly interrupted around ~440 Ma ago by the anomalously short (<1 Ma) glacial episode that resulted in deposition of the Pakhuis Tillite on top of the Peninsula Formation in the TMG (see **Table 3-1**). This brief glaciation was immediately followed by an extensive sea-level rise, which is associated with the deposition of the Cedarberg shales. The different rock types, their stratigraphic sequence, and lithological details provide information, not only about the hydraulic behaviour, but also about the host-rock geochemistry and therefore the probable hydrochemical evolution of interstitial groundwater.

Another important episode is the later stage of Gondwanaland break-up, during which time the western part of southern Africa was apparently subjected to compressional forces that resulted in late N/S folding and strike-slip faulting in the north-south trending western arm of the Cape Fold Belt. The development of extensive, interconnected fracture systems in strong quartzitic units, and the changing regimes of tectonic stress during the subsequent evolution of the African plate, have important implications for TMG fractured-rock hydrogeology.

The Berg River drainage basin has developed between the coastline and the Escarpment under strong bedrock-compositional and -structural controls imposed by the tectonic grain of the N/S-trending limb of the Cape Fold Belt. The Breede River basin formed in the interior of the Cape Fold Belt syntaxis zone as a result of stream drainage and associated erosion-aggradation processes below from the surrounding, high-lying mountain ranges. Where these and other river systems debouch onto the coastal plain of the south-western Cape region, their geomorphological development has been affected by marine transgressions and regressions that allowed onshore carbonate-rich sediment movement and subsequent aeolian reworking to occur at similar points in the landscape on a number of occasions (Bateman et al., 2004). Combined with a trend of increasing aridification during the past 2.5 million years, affecting the type and density of riverine vegetation and the facies of fluvial sedimentation, the history of Late Quaternary sea-level fluctuations and palaeocoastline configurations has important implications for the hydrogeology of primary or intergranular aquifers beneath the coastal plain.

From recent dating programmes (Bateman et al., 2004), interglacial and subsequent interstadial sea-level high stands appear to have controlled the deposition of extensive coastal aeolianites and barrier dunes, from which there has been intermittent dune-field advance, and partial or complete blocking/disruption of fluvial drainages, during periods of intensified trade-wind activity. Consequently, a distinctive pattern has developed, of fluvial, hydraulically conductive sand/gravel aquifers along formerly continuous palaeodrainage channels overlain by lensoid, dune-bedded, aeolianites of lesser hydraulic conductivity in facies association with relatively impermeable, lacustrine, marly clays and evaporites deposited in endorheic environments behind advancing dune barriers.

Table A-1 Geological History

Age (Ma)	Episode	Description
0 - ~ 130	Seafloor spreading in the South Atlantic Ocean	Erosion and land-surface development along south-western African continental margin
135 - ~ 175	Palmer Land Orogeny	Major normal and oblique strike slip faults (Worcester and Cango megafaults), possibly also the N/S Cedarberg folds and "syntaxis"; Opening of proto-Indian Ocean and extensional tectonics in narrow back-arc oceanic basins; Complex microplate rotations producing compressional deformation of surrounding terranes between Africa, South America and West Antarctica.
~ 180	Gondwanaland break-up (onset)	Eruption of the Drakensberg flood basalts; concurrent intrusion of Karoo dolerite dykes and sills
~ 220 - ~260	Gondwanide Orogeny	Compressional tectonic, major E/W fold and thrust-fault structures of the Cape Fold Belt; fluviatile strata deposited in lower Beaufort Group from meandering continental river systems arising in the Gondwanide Mountains to the south; rapid deposition of sandstones form turbidity-current flows into the deep marine Ecca-basin; resurgence of subduction-related tectonism; appearance of thin, wind-blown, volcanic ash beds within the lower Ecca shales (from extensive areas of volcano-plutonism in parts of Patagonia).
~ 300	Dwyka Ice Sheet	Deposition of a major tillite
	Mild uplift and erosion	Significant regional pre-Karoo unconformity; hiatus in subduction/orogeny
~ 350	Famatinian Orogeny ("Chanic phase")	Deposition of the Bokkeveld and Witteberg Groups; subduction-related tectonism along active margin of Gondwanaland
~ 440	("Ocloyic phase")	Deposition of the Table Mountain Group; occurrence of short-lived glaciation, associated with Late Ordovician global mass-extinction event; accretion of "suspect" Occidentalia Terrane to western South America ends Gondwanaland assembly.
~ 480	Uplift and erosion	Peneplanation of pre-Cape rocks
~540 - 520	Saldanian Orogeny	Subduction, collision, mountain-building between the Southern African crustal block and island arcs of southern South America.
750	Adamastor Ocean opening	Rifting of a former ("Rodinia") supercontinent.

APPENDIX B

LITHOSTRATIGRAPHIC DETAILS

APPENDIX B : LITHOSTRATIGRAPHIC DETAILS

Lithostratigraphy				Lithology	Thickness
Super Group	Group	Sub Group	Formation		
			Witzand		
			Springfontein		
			Varswater		
			Elandsfontein		
			Saldanha		
	Intrusive rocks				
	Major erosional unconformity				
KAROO	Uitenhage		Enon	Conglomerate of well-rounded to sub-angular Witteberg sandstone and grit in a bedded, reddish-argillaceous sandstone. Wood fragments and vein quartz occur. Grain size increases with depth as depositional environments change from distal to proximal.	
	Ecca		Waterford	Fine to medium-grained micaceous sandstones and siltstones alternate with green-brown shales and mudstone. Plant fragments and shallow water structures occur.	
			Tierberg	Grey-black to olive green, well-laminated shale, mudstone and siltstone.	460
			Collingham	Interbedded sequence of tabular dark-grey shale, yellow-coloured claystone, siltstone and cherty mudstone. It is typified by a yellow-weathered illite-rich claystone interpreted as airfall tuff.	30-45
			Whitehill	Thinly laminated, pyritic, carbon-bearing black shale. It weathers to a characteristic gypsiferous, lime-rich zone with dolomitic concretions and gypsiferous lenticles. Fossils have been reported.	30
			Prince Albert	Thinly laminated, dark bluish grey shale with intermittent silty and cherty layers.	120
	Dwyka			Hard, massive, dark grey-green tillite of angular to rounded erratics in a fine-grained matrix. Erratics include quartzite, vein quartz, chert, banded ironstone, jasper, hornfels, limestone, sandstone, conglomerate, granite, gneiss, basalt, amygdaloidal lava, dorite and quartz porphyry. Some erratics display glacial striations. Selective weathering gives it a characteristic tombstone weathering.	485
	Major regional unconformity				

Lithostratigraphy				Lithology	Thickness
Super Group	Group	Sub Group	Formation		
CAPE SUPERGROUP	Witteberg	Lake Mentz	Waaipoort	Shale, mudstone, siltstone and thin, intermittent, immature sandstone beds. Bioturbation, trace fossils and shallow water features present. Lower sandy, micaceous portion and upper more pelitic portion are discernible. Upper mudstones contain black dolomitic and cherty mudstone lenses that are markedly fossiliferous.	25-30
			Floriskraal	Yellow-brown weathering, medium-coarse grained, often feldspathic, quartzitic sandstones alternating with siltstone and sandy micaceous shale. Thin grit and conglomerate layers present. Strongly cross-laminated.	35-70
			Kweekvlei	Dark grey micaceous shale and subordinate micro cross-laminated siltstone. Bioturbation and plant fragments present. Graphitic in character.	30-50
		Weltevrede	Witpoort	Upper discontinuous Skitterykloof Member: coarse-grained pebbly sandstone and thin conglomerates. Central white-weathering Perdepoort Sandstone Member: a prominent marker horizon termed the "White streak". Light-grey, well-sorted, medium-fine grained quartzitic sandstone. Prominent tabular cross bedding. Dark heavy-mineral laminae. Occasional plant fragments. Basal reddish-brown weathering Rooirand Member: grey, fine- to medium grained quartzitic sandstone. Trace fossils, bioturbation and channeling in places.	65-310
			Swartruggens	Micaceous siltstone and mudstone alternating with grey, fine-grained sandstone. Sand content decreases to the South. Trace fossils and shallow water features present.	280
			Blinkberg	Medium-grained, light-grey quartzitic sandstone. Tabular cross-bedding and heavy-mineral laminae accentuate small bedding features. Trace fossils present.	50-90
			Wagendrift	Grey, black siltstone, sandy shale and mudstone with interspersed light-grey sandstone. Sandstones are tabular and mica rich. Trace fossils, and shallow water features are abundant. Extensive bioturbation.	135-165
	Bokkeveld		Karoopoort	Dark-grey siltstone, sandy shale and minor mudstone. It displays bioturbation and ball-and-pillow structures.	40
			Osberg	Light-grey, feldspathic protosandstone separated by a central shale, mudstone and siltstone sequence. It displays cross-bedding, bioturbation, plant material and intraformational conglomerate lenses of blue-black cherty mudstone and ferruginous shale.	30
			Klipbokkop	Reddish-grey weathering, micaceous siltstone and mudstone, alternating with argillaceous sandstone and protosandstone interbeds. Bioturbated lenses and a wide variety of trace fossils occur.	170-300
			Wuppertal	Grey, fine- to medium-grained protosandstone with interbedded siltstones and shales. Trace fossils and intraformational conglomerate lenses occur.	26-65

Lithostratigraphy				Lithology	Thickness
Super Group	Group	Sub Group	Formation		
			Waboomberg	Dark-grey siltstone with immature sandstone and thin shale intercalations in the lower half overlain by dark-grey carbonate-bearing shale and mudstone. The upper mudstone portion is fossiliferous, with mainly mollusc species.	200
		Ceres	Boplaas	Micaceous, feldspathic protosandstones, host to plant fragments and trace fossils. Decreasing sand content to the south.	35-60
			Tra-Tra	Dark-grey micaceous shale, siltstone and mudstone. The beds contain coarse-grained sandstone lenses and intense bioturbation.	250-300
			Hexriver	Dark-grey wacke overlain by light-grey, fine- to medium-grained, feldspathic and micaceous proto-sandstones, which form the prominent red-weathering cliffs in the Hex River Valley. Occasional intraformational conglomerate lenses occur and fossils are scarce.	55
			Voorstehoek	Dark grey mudstones and shales with thin calcareous lenses. A wide variety of fossils are present in the lower half of the formation.	200-300
			Gamka	Dark-grey to feldspathic sandstones and siltstones. These rocks develop a thin, red crust on weathering.	30
			Gydo	Dark-grey to black shale mudstone and siltstone, scattered with black, cherty mudstone nodules and yellow-weathering nodules and lenses. Especially the lower carbonate-bearing shales contain a wide variety of invertebrate fossils.	160
	Table Mountain	Nardouw	Rietvlei	Thin- to medium-bedded quartzitic sandstone with intercalated siltstones and shale.	120-200
			Skurweberg	Medium- to thick-, coarse-grained quartzitic sandstone, characterized by strong planar and trough cross-bedding and thin stringers of vein-quartz pebbles.	120-210
			Goudini	Brown-weathering quartzitic sandstones and interbedded micaceous reddish siltstones.	100-160
			Cedarberg	Upper Disa Member consists of a basal thin-bedded siltstone overlain by more massively bedded, bioturbated fossiliferous siltstone and mudstone, followed by fine-grained, dark-grey sandstone. Lower micaceous Soom Shale.	45-120
			Pakhuis	Upper Steenbras Member consists of a thin, dark bluish-green, poorly bedded quartzose diamictite. Central Oskop Member consists of water-deposited orthosandstones. Basal Sneeukop member is a diamictite of lithic quartz arenite with abundant faceted and striated erratics consisting mainly quartzite and metamorphic rocks including chert, black siltstone, blue and white vein-quartz, rare jasper and chalcedony that underwent pre-glacial rounding.	40-100

Lithostratigraphy				Lithology	Thickness
Super Group	Group	Sub Group	Formation		
			Peninsula	Planar-bedded, light-grey, coarse-grained quartzitic sandstone, with occasional thin layers of vein quartz pebbles. Contains isolated bioturbated zones, biogenic trails and rare anthropod traces. Subdivided in the Cape Peninsula into a lower Leeukop Member, distinguished by repeated fining- and thinning-upward sedimentary cyclicity, and upper Platteklip Member, which is generally thick bedded and lacks the aforementioned cyclicity.	550-1300
			Graafwater	Purple to reddish brown, thin-bedded, ripple-marked sandstones, siltstones and shales.	65
			Piekenierskloof	Separated into the Rest Conglomerate and De Hoek Sandstone members, deposited coevally with complex inter-fingering relationships (Rust, 1967). Rocks are light-grey quartzitic sandstone with occasional coarse-grained to gritty zones.Thins southward.	100?
	Regional unconformity				
	Klipheuwel		Populiersbos	mudstone	300-2000
			Magrug	conglomerate	
	Major regional unconformity				
	Vanryhnsdorp	Kwanous	Various	mixed clastic	?
		Gifberg	Various	mixed clastic and carbonate	?
	Malmesbury				?
		Boland	Porterville	slate, phyllite, greywacke	
		Tygerberg		Brown, yellow, reddish, sericitic to chloritic phyllites. Completely overprinted by intense deformation of the Cape Orogeny.	

APPENDIX C

HYDROSTRATIGRAPHY

APPENDIX C : HYDROSTRATIGRAPHY

A “hydrostratigraphical unit” is defined by Al-Aswad and Al-Bassam (1997) as

> *“a body of rock (with wide aerial extent) distinguished and characterised by its porosity and permeability”.*

A quantifiable measure of hydraulic properties for these different units is used to assess whether they would be hydrogeologically classified as an aquifer, an aquitard or an aquiclude (see **Section 3.3**). The approach offers a distinct advantage in that the geological mapping and description of the different units is a knowledge base for the extrapolation of hydrogeological data and prediction of the presence or absence of aquifer and aquitards.

An intrinsic permeability (***k***) of 10^{-16} m^2 (0.1 millidarcy in oil industry units) is set as the approximate basis (± one order of magnitude) of a proposed hierarchical division of hydrostratigraphical units into “aquizones” and “aquitards” (from Al-Aswad and Al-Bassam, 1997). The “aquifer” is formally defined as “the fundamental unit of the hydrostratigraphical classification … a mappable unit consisting of one or more permeable beds containing water or having the potential of bearing it, and having a minimum intrinsic permeability (***k***) greatly exceeding 10^{-4} darcy (10^{-12} cm^2)” (*op. cit.,* p. 500).

Permeability and hydraulic conductivity are often used interchangeably. Technically speaking, an aquifer has an "intrinsic" permeability that is a function of the media properties only (units of length-squared), whereas hydraulic conductivity is a function of both media and fluid properties (units of length per time). The borderline permeability value (± one order of magnitude) between aquitard and aquifer (***k*** = 10^{-16} m^2) corresponds to a hydraulic conductivity (***K***) of 10^{-9} m/s or ~10^{-5} m/day (0.01 mm/day).

The presence of laterally continuous aquitards that separate the aquifers, and have sufficient thickness to retard fluid flow between them, is an important criterion in the classification and can be obtained from geological knowledge and mapping. The designation of “aquitards” as “mini-“, “meso-“ and “mega-“ is nominally based on formational thickness, with divisions being placed at 50 m between mini- and meso-aquitards, and at 150 m between meso- and mega-aquitards. On this basis, the Graafwater Formation and the Cedarberg Formations, both of ~100 m thickness, would be classified as “meso-aquitards” (see **Table 3-4**). Lateral continuity is, however, considered to be “more important than thickness in defining the type of aquitard” (Al-Aswad and Al-Bassam, 1997, p. 500).