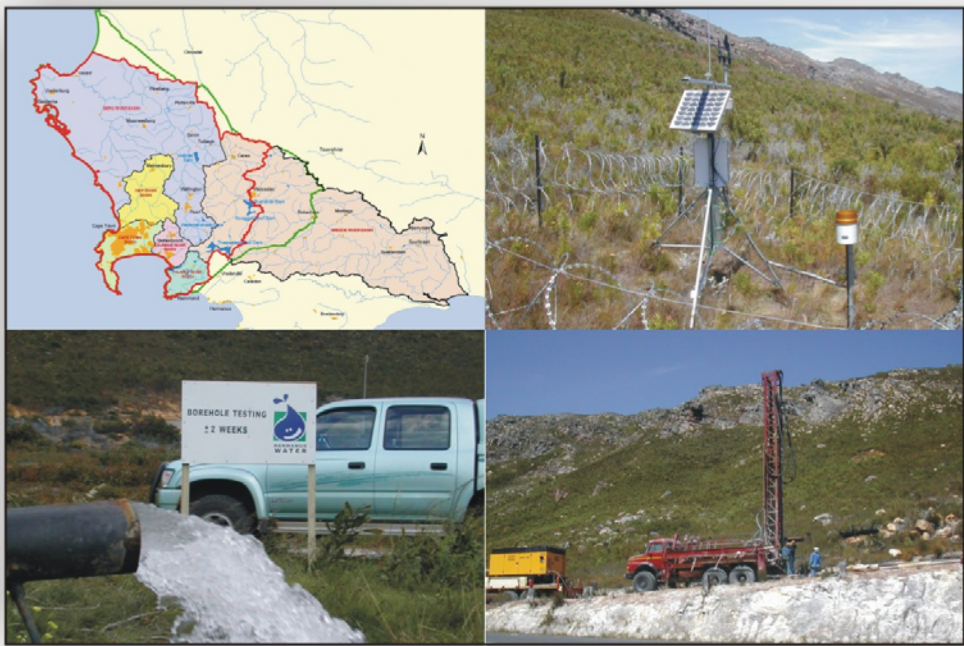
Ref No: P WMA19/000/00/0407

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. 2
DATA AVAILABILITY AND EVALUATION



FINAL **December 2007**

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 2

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APPROVAL

TITLE	:	**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**
DWAF REPORT NO.	:	**P WMA 19/000/00/0407**
CONSULTANTS	:	**Umvoto Africa in association with Ninham Shand**
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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 2
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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 2 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.

DATA SETS

In order to determine the groundwater available in the WCWSS area by means of deterministic and numerical models, a variety of data is required for the different methods and modelling approaches employed. The required data sets refer to the 3D physical, chemical and biological conditions in the study area and the changes thereof over time. These parameters are grouped into the following categories:

- Topography,
- Hydrology,
- Hydroclimatology,
- Geology,
- Hydrogeology,
- Land Cover, and
- Water Use

Topography

The 20 m Digital Elevation Model (DEM) was purchased for this project and is considered adequate for the groundwater tasks.

Hydrology

<u>Catchments</u>

Current catchment areas are defined by hydrological divides or watersheds. However, surface and groundwater catchment areas may not coincide and there is not a formally accepted delineation of how, in the IWRM context, these differences can be addressed when establishing a water balance for any one quaternary catchment. The delineation of IWRM domains for use as model domains for this study will be addressed in the Regional Conceptual Model Report (Volume 3).

<u>River flow and water level</u>

The river flow and water level data are only available from selected gauging stations and there are no hydrodynamic data along river reaches. The elevation between flow gauging stations will be automatically estimated in the GIS using the natural gradient of the river based on the 1:50 000 and 20 m DEM.

There are a number of rivers in which no flow gauges are available. Data from existing flow gauges will be used in model calibration for quaternary catchments without gauging stations under Task 8 to Task 10. Umvoto will use the model results for the groundwater modelling.

<u>Geometry and geological context of surface water bodies</u>

There is no site-specific or detailed data available on the geometry of river reaches, i.e what they look like in cross section, in the study area. However, these can be inferred from topographic and geological information. The basic geological context of a river reach – i.e. the stratigraphy underlying the river, can be determined from topographic and geological maps.

Run-off

The run-off data is only available as mean annual values per quaternary catchment. Time series data is only available as river flow at flow gauging stations at the downstream end of catchments. Since this parameter is important for the water balance model, it will be required to undertake a GIS model of the spatial distribution of run-off as a function of rainfall, altitude and slope.

Baseflow

There are no aquifer-specific values of baseflow, as the published data are summed per quaternary catchment. Additionally the published data display a huge range of values, depending upon the author and methodology.

In the fold terrain of the Western Cape it is unlikely that the aquifer, which outcrops on the valley sides, is in direct hydraulic contact with the river, except along specific reaches of a river where either the Skurweberg or the Peninsula Formation comprise both the valley sides as well as the valley floor and or the Rietvlei Formation is not overlain by the Gydo Formation of the Bokkeveld Group in the valley floors. These circumstances can be established from aerial photos, 1:50000 topographical and geological maps or at a more local scale from an orthophoto, if available.

The methodology adopted for this study comprises the following:

- As 1st order estimate the values for groundwater contribution to baseflow, as given in the GRDM software (DWAF, 2006c), will be used.
- An attempt will be made to disaggregate these baseflow values within each catchment, based on outcrop area, location of springs, aquifer-specific recharge distribution and geological reasoning.
- The values will be updated during the study in an iteration process, based on results from both the surface water and groundwater modelling.

Hydroclimatology

Rainfall

There is sufficient rainfall data available, both as spatial distribution of mean annual and mean monthly values and as time series (daily or monthly) at several rainfall stations. However, due to inconsistencies between the MAP distribution from the CCWR in the high mountainous areas and the MAR values for these catchments, it was decided to develop a revised spatial distribution of MAP, based on additional rainfall data and rainfall stations. This revised MAP distribution will be used in the study.

Temperature

There are only few time series temperature data from selected weather stations in the study area available. However, there are spatial distributions of mean monthly temperature from the Agrohydrology data set that will be used for the project. The spatial distribution reflects the relationship between temperature and altitude. Mean monthly data are sufficient for estimation of actual evapotranspiration.

Evapotranspiration

The only available data are measurements and spatial distribution of potential evaporation. However, the actual evapotranspiration can be modelled, based on monthly temperature and monthly rainfall, applying the formula by Turc (1954) as adapted by Santoni (1964) for use in Mediterranean climate. In addition, transpiration data or water requirements for different vegetation types can be used to estimate spatial and seasonal distribution of evapotranspiration if this is required.

Geology

<u>Lithology</u>

The lithological data as digitised from the geological maps in 1:50 000 obtained from the Council for Geoscience (CGS) combined with the in-house local knowledge is sufficient for the purpose of this project.

<u>Structural Features</u>

The existing information and data on faults are sufficient and can be refined in the detailed model domains, if required, from structural analysis of existing data. However, the currently available data about the fracture network is very detailed in some areas of the study area, e.g. Piketberg and Hottentots Holland, while the data is not available at the required scale in other areas, especially in the northern part around Tulbagh, Ceres and Hex River. The information about fracture distribution and density is crucial for determining hydraulic parameters, hydraulic relevant thickness and interaction with surface water bodies.

It is therefore recommended to undertake a fracture mapping in the study area to fill these data gaps in all areas relevant for detailed modeling and for groundwater – surface water interaction.

<u>Aquifer geometry</u>

The aquifer thickness or saturated thickness values given in the GRA II data sets are unrealistic for the primary aquifers and the TMG aquifers. They do not take into account the vertical extent of water-bearing fracture systems in the TMG and the structurally controlled variability in thickness of the primary aquifers. Furthermore, the possibility of multi-layered aquifer systems and the occurrence of unconfined and confined aquifers are not considered.

The currently published information on paleochannels in the primary aquifers of the West Coast (SRK, 2004) and the Cape Flats does not coincide with the conceptual understanding of the geological processes for developing these paleochannels. Therefore, the bedrock topography will need to be revised, based on borehole information and first principles of geological processes.

For the purpose of this study the aquifer thickness of the relevant TMG aquifers will be modelled in the GIS from lithological contacts, faults, dip and strike information and geological reasoning.

Hydrogeology

<u>Hydraulic Parameters</u>

The regional parameter values given in the GRA II database are not reasonable and will not be used in this project. The spatial distribution does not take the different aquifers and the 3rd dimension into account. The preferred flow paths in the fractured rock aquifers are not considered.

However, there are sufficient localised data for the different aquifers under consideration, e.g. Cape Flats Aquifer, Langebaan Road Aquifer, Atlantis Aquifer, Peninsula Aquifer in Hermanus, Piketberg, Hex River and Citrusdal. The adopted approach can be summarised as follows:

- It is envisaged for the regional scale model to apply reasonable average values for different aquifers, based on local knowledge, literature, geological reasoning and actual measurements.
- For the detailed model areas, existing field data, additional field measurements, local knowledge and geological reasoning will be used to provide reasonable estimates of the relevant parameters and to develop spatial distribution maps for these.
- Finally, the transmissivity or hydraulic conductivity will be calibrated during the detailed numerical models and become a model output.

Recharge

The available spatial distribution of recharge does not take into account the behaviour and infiltration capacity of the different aquifers. Furthermore, there is no distinction between recharge and discharge areas of the different aquifers.

The approach adopted to estimate aquifer-specific recharge values is scale dependent, as described in the Inception Report (DWAF, 2005a). The following steps will be undertaken to estimate recharge on a regional scale:

- Applying the aquifer-specific recharge model, as developed for the ISPs;
- Applying map-centric recharge simulation model with modelled distribution of run-off and actual evapotranspiration (see above). This type of model was originally developed in the CAGE project (DWAF, 2000) and calibrated in the recent Clanwilliam project (DWAF, 2006d). The original methodology will be revised and tested in this study area.
- Create time series data for monthly recharge values, based on monthly rainfall data, and apply seasonal changes to spatial distribution from map-centric simulation.

Groundwater levels

The national scale spatial distribution of groundwater levels from the GRA II project is not realistic, as it does not take into account the occurrence and 3rd dimension of the different aquifers. However, there are sufficient point data of groundwater level measurements on the NGDB and from local hydrocensus surveys for the detailed model domains.

- For the regional scale model it is envisaged to apply reasonable average values for different aquifers, based on local knowledge, literature, geological reasoning and actual measurements
- For the local scale models a spatial distribution of average values, based on field measurements, local knowledge and geological reasoning will be established as input into the models.
- The time series data from field measurements will be applied to transient model runs.
- Both the spatial distribution and the time series data are then used as reference data for the calibration of the models.

Springs

There is insufficient information about the distribution of distinct discharge sites and the actual discharge at springs. Additionally, the use of water from springs is often not registered with the DWAF and therefore the uptake is not recorded, other than via allocation in the surface water system.

It is envisaged using the currently mapped springs and starting points of perennial rivers as 1st order indication of groundwater discharge sites. An estimation of discharge rates will be obtained by extrapolating flow records from hydrocensus data and the NGDB. The discharge sites will be assigned to the different aquifers, based on geological mapping and reasoning.

Hydrochemistry

There is no coherent data set on hydrochemistry for the whole study area available. There is good data coverage for EC and TDS as indicators of water quality, while only isolated data on other parameters exist. The importance of good hydrochemistry data is threefold:

- The fitness for use depends upon the chemical constituents in the water;
- Chloride and isotope data can be used to support recharge estimation and therefore the water resource evaluation;
- Macro and trace elements and isotope data can be used to distinguish between water from different aquifers as well as between surface water and groundwater.

The available regional water quality data are sufficient as indicators of fitness for use and will be used to determine the quantity of potable water. Sampling and analysis of groundwater and rainfall for Chloride is undertaken in several areas within and outside of the study domain and the data are considered sufficient on the regional scale.

Thermal Data

There is no comprehensive mapping of thermal springs available. There are also no time series data of temperature changes at hot springs. It is therefore envisaged to use the limited thermal data for the groundwater flow modeling as follows:

- Applying thermal data from the NGDB and TMGAA hydrocensus as indicators for the regional flow model
- Applying thermal data from selected boreholes and springs within the TMG Aquifer domain for calibration of heat and groundwater flow models.

Land Cover

Soil Cover

The scale of the available soil type map from the WR90 is very coarse. This information will only be used as background information and to qualitatively evaluate the recharge model results.

Vegetation Cover

There are two different existing data sets with vegetation data available, viz. the natural vegetation cover after Acocks and the land cover from the NLC 2000 project. Since the land cover represents the most recent situation of vegetation cover and land use, the NLC coverage will be used as support parameter for the recharge estimation and water use calculation. The results of both estimations will be qualitatively checked against the pattern of land use.

Water Use

Groundwater

The information on groundwater use in its current format is not sufficient for the purpose of this project. The data are averaged or summed per quaternary catchment (GRA II) or per cadastral farm (WARMS) and are therefore not aquifer specific.

There is also no information in these sources that indicates the seasonal fluctuations of groundwater use, the historical growth (or decline) in groundwater use, or in the case of WARMS from which aquifer the water is being abstracted. The following is envisaged to overcome these problems:

- Spatial disaggregation of water use data per catchment with respect to aquifers, based on registered usage, borehole distribution, land use, aquifer properties and local knowledge;
- Estimation of seasonal fluctuation of groundwater use, based on the assessment of irrigation requirements and percentage split between sectors;
- Indication of historical change in groundwater use, based on boreholes drilled per year, increase in agricultural areas, population growth and general development.

Surface water

There is sufficient spatial information about the allocation from surface water and the capacities and yields of dams. However, the actual consumption is monitored only in terms of the major dams and mainly in terms of domestic and urban use. The uptake by farmers for irrigation can only be estimated from land use, irrigation requirements and actual climatic conditions.

CONCLUSIONS AND RECOMMENDATIONS

The main conclusion that can be drawn from the assessment of available data is that there is adequate data to initiate modelling, to configure the proposed models, and to run these models to contribute to an improved groundwater resource evaluation.

Conceptual and semi-quantitative understanding can be tested against available field measurements and records of exploration results. If the conceptual model proves to be robust, careful selection of measured, derived and extrapolated data sets to configure, calibrate and test the model in a predictive mode will support sensitivity analysis of input parameters to model output and the evaluation of uncertainties in model results.

This approach supports the management of uncertainties in groundwater assessment and it also allows the modeller to prepare a physically real mesh yet limit numerical instabilities. Ongoing upgrade and revision of the model configuration and calibration will provide a sound analytical tool to be used in a Model, Monitor and Manage strategy for groundwater resource evaluation, development and management.

The required parameters, data sources and specific comments are documented in **Table E-1** below.

Table E-1: Summary Table of Parameters and Data Sources used in the Project

Parameter	Data used	Comment
Topography		
Digital elevation model (DEM)	ComputaMaps	
Hydrology		
Quaternary catchments	WR90	
IWRM Domain		Model Output
Surface Water Bodies	CDSM	
Rivers	CDSM	
Flow gauges	WR90, NS	
Stream flow records	DWAF, NS	
Run off	WR90, NS	Model Output
Baseflow	Different Sources	
Groundwater contribution to Baseflow	GRDM	Model Output
Hydroclimatology		
Mean Annual Precipitation	NS	
Median monthly rainfall	Agrohydrology	Adjusted with NS MAP
Rainfall stations	SAWS, NS	
Rainfall time series	NS	
Mean Annual Temperature	Agrohydrology	
Mean monthly maximum Temperature	Agrohydrology	
Temperature time series	SAWS	
Mean Annual Evaporation	Agrohydrology	
Mean Monthly Evaporation	Agrohydrology	
Mean Annual Evapotranspiration		Model Output
Mean Monthly Evapotranspiration		Model Output
Geology		
1:50000 geology maps	Council for Geoscience	
1:250000 geology maps	Council for Geoscience	
Folds		Umvoto mapping
Faults	Council for Geoscience	Re-interpreted
Fractures		Umvoto mapping
Bedrock topography for Cape Flats	Different sources	Re-interpreted
Bedrock topography for West Coast	Different sources	Re-interpreted
Bedrock topography for Breede Alluvium	Different sources	Re-interpreted
Porosity	Different sources	
Aquifer thickness	Different sources	Model Output
Hydrogeology		
Aquifer yield	Combined Database	Model Output
Groundwater Storage		Model Output
Transmissivity m^2/day	Combined Database	
Hydraulic conductivity	Combined Database	
Borehole yield	Combined Database	
Storage coefficient	Combined Database	
Specific Yield	Combined Database	
Spring locations	Combined Database	Re-interpreted

Parameter	Data used	Comment
Recharge	Combined Database	Model Output
Waterlevel (mamsl)	Combined Database	
Waterlevel (mbgl)	Combined Database	
Water chemistry data	Combined Database	
Water temperature data	Combined Database	
Land Cover		
Land Cover	NLC 2000	Updated by NS
Soil Cover	WR90	Partially updated by NS
Water Use		
Groundwater abstraction, water use	Combined Database	Re-interpreted
Annual groundwater abstraction	DWAF / GRA II	

The assessment of the data available for use in this study and the development of the conceptual models and approach at a regional and at an individual aquifer scale (see Volume 3) have highlighted the following data gaps:

- location of perennial springs
- time series for spring flow
- spring hydrochemistry (macro and trace)
- isotopic characterization of spring and seep zones and groundwater
- thermal measurements of springs and groundwater
- event response changes in spring flow and groundwater level
- widely-distributed hydraulic parameters for the TMG Aquifer
- bedrock topography along the West Coast
- volume and pattern of groundwater use per aquifer
- uniform scale of fracture mapping
- geological anomalies in the 1:50 000 geological field sheets.

It is therefore recommended that the following data collection activities be undertaken in a follow up study:

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

Since it is not expected that these will be undertaken and or become available in time for use in this study, preliminary assumptions will be made as part of this study.

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

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ABBREVIATIONS

ASR	Aquifer storage and recovery
BRBS	Breede River Basin Study
BRHS	Breede River Hydrological Study
CAGE	Citrusdal Artesian Groundwater Exploration
CCWR	Computing Centre for Water Research
CDSM	Department of Land Affairs - Chief Directorate Surveys and Mapping
CGS	Council for Geo Science
CMA	Catchment Management Agency
CRD	Cumulative Rainfall Departure
CSIR	Council for Scientific and Industrial Research
CVA	Change Vector Analysis
DEM	Digital Elevation Model
DISA	Daily Hydrosalinity Model
DWAF	Department of Water Affairs and Forestry
EC	electrical conductivity
ECA	Environmental Conservation Act
EFR	Ecological Flow Requirements
E-W	east west
EWR	Ecological water requirement
FE	Finite Element
GIS	Geographical Information System
GRA	Groundwater Resources Assessment
GRDM	Groundwater Resource Directed Measures – Software
IAP	Invasive alien plants
IFR	Instream Flow Requirements
ISP	Internal Strategic Perspective
IWR	Integrated Water Resources
IWRM	Integrated Water Resources Management
km	kilometre
LRA	Langebaan Road Aquifer
m	metre
MAP	Mean annual precipitation
MAR	Mean annual run-off
N-S	north-south
NEMA	National Environmental Management Act
NEMP	National Eutrophication Monitoring Programme
NGA	National Groundwater Archive
NGDB	National Groundwater Database
NLC	National Land Cover
NMMP	National Microbiological Monitoring Programme
NWRS	National Water Resources Strategy

NWA	National Water Act
op.cit.	work previously cited
PhD	Doctor of Philosophy
PAJA	Promotion of Administrative Justice Act
RDM	Resource Directed Measures
RQO	Resource Quality Objectives
SAPWAT	Computer programme for the estimation of irrigation requirements of crops in Southern Africa
SAWS	South African Weather Service
SFRA	streamflow reduction activities
SRK	SRK Consulting – Steffen, Robertson and Kirsten (Pty) Ltd
STCC	short term characteristic curve
SVF	Saturated Volume Fluctuations
TDS	Total dissolved solids
TMG	Table Mountain Group
TMGA	Table Mountain Group Aquifer
TOR	Terms of Reference
UWC	University of the Western Cape
VAS	Voëlvlei Augmentation Scheme
VHIMS	Vaal Hydrological Information Management System
WAA	Water Availability Assessment
WAAS	WAA Study
WARMS	Water-use Authorisation and Management System
WCSA	Western Cape System Analysis
WCWSS	Western Cape Water Supply System
WECSA	Western Cape Situation Assessment
WfW	Working for Water
WMA	Water Management Area
WRC	Water Research Commission
WRPM	Water Resources Planning Model
WRSM	Water Resources Simulation Model
WRYM	Water Resources Yield Model
WR	Water Resources
XLS	Excel Spreadsheet

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.

a) 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.

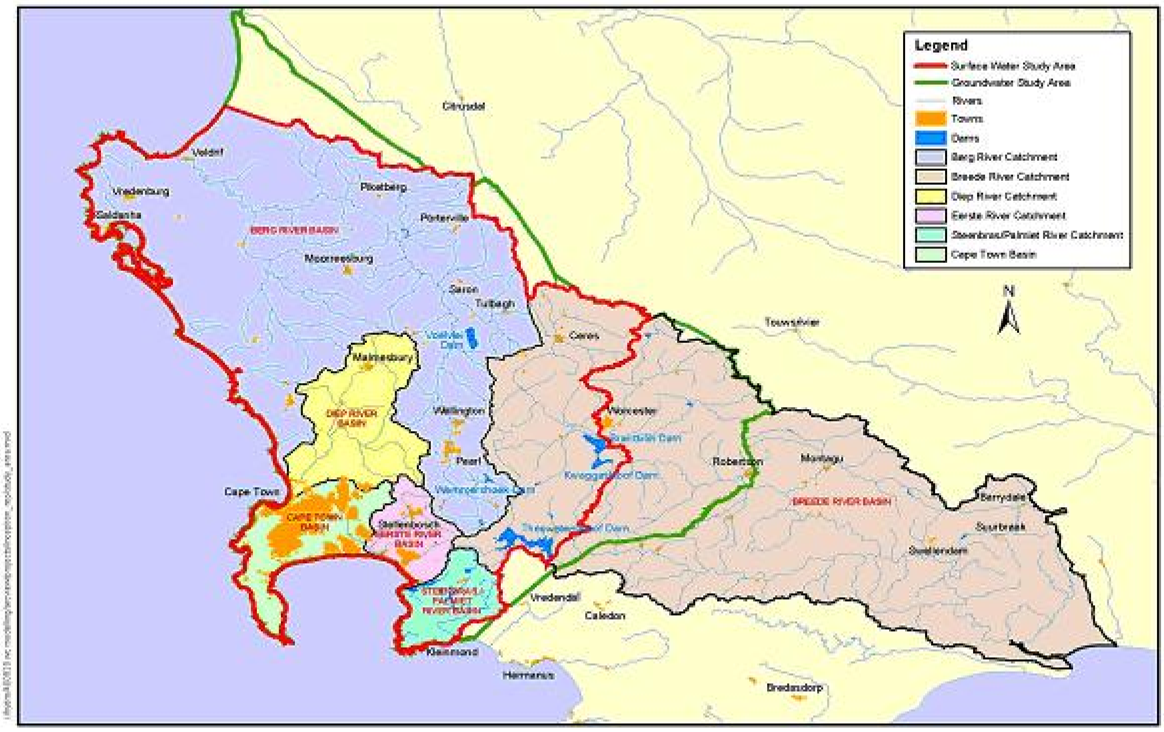


Figure 1-1: Study Area Locality

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 2 in the project series.

1.2 DATA AVAILABILITY AND EVALUATION REPORT

It was anticipated at the outset of this project that there could, in some areas, be a restricted spatial coverage and or limited time series of aquifer specific data, whether it be simple water level fluctuations in response to abstraction or recharge or for event response in spring flow. Thus the planning for the groundwater modelling tasks of this project assumed to use all 'best available data' about the study domain.

The term 'best available data' is interpreted as also meaning the best available insight based on empirical evidence and process understanding. The latter, i.e. knowledge, can be used to make decisions as to reasonable extrapolation and inference of data, in order to supplement a restricted data base in any one model domain. This is little different from the manner in which the surface water modelling is undertaken when insufficient flow data, or no flow gauges, are available in any one catchment and the best available data or calibration from a comparable catchment is used in the model. In this project data from a comparable geological and hydrogeological context are used until such time as new and or improved data warrants recalibration and or reconfiguration of the model.

This requires that the team establishes, by working from first principles, what process understanding and quantification can reliably be extrapolated to the study domain, documents why it can be done and how the models configured with such data would need to be validated in the future, using or comparing the model input data with site specific data. This will be specified in Volume 3 – 9 of this report.

Provided there are adequate ground-truth controls and empirical evidence within the model domain, process understanding and selected model input parameters can be extrapolated from data bases outside the study domain. Both geological and hydrogeological data and understanding that are informed by drilling results and down-hole logging as well as field measurements are used to supplement and complement the database. This approach requires a rigorous physical understanding of the aquifer context and processes as well as the various rock-water chemical interactions and depends upon the skills, experience and knowledge base of the modelling team. It precludes black-box modelling approach, which, in any event, is not recommended.

1.2.1 Purpose of this Volume

The primary purpose of this volume is to introduce the different sets of data available, either nationally, regionally or local, the applicability thereof to this project, the how and why of data selection for the different models to be used in this project and to provide a reference and source volume for both the project and the task teams. It does not address the data selection and evaluation for local-scale numerical models. This will be addressed in the individual model reports (Volume 5 – 9).

1.2.2 Structure of this Volume of the Report

This volume of the report is structured into nine main sections with a number of sub-sections each:

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

<u>Section 2</u> lists the required data sets and distinguishes between model input and calibration parameters, as well as supporting parameters.

<u>Section 3</u> gives an overview of the available data sources in terms of their potential relevance to the study and describes the preprocessing of data for selection and use in the project.

<u>Section 4</u> describes and evaluates the available topographical and cadastral data sets.

<u>Section 5</u> describes and evaluates the available data sets for the hydrology and hydroclimatology.

<u>Section 6</u> describes and evaluates the available data sets for the geology and hydrogeology.

<u>Section 7</u> describes and evaluates the available land and soil-cover data sets.

<u>Section 8</u> describes and evaluates the available water-use data sets.

<u>Section 9</u> provides conclusion on the current status of available data and recommendations for improving the spatial and temporal data for use in future modelling studies.

Supporting documentation is provided in several appendices.

2. REQUIRED PARAMETERS

A variety of data is required for the description and modelling of the three dimensional physical, chemical and biological conditions of the different aquifers. The parameters are grouped into the following categories:

- Topography
  - Elevation
  - Slope and Aspect
- Hydrology
  - Catchments
  - River network
  - River flow and river stage
  - Geometry and geological context of surface water bodies
  - Surface run-off
  - Base flow
- Hydroclimatology
  - Precipitation
  - Temperature
  - Evaporation / Evapotranspiration
- Geology
  - Lithology
  - Structural features
  - Porosity
- Hydrogeology
  - Aquifer geometry
  - Hydraulic parameters
  - Groundwater level
  - Hydrochemistry
  - Thermal data
  - Recharge
- Soil type
- Land cover
  - Vegetation cover
  - Land use
- Water use
  - Groundwater abstraction
  - Springs
  - Surface water allocation

The proposed use of these data and the data gaps in the study area are described in Section 4 to 8 below. Please see the Glossary in **Appendix A** for the definition of terms used.

Table 2-1: Parameters for model input, calibration and output

Parameter	Type	Model Input	Calibration	Output
Elevation	2D spatial	X		
Slope and Aspect	2D spatial	X		X (DEM)
Catchments	2D spatial	X		X (DEM)
IWRM Domains	2D spatial	X		X (CM)
River network	2D spatial	X		
River flow and river stage	spatial and temporal	X	X	X
Geometry and geological context of surface water bodies	2D spatial	X		
Surface run-off	spatial and temporal	X		X (WBM)
Base flow	spatial and temporal	X		X (WBM)
Precipitation	spatial and temporal	X		
Temperature	spatial and temporal	X		
Evaporation / Evapotranspiration	spatial and temporal	X		X (WBM)
Lithology	2D spatial	X		
Structural features	3D spatial	X		
Aquifer geometry	3D spatial	X		X (WBM)
Porosity	3D spatial	X		
Hydraulic parameters	3D spatial	X		X
Groundwater level	spatial and temporal	X	X	
Hydrochemistry	spatial and temporal	Supporting		
Thermal groundwater data	spatial and temporal	X	X	
Recharge	spatial and temporal	X		X (WBM)
Soil type	2D spatial	Supporting		
Vegetation cover	2D spatial	Supporting		
Land use	2D spatial	Supporting		
Groundwater abstraction	spatial and temporal	X		X (WBM)
Water use from springs	spatial and temporal	X		
Surface water allocation	spatial and temporal	Supporting		

3. DATA SOURCES

3.1 WR 90 HYDROLOGY AND HYDROCLIMATOLOGY

The “Surface Water Resources of South Africa 1990” (WR90) project (Midgley et al., 1994), provides relevant data sets including:

- Delineation of Quaternary catchments,
- Mean Annual Precipitation as isohyets,
- Mean Annual Precipitation averaged per quaternary catchment,
- Mean Annual Run-off averaged per quaternary catchment,
- Run-off Efficiency per quaternary catchment,
- Mean Annual Potential Evaporation as isohyets,
- Mean Annual Potential Evaporation averaged per quaternary catchment,
- Mean Annual Baseflow averaged per quaternary catchment,
- Soil type.

Currently these data sets are being updated but are not available yet. Due to the scale of the data and the aggregation per quaternary catchment the WR90 data can only be used as input for the regional conceptual and water balance model. For the detailed models, it will be necessary to disaggregate the data, if no other data sets are available.

3.2 AGROHYDROLOGY DATA SETS

The South African Atlas of Agrohydrology and Climatology (Schulze et al, 1997) provides averaged values for a number of hydrological and climatological parameters on a 1.75 km grid:

- Mean Annual Precipitation
- Mean Monthly Precipitation
- Mean Annual Evaporation
- Mean Monthly Evaporation
- Mean Monthly Maximum Temperature

The data will be used in the regional water balance model (see Volume 4; DWAF, 2007a). However, the coarse scale of the 1.75 km grid is not recommended for use in all of the detailed model domains. It can be disaggregated using the 20 m DEM as a guideline.

3.3 GRA II DATA SETS

The Groundwater Resource Assessment Phase II (GRA II) project aimed to develop a general methodology for groundwater resource evaluation and provide an estimate of groundwater potential on a national scale.

Although one of the criteria for the GRA II methodology is that the approach should be applicable at various scales, this is not achieved. In preparing the GIS layers for the quantification of groundwater resources, input data is averaged across aquifer boundaries. The 3rd dimension of geology and aquifer geometry is neglected and the differences in confined and unconfined aquifers are not considered. The resulting data sets are therefore not aquifer specific and therefore variably relevant to an aquifer under investigation. An aquifer-specific approach is adopted in this study, so that only data that can be reliably attributed to specific aquifers will be used.

The data quality and usability of the data sets for the modelling study are discussed in the following sections and a summary evaluation is given in **Appendix E**.

3.4 GRDM DATA SETS

The GRDM software program, Version 3, developed and compiled by DWAF (2006) comprises a graphical interface with different layers of data on a regional or national scale, a 'road map' to estimate the reserve components and special tools to assist in the resource evaluation.

The following data sets on a quaternary catchment scale were obtained from the GRDM software. The data are summarised or averaged per quaternary catchment and across aquifer boundaries. These data sets are only usable as first order regional indicators of groundwater resources as they cannot be disaggregated into aquifer-specific units.

The data sets are:

- Recharge (Dennis & van Tonder)
- Baseflow and Groundwater Contribution to Baseflow (Hughes, Pitman, Schulze, Vegter)
- Groundwater use (from GRA II)

3.5 NGDB / NGA

Data and information for 6734 points were received from the National Groundwater Database (NGDB). The most important data received from the NGDB included the following, but are not necessarily available for every data point:

- Basic information on water points (e.g. coordinates, status, water use)
- Information on geology,
- Pumptest results,
- Water level measurements,
- Water temperature,
- EC and pH as measured in the field,
- Hydrochemical data, and
- Discharge rates.

The processing of the data to facilitate data analysis and data selection for the different models involved:

- Database incorporation into MS Access
- Quality control of data sets
- Spatial distribution of data sets.

The quality control of data sets required checking of the location of the data point with regards to the geology and aquifer to confirm the aquifer with regards to the location and depth of borehole, and to verify drill rig accessibility (e.g. data from boreholes mapping on top of a mountain or in the ocean were excluded since it does not seem plausible to drill at such places) *inter alia*.

The "census" data used in this study is considered reliable and wherever possible is supplemented by in-house data. The final database of borehole information comprises the processed NGDB data, hydrocensus data from several projects, data from consulting reports (see Section 3.9) and in-house data.

3.6 WARMS DATABASE

Water use above Schedule 1 must by law be registered with the DWAF and is captured in the WARMS database. Groundwater allocation is normally authorised and registered per user or farm, which means that the spatial information about the number and location of boreholes is lost. A detailed analysis of the database entries and linkage with the spatial attributes in the GIS could minimise this uncertainty.

The current WARMS database was provided for Task 6 of the study. Registered groundwater use data was extracted from the database, using the types ‘groundwater’ and ‘spring/eye’ as indicator. This data set is not incorporated into the borehole database, as double counting of boreholes is most likely to occur.

3.7 GEOLOGICAL DATA

The published 1:250 000 geological maps and 1:50 000 geology field maps were obtained from the Council for Geoscience and underwent preprocessing involving:

- data editing or cleaning to check for and correct errors in input data;
- re-projection, transformation and generalization; and
- edge matching and rubber sheeting.

The 1:250 000 geological maps were used as a guideline for verification of features in the 1:50 000 scale sheets, especially for labelling purposes. To solve for unlabelled polygons in the field sheets, the in-house local geological maps and knowledge and understanding were used to finalise the data. Once all the field sheets were digitised, labelled and cleaned, they were merged together to form one map.

3.8 REMOTE SENSING IMAGERY

Aerial photography

Digital JPEG copies of a set of 1:10 000-scale colour aerial photos covering the study area were acquired from the Department of Water Affairs and Forestry. Additional aerial photographs were acquired from the Chief Directorate Surveys and Mapping in MrSid format and from Ninham Shand in ER Mapper format (**Appendix F**). In addition selected orthophotographs (1:10 000 scale) out of the complete set of acquired orthophotographs for the study area were scanned and georeferenced to create raster copies.

Satellite Imagery

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

3.9 PREVIOUS STUDY REPORTS

Detailed studies were undertaken in some areas within the study domain. A full bibliography of known study reports is documented in **Appendix D**. A subset of these reports contains data and information that are used in this study. These are listed in the following sections 4 to 8 and the reference list in section 10.

4. TOPOGRAPHIC AND CADASTRAL DATA

4.1 TOPOGRAPHY

Topography is used to digitally define the drainage regions and directions of river flow. It influences the weather conditions and therefore is an essential parameter in extrapolation of climate data.

The topography is controlled by the underlying geology and therefore strongly influences the spatial patterns of aquifer recharge and discharge, groundwater flow direction and the hydraulic gradient and sites of surface and groundwater interaction.

The topography and elevation data will be used during the study for a variety of tasks, e.g.

- to convert water level data given in meter below ground level (mbgl) to hydraulic head in meter above mean sea level (mamsl);
- to evaluate certain data, e.g. borehole location and attributes thereof, can be verified with regards to drill-site feasibility;
- to develop a slope model of the terrain, and as the slope angle drives the surface run-off, this can be used to establish the run-off efficiency on an aquifer specific basis which provides a constraint on aquifer recharge;
- to develop an aspect model as this impacts on rainfall and recharge as well as vegetation cover, land use and evapotranspiration;
- the DEM is used for computer mapping of structures and of dip and strike for selected lithologies at a finer scale, facilitating modelling of rock geometry to gain rock volume and therefore aquifer storage;
- the use of a sun-shaded digital elevation model (DEM) facilitates structural geology mapping, and evaluation of structural and therefore likely hydraulic (dis-)continuities; and
- as direct input into the numerical models during mesh generation.

The topographic data acquired for the project comprised contour lines at 20 m interval, spot heights, roads and dams. The data was acquired in vector format either as lines, points or polygons at a scale of 1:50 000 from the Chief Directorate Surveys and Mapping (CDSM) in Mowbray, Cape Town. The data was received as 45 individual files for each 1:50 000 topographic sheet (see **Table 4-1** below and **Appendix B**).

Table 4-1: Topographic Data

Data	Format		Scale	Source
Contours	Vector	Line	1:50 000	Chief Directorate Surveys and Mapping (CDSM)
Spot Heights		Point		
Roads		Line		
Railway		Line		
Dams		Polygon		
Digital Elevation Model (DEM)	Raster	Data	20 m x 20 m	ComputaMaps cc

The contour data are illustrated in a light brown colour showing an interval of 100 m for easy viewing (**Figure 4-1**). The digital elevation model (DEM), as derived from the 1:50 000 topographic data, was acquired from ComputaMaps cc. The DEM has a 20 m x 20 m cell size, and a vertical resolution of approximately 5 m. The image has been checked to ensure that there are no linear edge artefacts at the junctions between map sheets. The DEM is illustrated in a green-brown coded mode with simulated sun-shading in order to enhance detection of structurally controlled topographic lineaments (**Figure 4-2**).

There are no critical gaps in the topographical data. The 20 m DEM is adequate for the purposes of this project.

4.2 CADASTRAL DATA

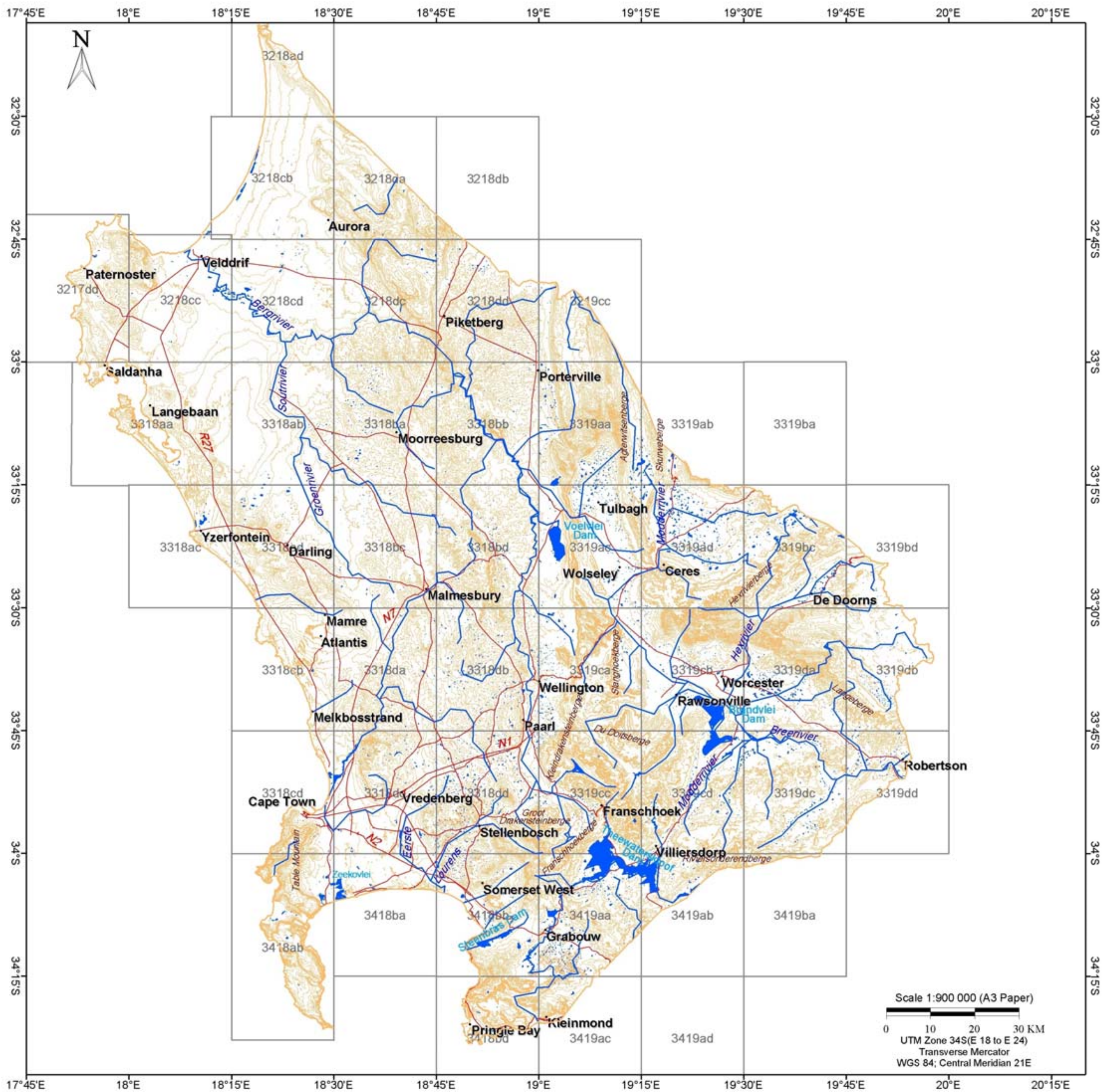
A cadastral data map shows the boundaries of subdivisions of land and the areas of individual title tracts for the purposes of recording and describing ownership.

The digital cadastral data was requested from the Department of Land Affairs – Surveyor General's Office in Cape Town and from SA Explorer Version 1.0 from the Demarcation Board. It included farm boundaries, municipal boundaries and towns (see **Table 4-2**).

Table 4-2: Cadastral Data

Data	Format		Scale	Source
Farms	Vector	Polygon	1:50 000	Chief Surveyor General / Demarcation Board
Municipality				
District Council				
Towns		Point		

It is also possible to get information regarding the owner of the farm from the Deeds Office. Landowner information is not explicitly required for this project but would be useful if it becomes necessary to directly query any WARMS data. The farm boundaries are used to link specific boreholes from the NGDB with the WARMS database.



LEGEND

- Towns
- Roads
- 20m Contours
- Perennial Rivers
- Dams
- 1:50 000 Toposheet

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

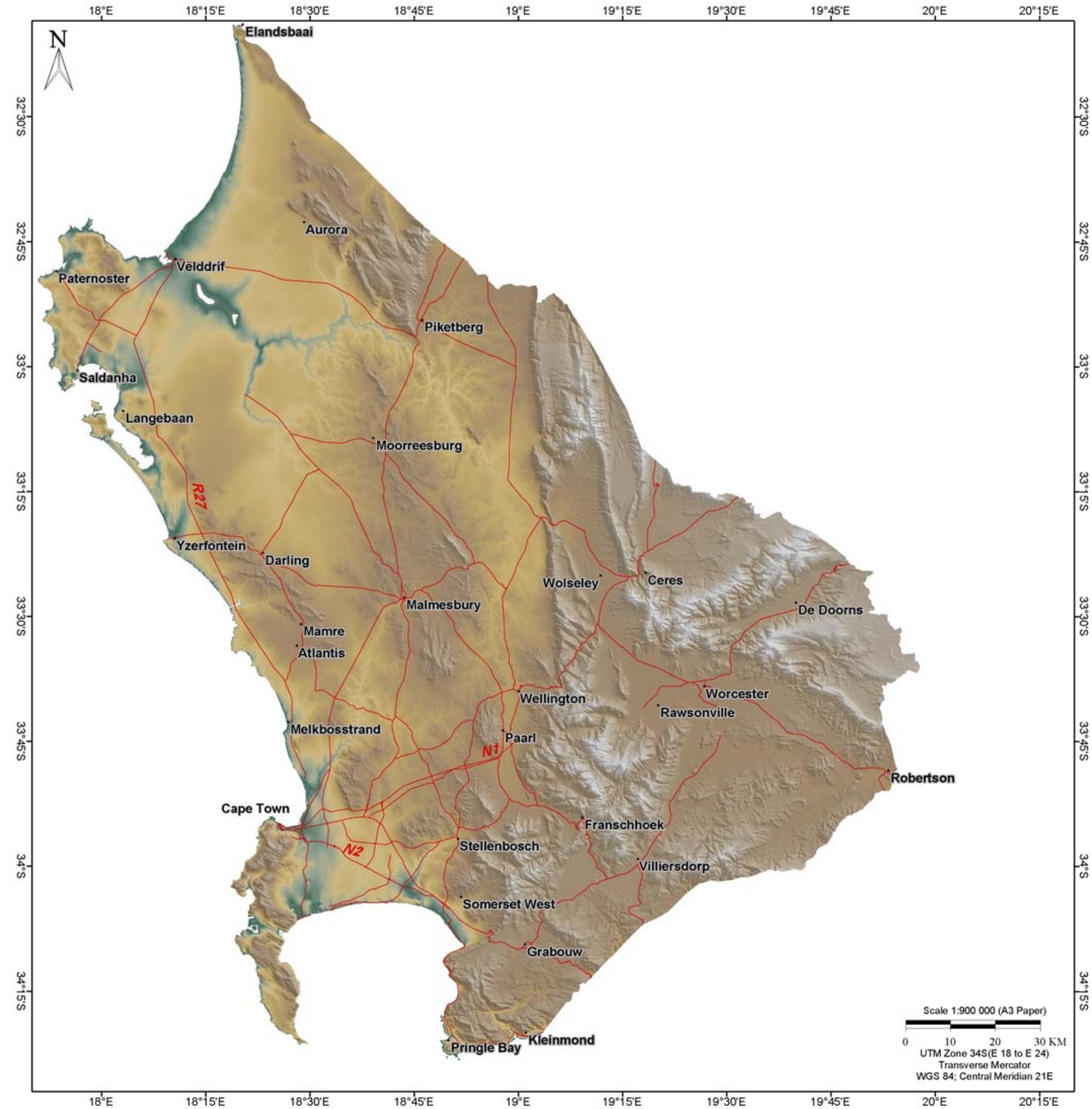
CONSULTANT

UMVOTO

TITLE

TOPOGRAPHY OF STUDY AREA

FIGURE 4.1



LEGEND

· Towns

Dgital Elevation Mode (masl)

2101
1261
840
420
0

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

DIGITAL ELEVETION MODEL OF STUDY AREA

FIGURE 4.2

5. HYDROLOGY AND HYDROCLIMATOLOGY

5.1 HYDROLOGY

5.1.1 Catchments

The study area covers 78 quaternary catchments in the E, G and H primary drainage basins (**Figure 5-1**). A list of these quaternary catchments and the attached spatial hydrology data is given in **Appendix C**. The acquired data further included rivers captured at 1:50 000 scale by CDSM. The rivers are classified as either perennial or non-perennial.

Table 5-1: Catchment Data

Data	Format		Scale	Source
Rivers	Vector	Line	1:50 000	CDSM
Quaternary Catchments	Vector	Polygon	1:250 000	WR90 (Midgley et al 1994)

It is required that all hydrogeological results be presented on a quaternary catchment scale in this project for comparison and integration with the surface water model results. This increases the element of uncertainty in groundwater model results, since it requires that relatively detailed aquifer specific data be available within and between the quaternaries. This is not especially likely for groundwater because the demand and use of the groundwater is largely in the lower lying areas of any one catchment while the significant aquifers transect the watersheds, even at a basin scale. Furthermore it cannot be assumed that rainfall which recharges an aquifer in a specific catchment is discharged as baseflow or spring flow in the same quaternary.

For these reasons an aquifer-specific approach is adopted in this project and modelling results will be aggregated to quaternary catchment scale.

An attempt to overcome the above challenge has been proposed by Hay et al (2004) in the delineation of areas wherein the hydrologic and hydrogeologic boundaries reasonably coincide, and therefore mass balances can then be summed on a basin scale. These are called Integrated Water Resource Management (IWRM) domains and have been selected as model domains for this study. (See Volume 3, Regional Conceptual Model Report).

5.1.2 River flow

The flow rates and volumes in a river are available as time-series data for a number of flow gauging stations across the study area. These flow rates are also relevant parameters for the groundwater component of the study, as they normally comprise both the overland flow, termed run-off, and the groundwater discharge into the stream. The hydrographs are used to estimate the baseflow (see **Table 5-2**).

However, in order to determine the groundwater contribution to baseflow from specific aquifers along river reaches, a detailed network of gauging stations is required. The assessment of the current network is addressed in the Task 5 report of this study (DWAF, 2006), giving recommendations for upgrading some stations and constructing new stations. **Figure 5-2** below illustrates where the currently available flow gauges and stream flow measurements are located with respect to the river network.

The flow records and water levels from selected flow gauging stations are obtained from the DWAF. Missing and or exceeded data are patched as part of Task 8 to Task 10. Additional information on stream flow is obtained from recent hydrocensus data (City of Cape Town, 2004b, 2005b, 2006).

Table 5-2: River Flow Data

Data	Format		Scale	Source
Flow gauging stations	Vector	Points		DWAF
Flow records	Data	Time series	Daily	DWAF
Stream flow	Data			Hydrocensus (TMGA)
	Data			Hydrocensus Hex River

5.1.3 Water level in surface water bodies

The seasonal changes in water level in surface water bodies, such as river reaches, ponds and dams, are relevant for the quantification of surface water – groundwater interaction, as the hydraulic head difference between groundwater and surface water determines the gradient and direction of flow (i.e. influent or effluent system), required for any groundwater flow or mass balance model.

The two confined TMG aquifers that are primarily relevant to this study are some distance below the base of the riverbeds. There are discreet river reaches where either the Skurweberg or the Peninsula Formation are exposed at subsurface or at the base or on the sides of river reaches infilled by significant thicknesses of alluvium. These reaches can be identified from available geology and topocadastral data. In these areas and on the coastal plains, the monthly or at least seasonal elevation of the water in any one river together with the elevation of the groundwater table is needed to evaluate surface water-groundwater interaction.

Additional information on water levels is obtained from hydrocensus data and study reports and inferred from topographic and geological maps. These data and the model results from the surface water modelling will be used as input for the groundwater modelling.

Table 5-3: Water Level Data

Data	Format		Scale	Source
Flow gauging stations	Vector	Points		DWAF
Measured water level at gauging station	Data	Time series	Daily	DWAF
Average water level (Zeekoevlei)			Once-off	Parsons (2001)

5.1.4 Geometry and geological context of surface water bodies

The width and depth of the riverbeds are required input parameter for the hydrodynamic modelling tools, as these parameters directly influence the water level and flow rate.

There is no detailed geometry data available on river reaches in the study area. However, in the mountainous regions these can be inferred from topographic and geological information. It is more complex in the coastal plain where there has been greater lateral movement in river channels and changes in channel direction and or elevation over time and in response to sea level changes. Inferences are made on the basis of current understanding of the recent and tertiary geological history as well as borehole logs. The basic geological context of a river reach – i.e. the stratigraphy underlying the river, can be determined or for the purposes of this study adequately inferred therefore from geological history, topographic and geological maps and process understanding.

5.1.5 Run-off

Run-off is equal to the sum of river flow over a certain period of time. Due to its normal calculation and expression in this context, run-off includes the overland flow, interflow (see below) and the groundwater contribution to baseflow (see **Table 5-4**). It would be preferable for the groundwater balance model, to separate the groundwater contribution to baseflow.

Table 5-4: Run-off Data

Data	Format		Scale	Source
Mean Annual Run-off	Vector	Polygon	Per catchment	WR90 (Midgley et al 1994)

The run-off data is only available as mean annual values per quaternary catchment. Time series data is only available as river flow at flow gauging stations at the downstream end of catchments. Since this parameter is important for the water balance model, it will be required to set up a GIS model of the spatial distribution of overland flow as a function of rainfall, altitude and slope.

5.1.6 Baseflow

Baseflow is defined as sustained low flow in a river during dry or fair weather conditions, and groundwater makes a contribution to the baseflow component of river flow. The ‘groundwater contribution to baseflow’ is considered to be the portion of groundwater which contributes to the low flow of streams originating from the regional groundwater body. On the other hand, interflow, defined as “rapid flow of water along essentially unsaturated flow paths, water that infiltrates the subsurface and moves both vertically and laterally before discharging into other water bodies”, is not considered part of the ‘groundwater contribution to baseflow’ i.e. it is simply surface water that for a short period of time is subsurface and does not ever reach the saturated zone. In the context of a regional mass balance it is an ephemeral aspect of surface groundwater interaction.

Groundwater contribution to baseflow is an indication of the natural discharge of groundwater within each catchment including that from perennial springs. Since it is seldom that confined aquifers contribute directly to baseflow in the river bed, most groundwater contribution to baseflow from these aquifers is via spring flow at discreet locations. It is possible that these confined aquifers contribute directly to river flow only if the aquitard overlying them is continuously fractured. Where the aquifer directly underlies the river and is transected by large scale regional faults and fracture systems, there can be direct discharge to the river. These contexts can be mapped.

Table 5-5: Baseflow Data

Data	Format		Scale	Source
Mean Annual Baseflow	Vector	Polygon	1:7 500 000	Vegter
Mean Annual Baseflow	Vector	Polygon	Per catchment	WR90 (Midgley et al 1994)
Mean Annual Baseflow	Vector	Polygon	Per catchment	Hughes (in GRDM; DWAF, 2006c)
Mean Annual Baseflow	Vector	Polygon	Per catchment	Pitman (in GRDM; DWAF, 2006c)
Mean Annual Baseflow	Vector	Polygon	Per catchment	Schulze (in GRDM; DWAF, 2006c)
Mean Annual Baseflow	Vector	Polygon	Per catchment	GRDM (DWAF, 2006c)
Groundwater contribution to baseflow	Vector	Polygon	Per catchment	GRDM (DWAF, 2006c)

The published baseflow values from different sources vary significantly (see **Appendix C**), as the underlying assumptions and methodologies differ. The main differences are due to a different definition of baseflow. The Pitman and Hughes interpretation of baseflow includes all water that migrates through the subsurface, hence it includes seepage from perched aquifers, high lying springs and interflow (Parsons & Wentzel, 2005). A large fraction of this water never reaches the regional aquifer, hence it does not form part of the groundwater resources.

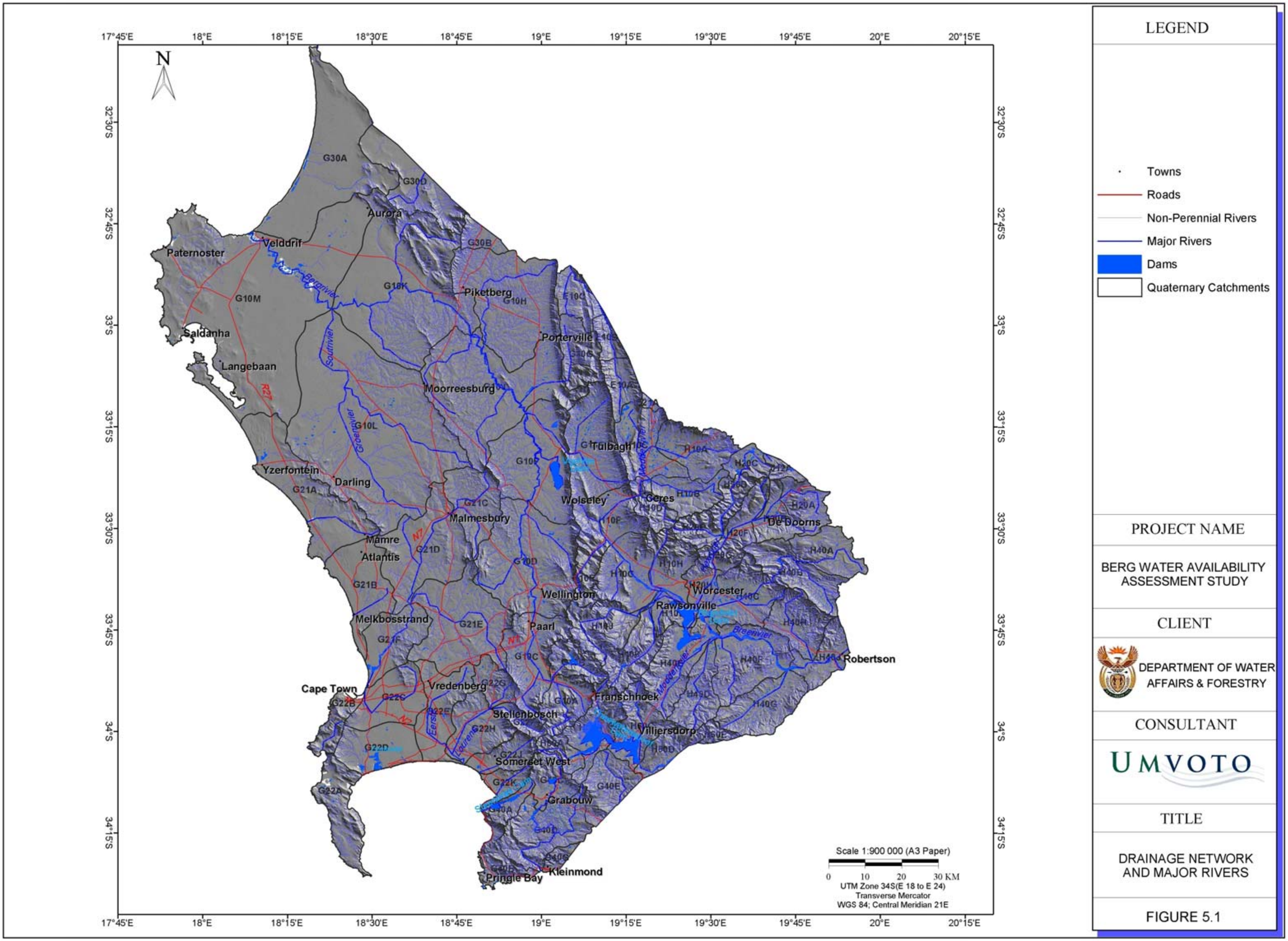
For the purpose of this study only the groundwater contribution to baseflow should be considered in further analysis. However, this data set is only available on a quaternary scale and is not aquifer specific.

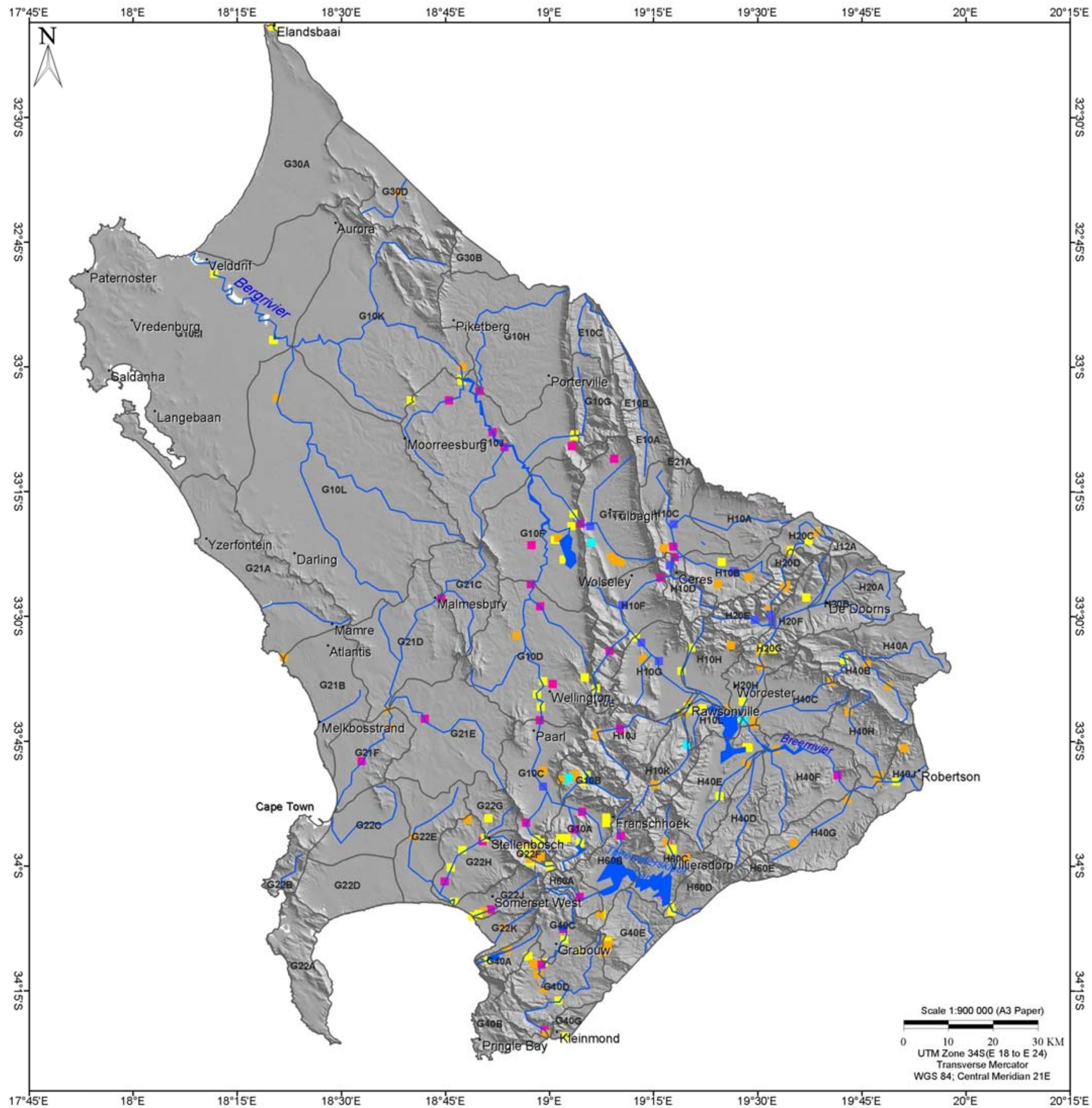
The methodology adopted for this study comprises the following:

- As a 1st order estimate the values for groundwater contribution to baseflow, as given in the GRDM software, will be used.
- An attempt will be made to disaggregate these baseflow values within each catchment, based on outcrop area, location of springs and geological reasoning, as indicated above.
- The values will be updated during the study in an iterative process, based on results from both the surface water and groundwater modelling.

5.1.7 Water quality

The change of water quality in surface water bodies can be an indicator of distinct groundwater discharge into the river. There is limited data in this regard. Further discussion on this particular aspect is contained in the Conceptual Model report (Volume 3). Recommendations to improve the spatial distribution and quality of the available data are contained in Section 9. For more details and modelling results on the water quality aspects of the surface water refer to Tasks 16 to 19 of this study.


LEGEND
Towns
Roads
Non-Perennial Rivers
Major Rivers
Dams
Quaternary Catchments
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
Paternoster
Velddrif
Aurora
Piketberg
Saldanha
Langebaan
Porterville
Moorreesburg
Tulbagh
Yzerfontein
Darling
Wolseley
Ceres
De Doorns
Malmesbury
Mamre
Atlantis
Wellington
Worcester
Rawsonville
Melkbosstrand
Paarl
Robertson
Cape Town
Vredenburg
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
Pringle Bay
Kleinmond
Bergrivier
Breerivier
G30A
G30D
G30B
G10K
G10H
G10M
G10L
G10F
G21A
G21C
G21D
G10D
G21B
G21E
G21F
G10C
G22B
G22C
G22E
G22G
G22H
G22D
G22A
G22K
G40A
G40E
H10A
H10B
H10C
H10D
H10F
H10G
H10H
H20A
H20F
H40A
H40B
H40C
H40E
H40F
H40G
H40H
H40D
R27
N7
N1
N2
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
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS & FORESTRY
CONSULTANT
UMVOTO
TITLE
DRAINAGE NETWORK AND MAJOR RIVERS
FIGURE 5.1



PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

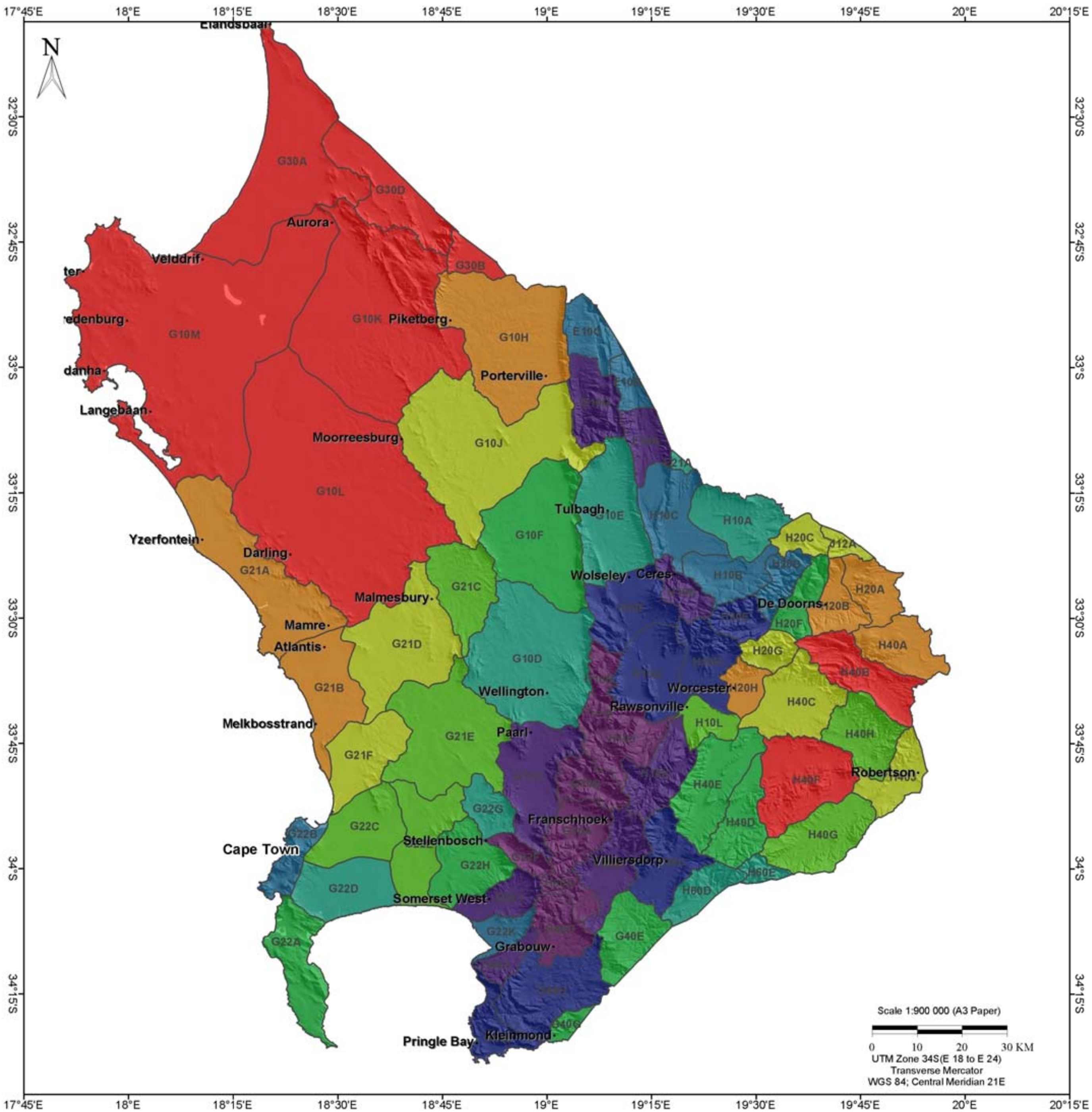
CONSULTANT

UMVOTO

TITLE

FLOW GAUGING STATIONS WITHIN STUDY AREA

FIGURE 5.2



LEGEND

Towns

Quatenary Catchments

MAR per Catchment (mm/a)

- 6.3 - 29.0
- 29.0 - 36.4
- 36.4 - 58.8
- 58.8 - 95.2
- 95.2 - 145.5
- 145.5 - 221.5
- 221.5 - 347.4
- 347.4 - 441.5
- 441.5 - 697.3
- 697.3 - 1206.8

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

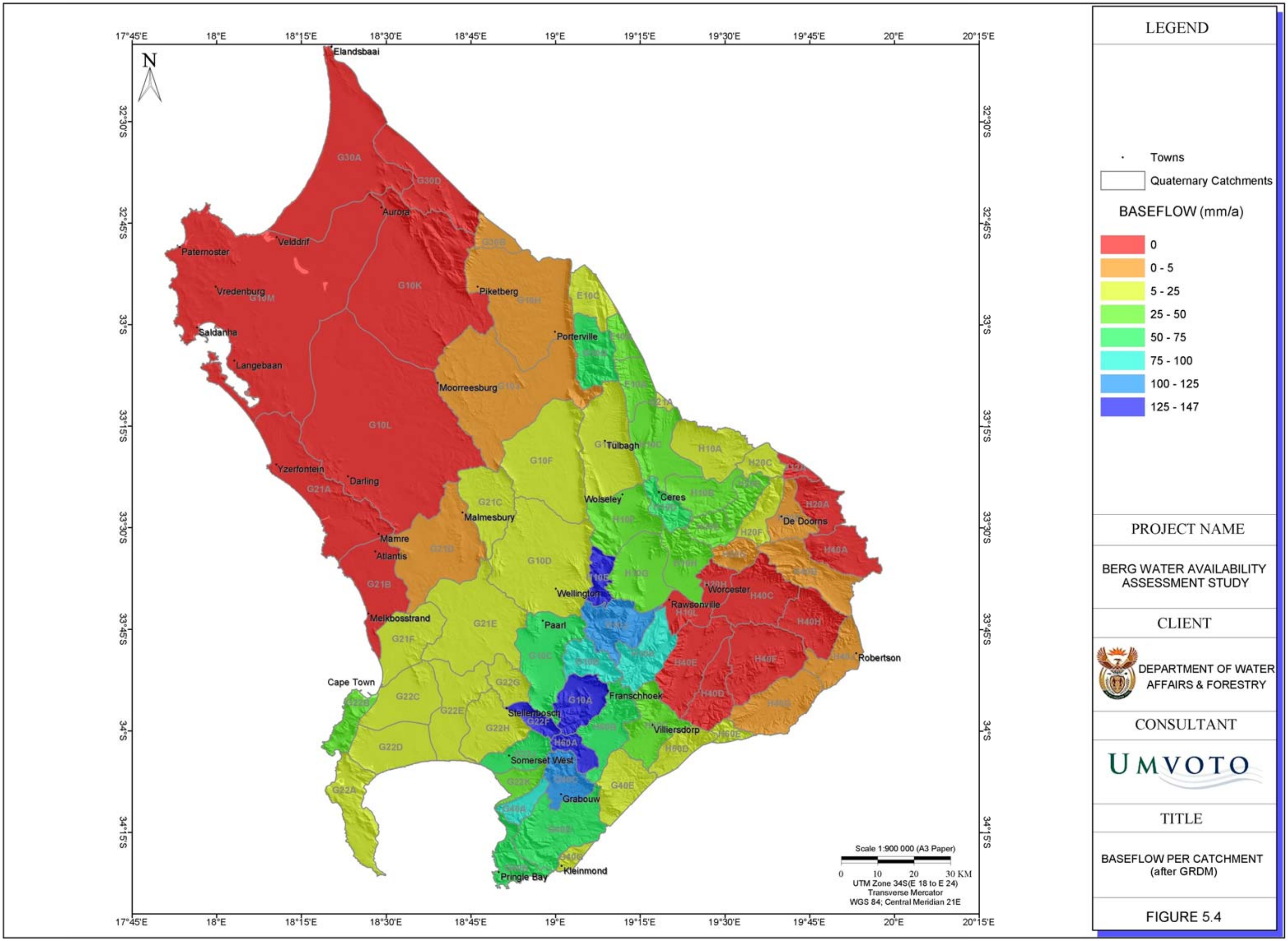
CONSULTANT

UMVOTO

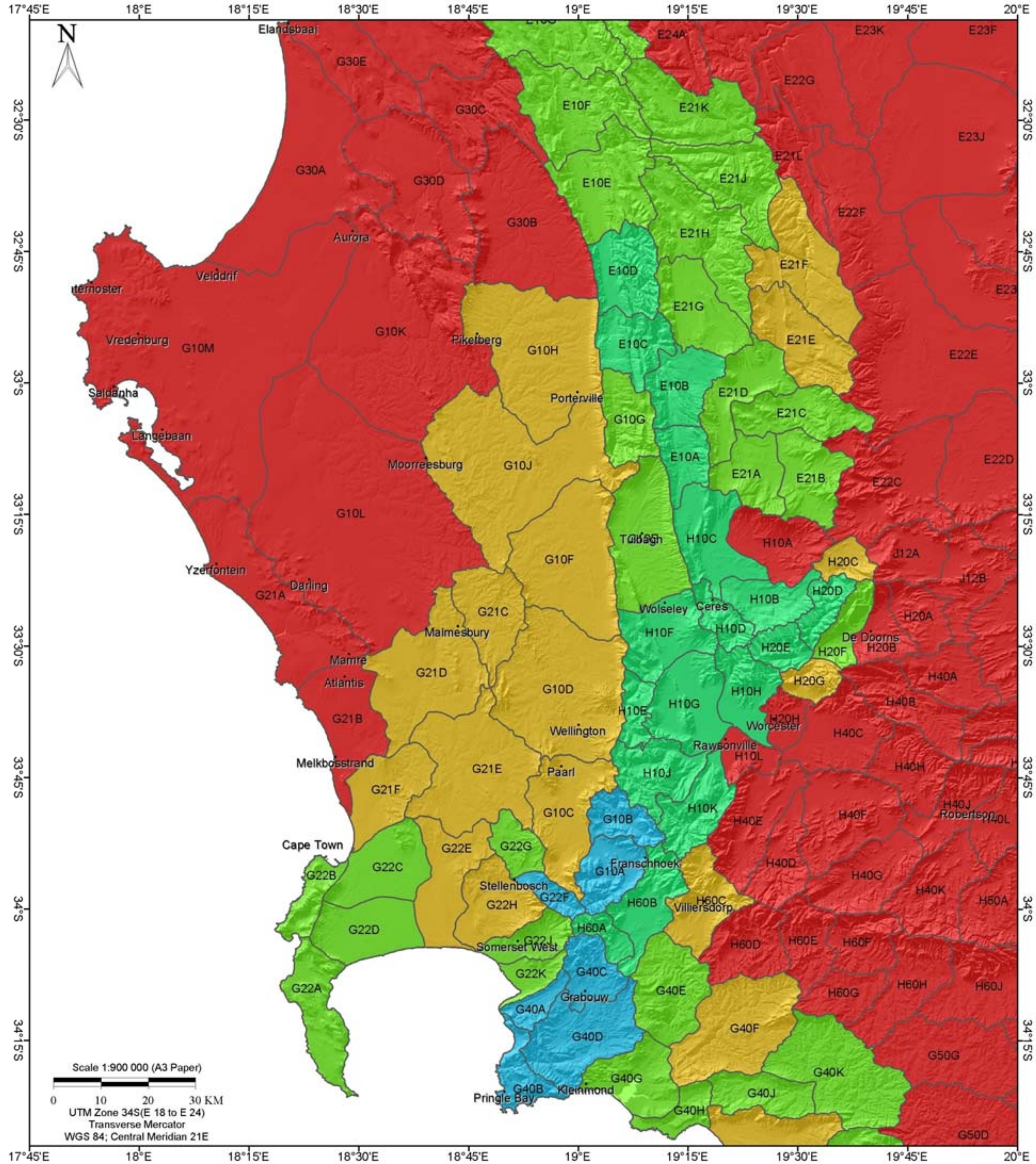
TITLE

MAR PER CATCHMENT IN STUDY AREA (WR90)

FIGURE 5.3



LEGEND
Towns
Quaternary Catchments
BASEFLOW (mm/a)
0
0 - 5
5 - 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 147
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS & FORESTRY
CONSULTANT
UMVOTO
TITLE
BASEFLOW PER CATCHMENT (after GRDM)
FIGURE 5.4
N
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
Elandsbaai
Aurora
Velddrif
Paternoster
Vredenburg
Saldanha
Langebaan
Piketberg
Porterville
Moorreesburg
Tulbagh
Yzerfontein
Darling
Wolseley
Ceres
Malmesbury
De Doorns
Mamre
Atlantis
Wellington
Worcester
Rawsonville
Melkbosstrand
Paarl
Robertson
Cape Town
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
Kleinmond
Pringle Bay
G30A
G30D
G10K
G10M
G10L
G21A
G21B
G21C
G21D
G21E
G21F
G10F
G10D
G10A
E10C
H10A
H20C
H20A
H20F
H40A
H40C
H40H
H40E
H40D
H10L
G22A
G22C
G22D
G22E
G22G
G22H
G22F
H60A
G40E
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

Quaternary Catchments

GROUNDWATER CONTR. BASEFLOW (mm/a)

- 0 - 5
- 5 - 10
- 10 - 20
- 20 - 40
- 40 - 60

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

GROUNDWATER CONTRIBUTION TO BASEFLOW PER CATCHMENT (After GRDM)

FIGURE 5.5

5.2 HYDROCLIMATOLOGY

5.2.1 Precipitation

Precipitation is the summary of the discharge of water out of the atmosphere upon a water or land surface, and includes rain, snow, hail, sleet and mist.

Monthly rainfall data is key to determining recharge to the different aquifers during modelling. It is preferable that the data is spatially well spread with respect to altitude because the rainfall in the Western Cape is orographically controlled and most recharge to groundwater happens in the high mountain regions.

Rainfall and therefore recharge and abstraction is seasonal in the Western Cape. There is limited knowledge on the nature of event response recharge. To begin to understand the recharge process at this level of detail would require daily rainfall records as well as run off data at selected sites and, in the case of fractured rock, it is important that these sites are along local and regional preferred flow paths. These are presently unavailable. However given the seasonal pattern of rainfall, monthly and seasonal averages are relevant rather than annual averages.

The regions of high rainfall coincide with topographically elevated mountain chains, mainly underlain by erosion-resistant, but highly fractured TMG rocks. The rainfall values are as high as 3400 mm/a; this is illustrated by the colour codes from red to purple (**Figure 5-6** to **Figure 5-8**). A comparison of average values per catchment is tabled in **Appendix C**.

Table 5-6: Rainfall Data

Data	Format		Scale	Source
Mean Annual Precipitation	Raster	Data	1 km x 1 km grid	Groundwater Resource Assessment II (GRA II) (DWAF, 2004)
	Raster	Data	1750 m x 1750 m grid	Agrohydrology (Schulze R E et al 1997)
	Vector	Points	1750 m x 1750 m grid	Computing Centre for Water Research (CCWR)
	Raster	Data	100 m x 100 m	Ninham Shand
	Vector	Polygon	Per catchment	WR90 (Midgley et al 1994)
	Vector	Polygon		WR90 (Midgley et al 1994)
Mean Monthly Rainfall	Raster	Data	1750 m x 1750 m grid	Agrohydrology (Schulze R E et al 1997)
Rainfall stations	Vector	Point		Ninham Shand (SAWS)
Rainfall	Data	Time series	Daily	South African Weather Service
	Data	Time series	Daily	Ninham Shand

There is sufficient rainfall data available, both as spatial contribution of mean annual and mean monthly values and as time series at several rainfall stations.

However, there are conflicting data on the MAP distribution from the different sources. Findings in previous studies revealed that the MAP distribution from the CCWR in the high mountainous areas was lower than the MAR values for these catchments. It was therefore decided to develop a revised spatial distribution of MAP, based on additional rainfall data and rainfall stations. The revised distribution (DWAF, 2007b) will be used and the monthly rainfall data from Agrohydrology will be recalculated proportionally.

In other studies, it has been found that where there is no [SAWS] data there is often very good rainfall data from farmers in particular areas of commercial agriculture. In this study, however, the private data has not been integrated into the hydroclimatology data set.

5.2.2 Temperature

Daily temperature data and or long-term monthly averages for temperature are used in the water balance model. There is a significant difference in temperature depending upon the altitude. Given that the highest recharge happens in the high mountains during winter (May – September), and that there is evidence of pseudo-karstic terrain in these areas, appropriate temperature averages are used in any evapotranspiration calculation as there is a significant difference between the seasons (up to 11ºC in average monthly values).

The available temperature data are time series at selected weather stations as well as modelled spatial distribution of mean monthly temperature. The spatial distribution reflects the relationship between temperature and altitude. Mean monthly data are sufficient for estimation of actual evapotranspiration (see **Table 5-7**) in the mapcentric recharge model.

Table 5-7: Temperature Data

Data	Format		Scale	Source
Mean Monthly Temperature	Raster	Data	1750 m x 1750 m grid	Agrohydrology (Schulze R E et al 1997)
Temperature	Data	Time series	Daily	South African Weather Service (SAWS)

5.2.3 Evaporation / Evapotranspiration

Potential evaporation is defined as the evaporation rate from open water, i.e. from a free water surface and is dependent on factors such as temperature and wind speed. As it is from open water it can be thought of as an evapotranspiration maximum. Actual evapotranspiration rates are dependent on the potential evaporation, vegetation type, vegetation age (i.e. root depth), soil type and weather conditions.

Monthly actual evapotranspiration data is needed in the Water Balance Model to calculate recharge.

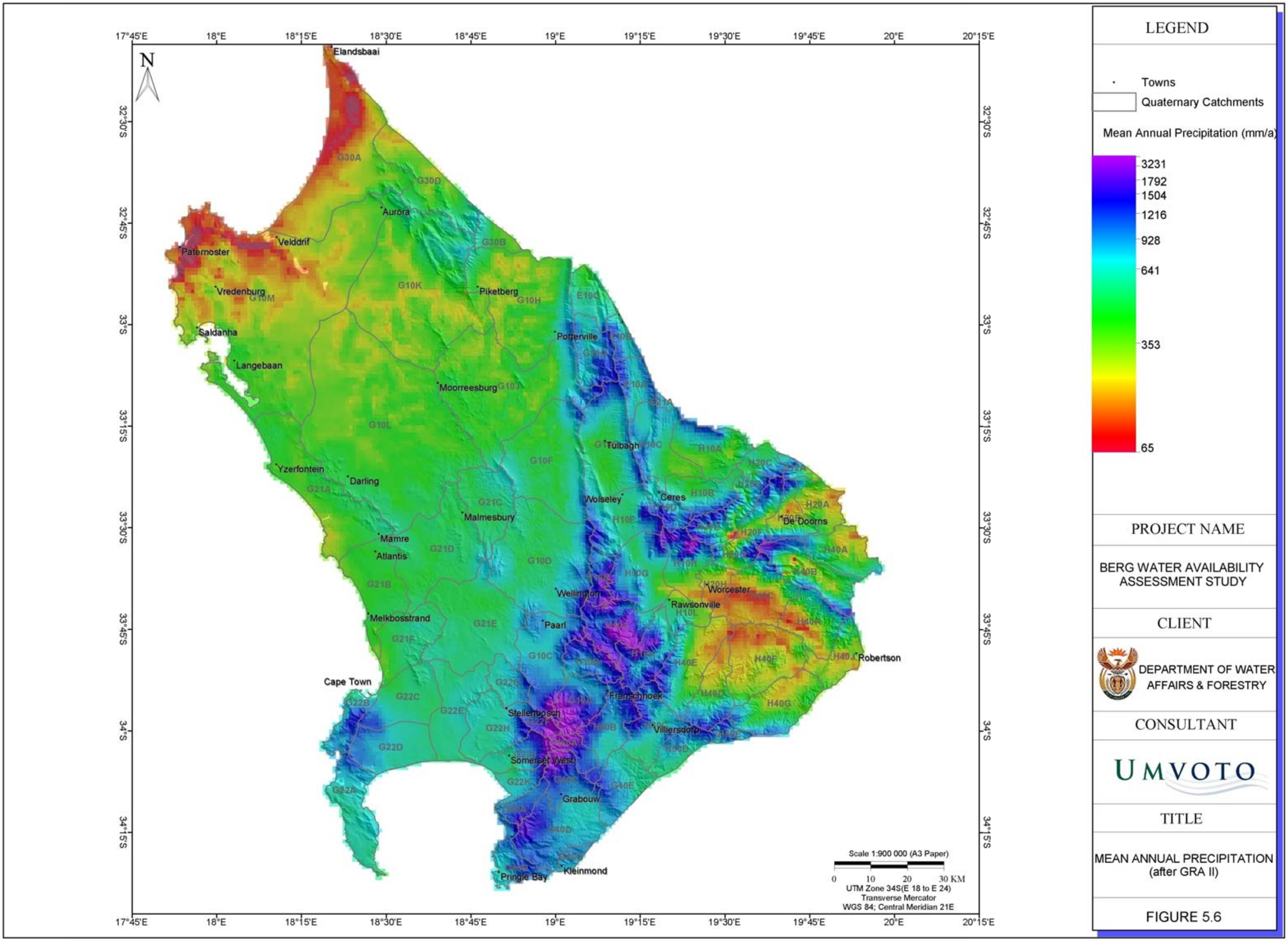
Mean annual and mean monthly evaporation and evapotranspiration data are available on a 1.75 km grid for the whole country from the Agrohydrology Atlas (Schulze et al, 1997). In addition, crop factors for agricultural crops are available from SAPWAT. Crop factors for plantation can be obtained from the Gush tables, while factors for invasive alien plants (IAP) can be obtained from the CSIR biomass curves.

Table 5-8: Evaporation and Transpiration Data

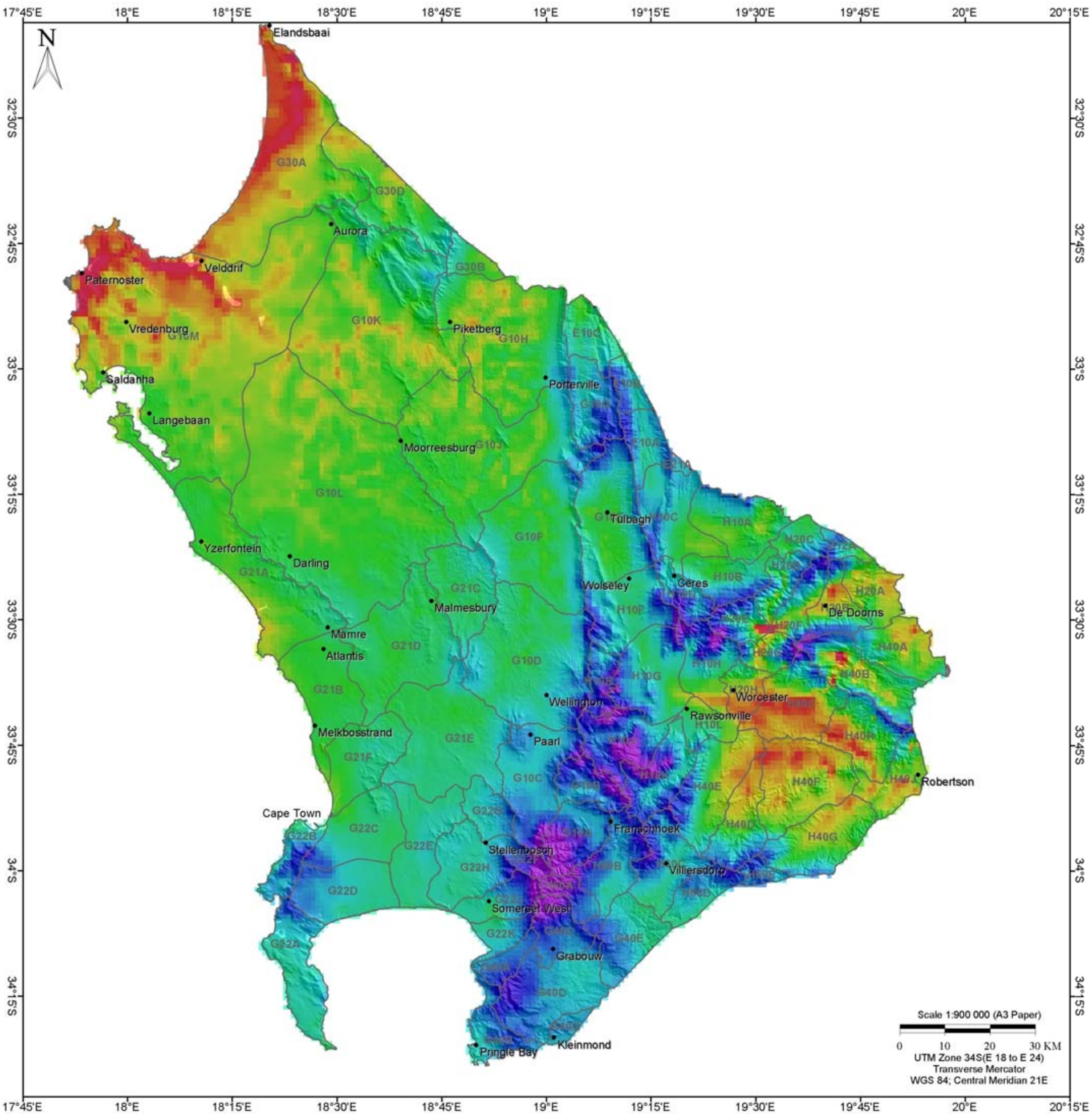
Data	Format		Scale	Source
Mean Annual Potential Evaporation	Vector	Polygon	1:1 000 000	WR90 (Midgley et al 1994)
Mean Annual Potential Evaporation	Raster	Data	1750 m x 1750 m grid	Agrohydrology (Schulze R E et al 1997)
Crop Factors	Data			SAPWAT
Factors for plantations	Data			Gush Tables
Factors for IAPs	Data			CSIR biomass curves

The only available data are measurements and spatial distribution of potential evaporation. There are no data on actual evapotranspiration and no time series data available.

The actual evapotranspiration will be modelled, based on monthly temperature and monthly rainfall, applying the formula by Turc (1964). In the future, transpiration data or water requirements for different vegetation types can be used in order to refine the results.



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
Elandsbaai
Aurora
Velddrif
Paternoster
Vredenburg
Saldanha
Langebaan
Piketberg
Porterville
Moorreesburg
Tulbagh
Yzerfontein
Darling
Wolseley
Ceres
De Doorns
Malmesbury
Mamre
Atlantis
Wellington
Worcester
Rawsonville
Melkbosstrand
Paarl
Robertson
Cape Town
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
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
Quaternary Catchments
Mean Annual Precipitation (mm/a)
3231
1792
1504
1216
928
641
353
65
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS & FORESTRY
CONSULTANT
UMVOTO
TITLE
MEAN ANNUAL PRECIPITATION (after GRA II)
FIGURE 5.6



LEGEND

• Towns

Quaternary Catchments

Mean Annual Precipitation(mm)

3070
1870
1570
1270
970
670
370
70

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

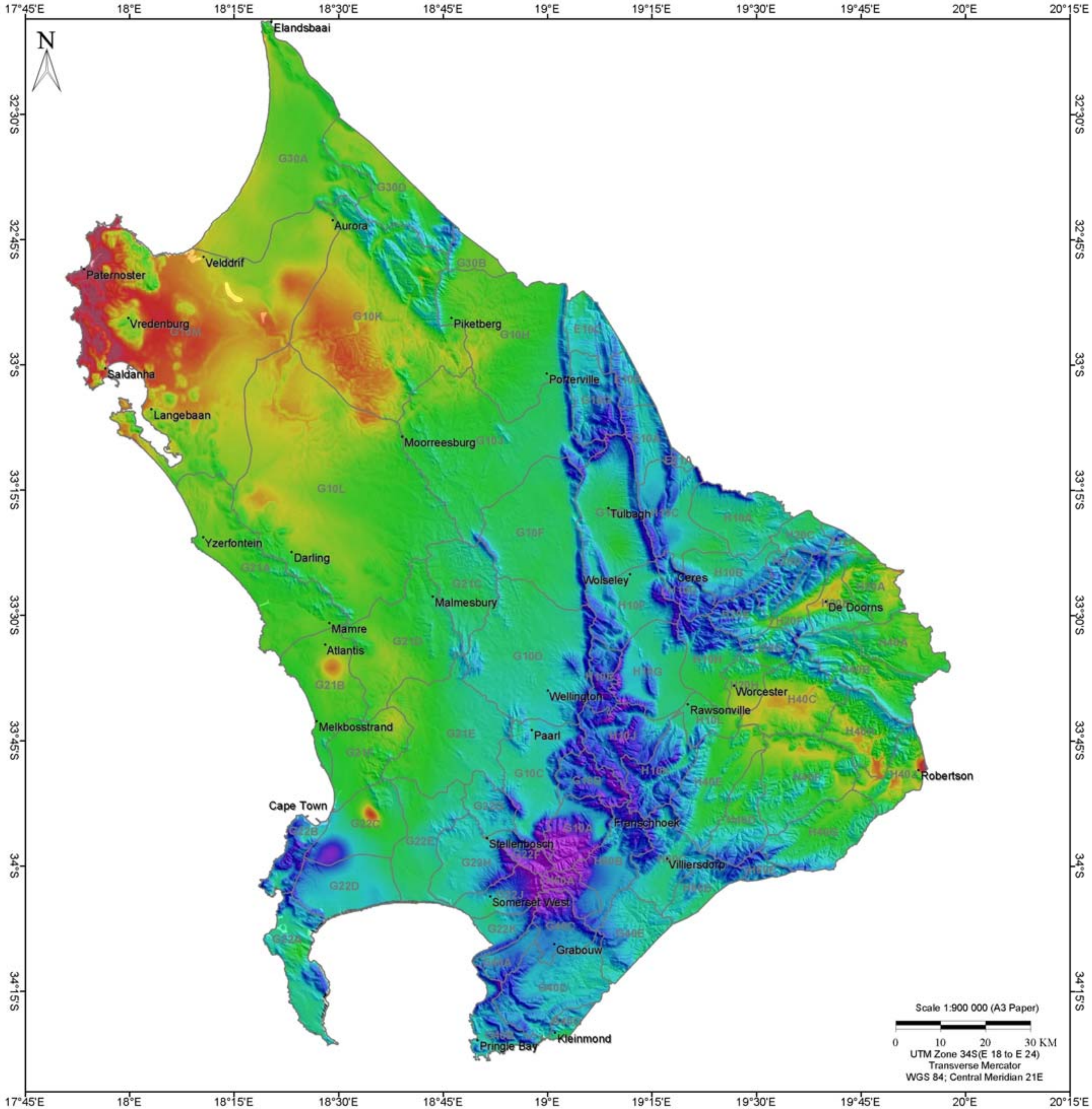
CONSULTANT

UMVOTO

TITLE

MEAN ANNUAL PRECIPITATION (after CCWR)

FIGURE 5.7



LEGEND

Towns

Quaternary Catchments

Mean Annual Precipitation(mm)

3238

1147

624

101

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

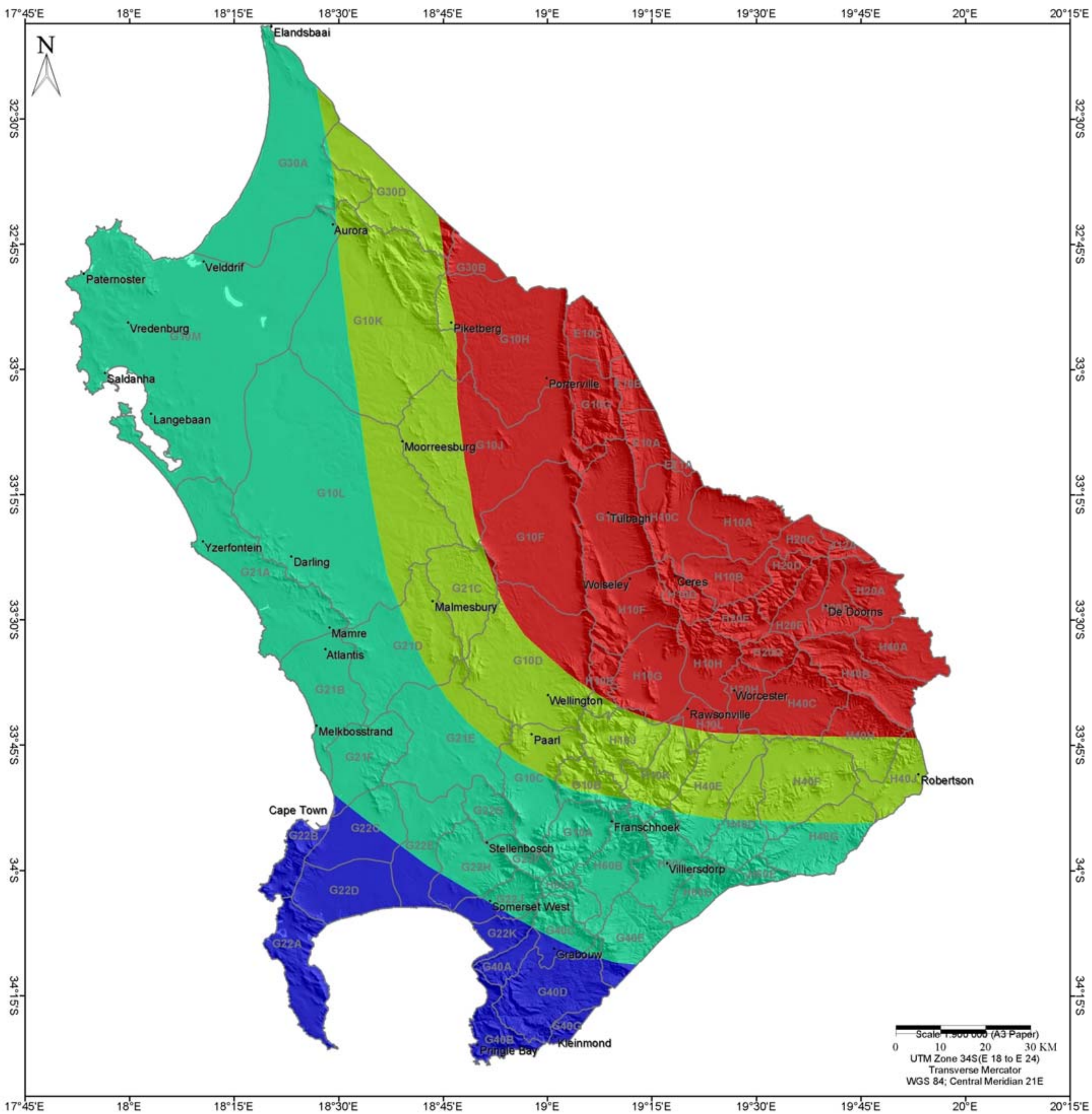
CONSULTANT

UMVOTO

TITLE

MEAN ANNUAL PRECIPITATION (after CCWR revised by Ninham Shand)

FIGURE 5.8



LEGEND

Towns

Quaternary Catchments

Mean Annual Potential Evaporation(mm)

- 1200 - 1299
- 1300 - 1399
- 1400 - 1499
- 1500 - 3000

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

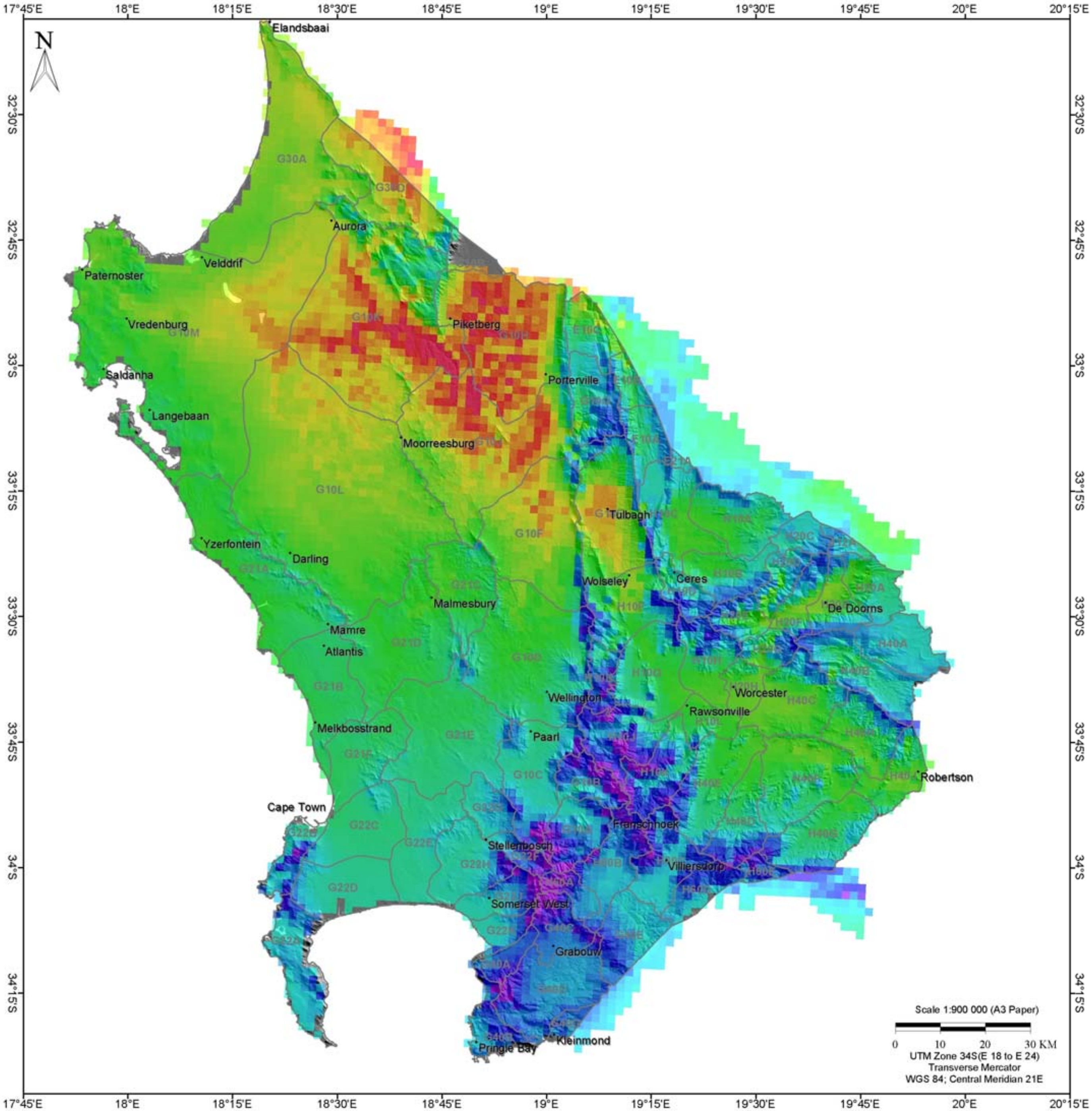
CONSULTANT

UMVOTO

TITLE

MEAN ANNUAL POTENTIAL EVAPORATION (after WR90)

FIGURE 5.9



LEGEND

Towns

Quaternary Catchments

Mean Annual Potential Evaporation(mm)

2442

2109

1776

1443

444

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

MEAN ANNUAL POTENTIAL EVAPORATION (After Agrohydrology)

FIGURE 5.10

6. GEOLOGY AND HYDROGEOLOGY

6.1 GEOLOGY

6.1.1 Lithology

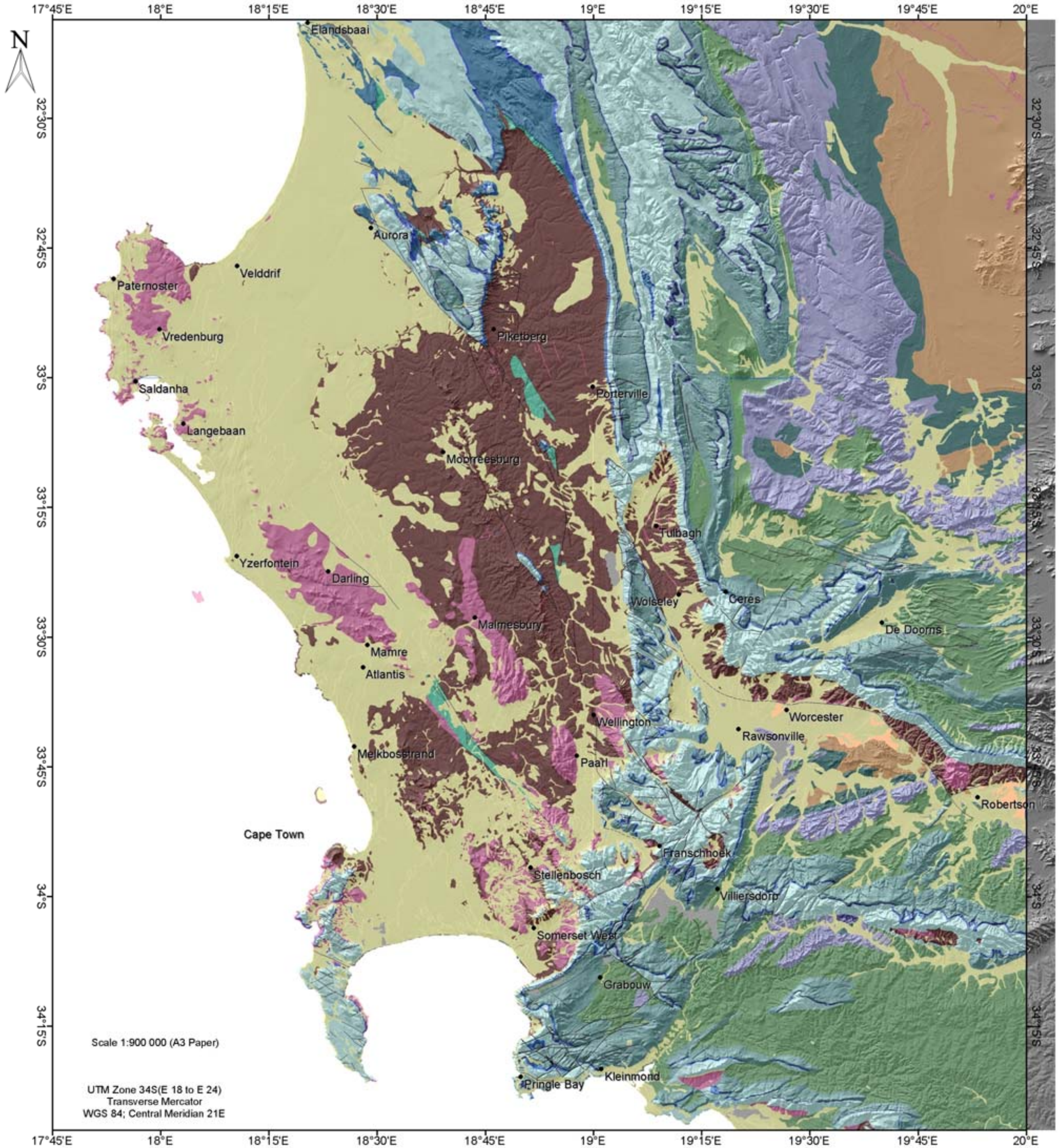
Lithological and structural geology data at 1:250 000 and 1:50 000 scale are used to plot the spatial distribution of the key formations in a stratigraphic sequence for the production of geological maps. These are used to establish the aerial extent and vertical dimensions of the aquifers of interest and whether there is reasonable expectation that the aquifers are confined and unconfined. The geology and topography coupled with surface water, spring and borehole data patterns and detail are used to determine areas of recharge, storage and discharge of water and provide a composite 3D model of the aquifers.

The study area is covered by existing geological map data at a scale of 1:250 000. The Worcester Sheet 3319 (Gresse 1997), the Cape Town Sheet 3318 (Theron et al. 1992) and the Clanwilliam Sheet 3218 (Visser et al 1973) were acquired and scanned to produce digital images of these maps.

The regional geology or 1:250 000 maps are used for conceptual modelling as well as input to the regional mass balance. However for the detailed flow and mass balance modelling geology data at a scale of at least 1:50 000 is needed. The 1:50 000 geological sheets were acquired from the Council for Geoscience (CGS) in different formats as illustrated in **Table 6-1** and **Figure 6-2**.

Table 6-1: Geology Data

Data	Format		Scale / Extent	Source
Geology	Raster	Scanned - Map	1:250 000	Council for Geoscience (CGS)
	Vector	Polygon	1:250 000	Umvoto Africa (after CGS)
	Vector	Polygon	1:50 000	City of Cape Town (after CGS)
	Raster	Scanned-Map	1:50 000	CGS
	Vector	Polygon	1:50 000	
	Vector	Polygon	1:50 000	Umvoto Africa (after CGS)
Borehole logs	Data			NGDB/NGA
	Data	Figure	Cape Flats	Wessels and Greeff, 1980
Geological cross sections	Data	Figure	Cape Flats	Henzen, 1973
	Raster	Map	Langebaan	SRK, 2004



LEGEND

- Towns
- Faults

LITHOLOGY

- Quaternary Sediments
- Uitenhage Group
- Ecca Group
- Dwyka
- Witteberg Group
- Bokkeveld Group
- Nardouw_Sub Grp
- Cedarberg Formation
- Pakhuis Formation
- Graafwater Formation
- Peninsula Formation
- Piekenierskloof Formation
- Klipheuwel_Grp
- Dolerite_dyke
- Malmesbury_Grp
- Cape_Granite Suite
- Dam

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

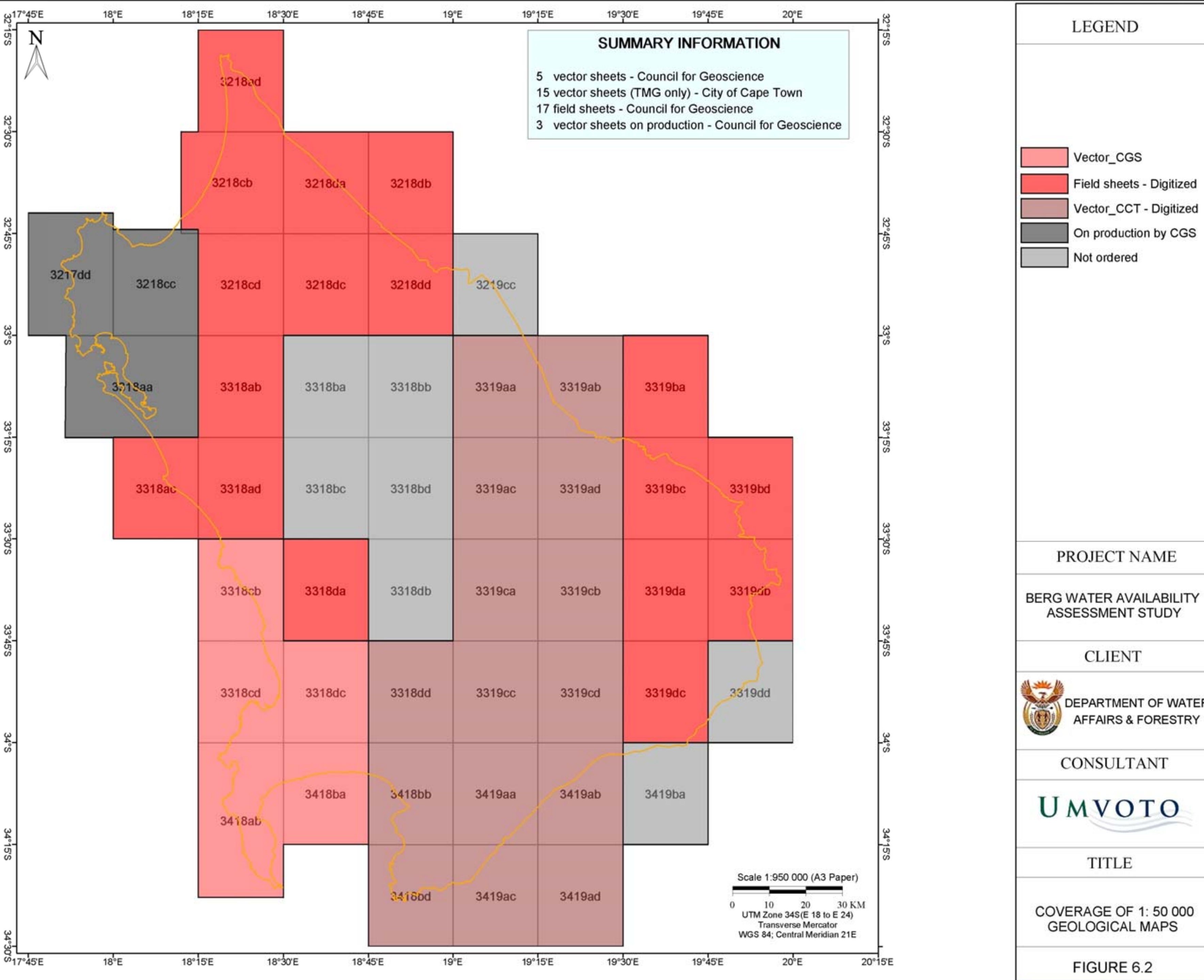
CONSULTANT

UMVOTO

TITLE

1 : 250 000 GEOLOGY MAP (After CGS)

FIGURE 6.1



PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

COVERAGE OF 1: 50 000 GEOLOGICAL MAPS

FIGURE 6.2

6.1.2 Structural Features

Structural information of fault lines, strike/dip information of geological units and linear axes of anticlinal and synclinal folds are used together with the lithological data in the development of the geological maps and in structural studies in the 3D distribution of the geological formations.

Fault lines and fold axes indicate complications in the orientation and position of an otherwise layer cake stratigraphy. Fault planes act as boundaries to hydrogeological units. The faults themselves can be conduits for water flow in the subsurface as can the wide fracture zone on one or either side of a fault. If the fault is annealed, it can act as a hydrogeological barrier. In this case, the primary water flow can take place in the fractured zone on either side, or on just one side of the fault, depending upon the fault character.

Structural geological data, in terms of faults were acquired in two ways. Firstly, the data were digitised from the 1:250 000 geological maps. Secondly, 1:50 000 fault lines were received from the CGS with the vector geological map. No faults were captured from the 1:50 000 field sheets received from the CGS.

Table 6-2: Structural Data

Data	Format		Scale	Source
Faults	Raster	Scanned-Map	1:250 000	CGS
	Vector	Line	1:250 000	Umvoto Africa (after CGS)
	Vector	Line	1:50 000	CGS
Fractures	Vector	Line	1:100 000 1:40 000 1:10 000	Umvoto Africa

The fracture-trace analysis was conducted for the TMGA project (City of Cape Town, 2004a) at 1:100 000 scale and at 1:40 000 scale from Landsat, and at 1:10 000 from the orthorectified imagery. In addition, a comparative lineament study based on variously sun-shaded DEMs was undertaken to augment the Landsat-based interpretations. The remote-sensing structural interpretation involved data collection through aerial photographic interpretation (API), Landsat 7 ETM+ image processing and interpretation, digital elevation model (DEM) and their derivative products, and fracture analysis by way of conventional structural geological techniques. The remote-sensing structural interpretation was done for selected areas of key hydrogeological significance only. These data sets are available for this study to supplement the broader scale mapping from existing geological maps.

The existing information and data on faults is sufficient for the regional model and can be refined in the detailed model domains, from structural analysis of existing data. However, the currently available data about the fracture network is very detailed in some areas of the study area, e.g. Piketberg and Hottentots Holland, while the data is not available at the required scale in other areas, especially in the northern part around Tulbagh, Ceres and Hex River. As discussed above, the information about fracture distribution and density is crucial for determining hydraulic parameters, hydraulic relevant thickness and interaction with surface water bodies. It is therefore recommended to undertake a fracture mapping in the study area to fill these data gaps in all areas relevant for detailed modeling and for groundwater – surface water interaction.

6.1.3 Geometry of lithological units

The geometry of the fractured rock aquifers is defined by the thickness of the lithological units, as well as its orientation (i.e. dip and strike) and its structural nature such as folding and boundaries. The national scale estimation of aquifer thickness from the GRA II is presented in **Figure 6-3**. The GRA II data are not feasible for the project. For the purpose of this study the aquifer thickness of the relevant TMG aquifers will be modelled in the GIS from lithological contacts, faults, dip and strike information and geological reasoning.

The above geological properties, in addition to the GIS modeling, field measurement and borehole data, is calculated during the process of constructing cross sections. Balanced cross sections approved by an experienced structural geologist are considered to be reliable 3D models of aquifer geometry. The cross section preparation is documented in Volume 3 – 9 of this report and comprises part of the data, information and knowledge available. These cross sections inform in-house structural and geological GIS and spreadsheet based models to calculate the aquifer volume.

Formations are tabular units and, although they do change thickness and facies (i.e subtle rock type changes) over distances, they do so in a systematic and therefore predictable fashion. This makes it possible to interpolate between particular reference sections where detailed thickness and orientation measurements have been taken either in the field or down a hole.

The geometry of the primary aquifers is determined by palaeo/bedrock and surface topography as well as the sedimentary process. Currently available data and information on paleochannels in the primary aquifers of the West Coast and the Cape Flats (see **Table 6-3**) do not coincide with the conceptual understanding of the geological processes for developing these paleochannels. It will be required to revise the bedrock topography, based on borehole information and first principles of geological processes, such as knowledge of sea level changes, geomorphology and in particular river capture and structural controls on past and present drainage patterns.

Table 6-3: Aquifer geometry data

Data	Format		Scale / Extent	Source
Saturated thickness	Raster	Data	1 km x1 km grid	GRA II
Dip and Strike	Vector	Points	1:50 000	CGS
Borehole logs	Data			NGDB/NGA
	Data	Figure	Cape Flats	Wessels and Greeff, 1980
Bedrock topography	Data	Figure	Cape Flats	Henzen, 1973
	Data	Figure	Cape Flats	Gerber, 1980
	Data	Figure	West Coast	Rogers, 1980
	Data	Figure	Langebaan	SRK, 2004
Cross sections	Data	Figure	Cape Flats	Henzen, 1973
	Data	Figure	Langebaan	SRK, 2004

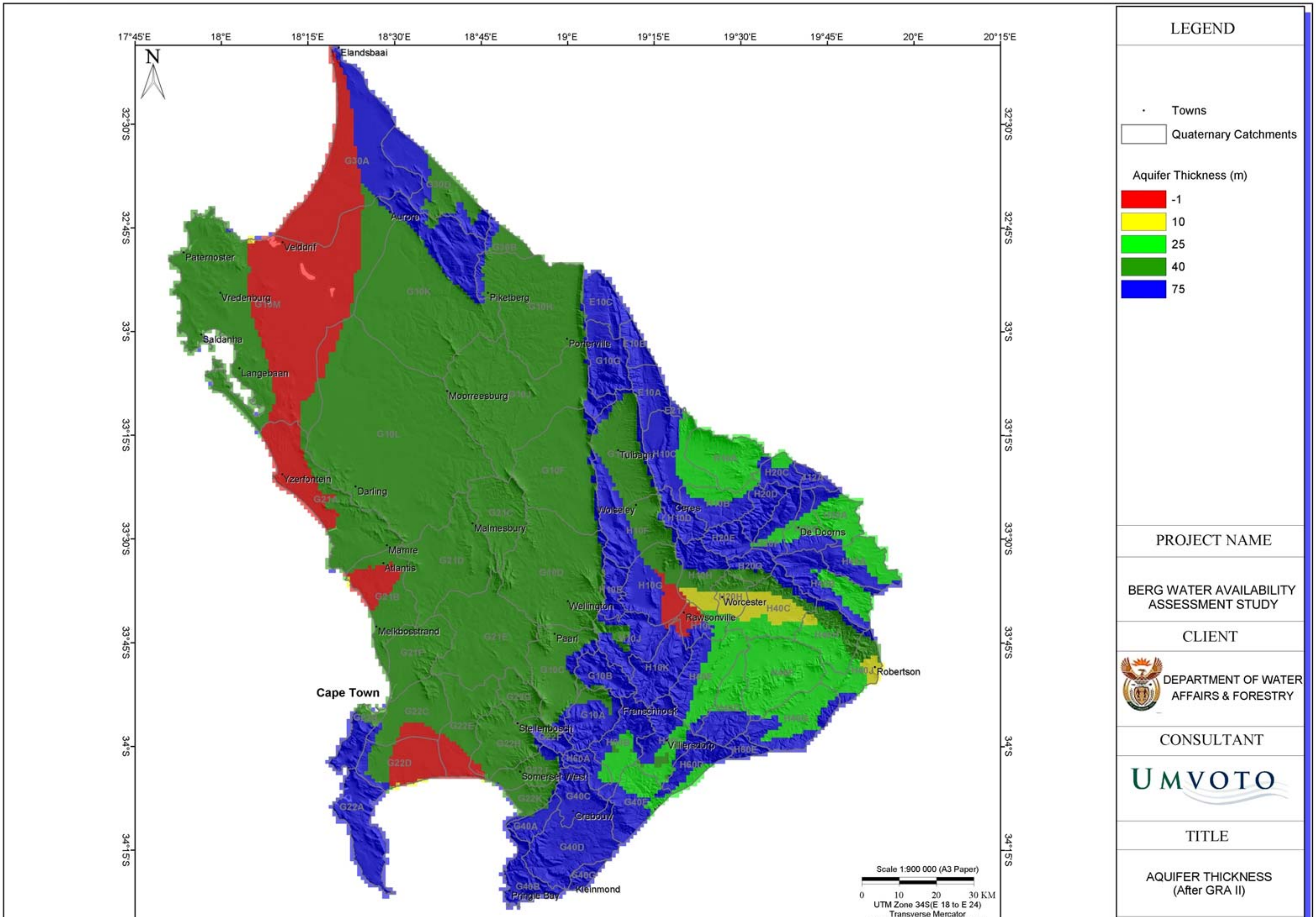

LEGEND
Towns
Quaternary Catchments
Aquifer Thickness (m)
-1
10
25
40
75
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS & FORESTRY
CONSULTANT
UMVOTO
TITLE
AQUIFER THICKNESS (After GRA II)
Scale 1:900 000 (A3 Paper)
0 10 20 30 KM
UTM Zone 34S(E 18 to E 24)
Transverse 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
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
Elandsbaai
Aurora
Velddrif
Paternoster
Vredenburg
Saldanha
Langebaan
Piketberg
Porterville
Moorreesburg
Tulbagh
Yzerfontein
Darling
Wolseley
Ceres
De Doorns
Malmesbury
Mamre
Atlantis
Wellington
Worcester
Rawsonville
Melkbosstrand
Paarl
Robertson
Cape Town
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
Pringle Bay
Kleinmond

FIGURE 6.3

6.1.4 Porosity

Porosity is defined as that fraction of a given volume of material that is occupied by void space. It is usually expressed as the ratio of the volume of voids to the total unit volume of a soil or rock. Hence, it is a measure of the maximum amount of water that can be stored in the aquifer.

There are standard textbook measures of porosity for various rock types (see **Table 6-5**). These are based on a wealth of field data and the values for rock types comparable to those in the study domain can be selected.

Table 6-4: Porosity values for different lithological units (after Driscoll, 1986, Freeze and Cherry, 1979)

Rocks	Porosity (%)	Unconsolidated sediments	
Sandstone	5 – 30	Gravel	25 – 40
Limestone	1 – 20	Sand	25 – 50
Karstic limestone	5 – 50	Silt	35 – 50
Shale	0 – 10	Clay	45 – 55
Basalt, fractured	5 – 50	Sand & gravel mixes	10 – 35
Dense crystalline rock	0 – 5	Glacial till	10 – 25
Crystalline rock, fractured	0 – 10		
Metamorphic rock, fractured	2 – 5		

Electrical resistivity, Gamma ray and Neutron data from down-hole geophysical logs for a number of boreholes that penetrate both the Nardouw Group and the Peninsula Formation is available (see Hartnady and Curot, 2002; Hartnady, in prep.; Mosala, 2006). Porosity can be calculated from resistivity data using Archie's Law, which involves making assumptions of the relative proportions of constituent minerals and using knowledge of mineral density. Neutron logs provide a qualitative proxy measure of the fluid content of the rock; however, the equipment is not calibrated to provide quantitative data.

These data support the estimation of water in storage in the aquifers, as well as the modelling of chemical transport in the aquifers, based on both measured data, if available, and first order estimates from literature.

Table 6-5: Porosity Data

Data	Format		Scale / Extent	Source
Porosity	Data			Literature
	Data		Blikhuis	Hartnady (in prep.)
	Data		DAGEOS	Mosala (2006)
	Data		Boschkloof	Hartnady (in prep.)
	Data		Hermanus	Riemann (unpubl.)
	Data		Cape Flats	Wessels and Greeff, 1980

6.2 HYDROGEOLOGY

Geological data defines the aquifer geometry and character (see section 6.1 above). A number of hydraulic parameters determine water movement in an aquifer (see below). To conduct a water balance model all inflow to and outflow from an aquifer must be determined. Inflow refers to vertical and lateral recharge (see Section 6.2.3 below), while outflow refers to groundwater discharge, springs and groundwater abstraction (see Section 5.1.6 and 8.2).

The following hydraulic parameters are required as direct input into numerical models when considering flow dynamics, depending upon type of aquifer and model:

- Hydraulic conductivity, Transmissivity
- Storativity / Specific Yield
- Recharge
- Groundwater levels.

Hydrochemical and thermal data are useful confirmation of model flow patterns and pathways.

6.2.1 Hydraulic Conductivity / Transmissivity

Hydraulic conductivity (K) is a measure of the ease with which fluid (of a given density and viscosity) flows through a porous material. Values of hydraulic conductivity for the movement of water display a wide range in nature, over 13 orders of magnitude, and in general are high for coarse-grained and fractured materials, while fine-grained silts and clays have low values (see **Table 6-6**). Facies and structural character of geological units may change vertically and laterally and will thus influence similar spatial variations in the aquifer.

Transmissivity (T) is equivalent to the hydraulic conductivity multiplied by the saturated thickness of the aquifer. As the saturated thickness in a confined aquifer is a constant parameter, the transmissivity is a constant and widely used parameter. However, the saturated thickness in an unconfined aquifer varies with time and so the transmissivity is changing over time. Therefore, transmissivity is used for a 2D confined aquifer model only, while hydraulic conductivity is used in 3D models and for unconfined aquifers.

Table 6-6: Hydraulic Conductivity Values for different lithological units (after Kruseman & de Ridder, 1990, Heath, 1983 and Freeze & Cherry, 1979,)

Rocks	K [m/d]	Unconsolidated sediments	K [m/d]
Sandstone	10^{-3} – 1	Gravel	10^{2} – 10^{3}
Limestone	10^{-2} – 1	Sand	5 – 10^{2}
Shale	10^{-7}	Silt	1 – 5
Dense solid rock	< 10^{-5}	Clay	10^{-8} – 10^{-2}
Volcanic rock	0 – 10^{3}	Sand & gravel mixes	5 – 10^{2}
Fractured weathered rock	0 – 3x10^{2}	Glacial till	10^{-3} – 10^{-1}
Fractured metamorphic rock	10^{-3} – 10^{2}		

The hydraulic conductivity or transmissivity of an aquifer together with the hydraulic gradient determines the flow velocity, or rate of flow, and relates to the efficiency of the borehole as well as the aquifer. For a regional model and for a water resource evaluation study, the use of an averaged transmissivity of the aquifer is sufficient.

6.2.2 Storativity/Specific Yield

Storativity (S), or storage coefficient, is defined as the volume of water a confined aquifer releases from elastic storage, per unit surface area per unit change of head.

The storage coefficient of a confined aquifer depends upon the compressibility of the rock and the porosity, as defined by Jacob's law, and is usually expressed as specific storage (Ss) per meter aquifer thickness. The values for Ss range from 10^{-6} to 10^{-3} m^{-1}.

Specific Yield (Sy) is the ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity from that mass and is valid for unconfined aquifers only. Typical values for specific yield are given in **Table 6-7** below.

While porosity determines the maximum amount of water in storage, storativity describes the potential for and impact of dynamic changes in storage. Thus, it is required for any transient model, either in the dynamic storage water balance model or a transient numerical model.

Storativity can be estimated from borehole pumping data analysis or calculated using the physical relationships defined by Jacob's Law and assumptions about the elastic parameters of the skeletal framework and the bulk modulus for water. The output from these calculations and modelling is contained in Volumes 4 – 9 of this report.

Table 6-7: Specific Yield Values for different lithological units (after Driscoll, 1986)

Sediment / Rock	Specific Yield [%]
Sandstone	5 – 15
Limestone	0.5 – 5
Shale	0.5 – 5
Fractured metamorphic rock	1.5 - 2
Gravel	15 – 30
Sand	10 – 30
Clay	1 – 10
Sand & gravel mixes	15 – 25

The available data sets for these parameters are acquired from different sources:

- National data set of spatial distribution (GRA II)
- Study reports
- Pumping data analysis
- Borehole information.

The regional parameter values given in the GRA II database will not be used in this project. The spatial distribution, as shown in **Figure 6-5** and **Figure 6-6**, does not take the different aquifers and the 3rd dimension into account.

There are localised data for the different aquifers under consideration, e.g. Cape Flats Aquifer, Langebaan Road Aquifer, Atlantis Aquifer, Peninsula Aquifer in Hermanus, Piketberg, Hex River and Citrusdal. The distribution of boreholes listed in the NGDB with pumptest data is shown in **Figure 6-7**, while boreholes with yield data are shown in **Figure 6-8**.

There are now a number of wellfields/boreholes in the TMG domain, which have been rigorously pump tested. The data from these wellfield and borehole tests is used as model input for study domain areas of comparable geological and hydrogeological context. The range in the data available provides a realistic basis for parameter testing and evaluation of model sensitivity and reality (see **Table 6-8**).

Table 6-8: Hydraulic parameters for the TMG from pumptests, numerical models and laboratory methods (after Pietersen & Parsons (Ed.), 2002; and other sources)

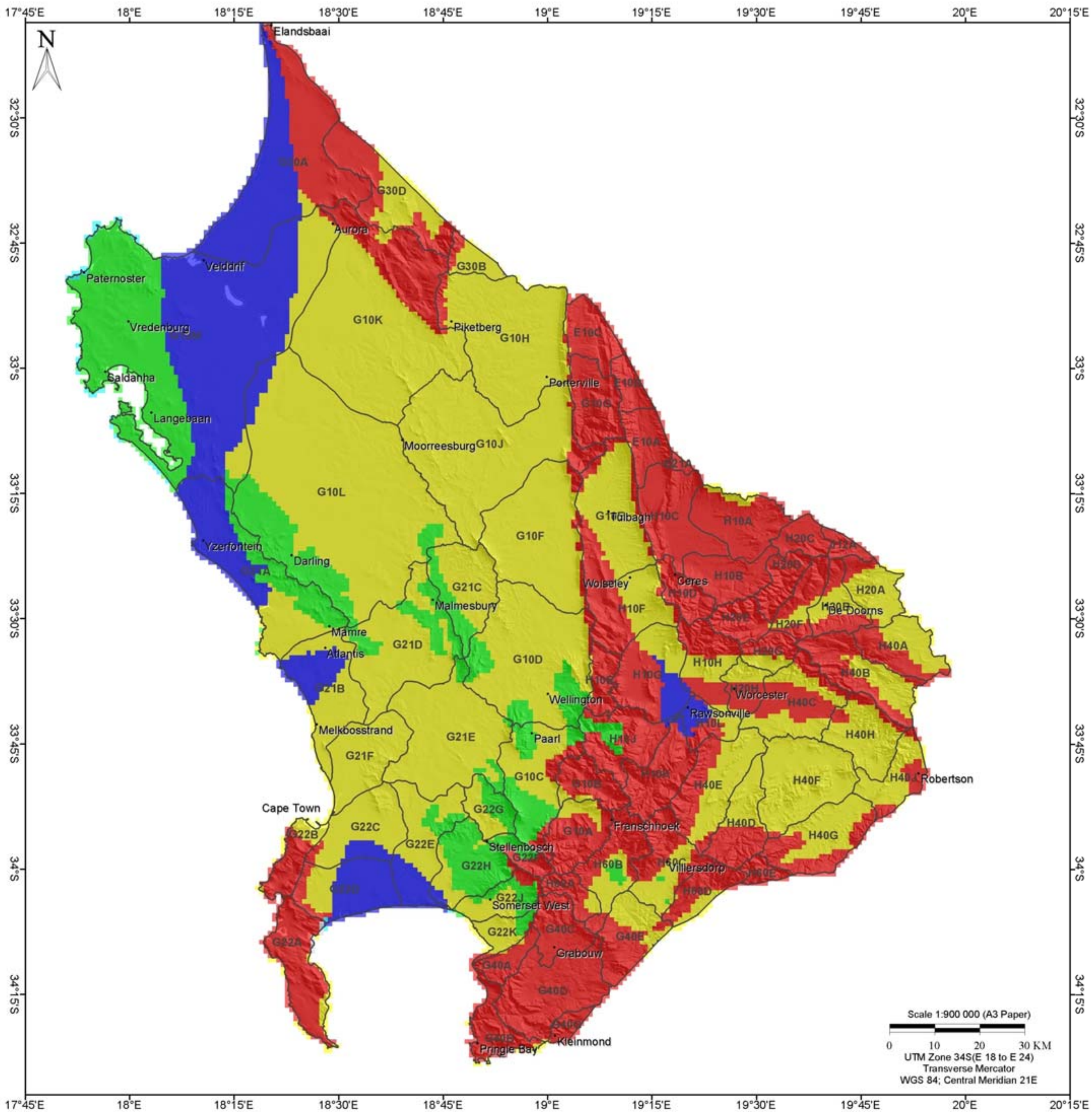
	Skurweberg Aquifer	Area / Source	Peninsula Aquifer	Area / Source
T	50 m^2/d (fractured)	Little Karoo	150 to 200 m^2/d (faulted keystones)	Little Karoo
	<1 m^2/d (matrix)	Little Karoo	10 to 100 m^2/d (microfractured - matrix)	Little Karoo
	68 to 320 m^2/d	Arabella	3 to 200 m^2/d	Citrusdal
	145 to 205 m^2/d	Struisbaai	120 to 270 m^2/d	Hermanus
K	0.5 to 1.0 m/d	Citrusdal	1.4 to 2.5 m/d	Citrusdal
	0.5 to 5 m/d	Agter-Witzenberg		
	0.07 to 0.26 m/d	Dam foundation	0.17 to 0.26 m/d	Dam foundation
			< 3000 m/d (fracture)	Hermanus
Ss			1.295e-6	IGS
S	1E-4 to 5E-4	Arabella	1.1E-5 to 4.6E-3	Citrusdal
	8.6E-3	Struisbaai	1.4E-4 to 5.5E-3	Hermanus
	1.1E-3 to 2.2E-3	Little Karoo	1E-3 to 2.2E-3	Little Karoo

In addition, borehole drilling information, such as geological logs, can be used to determine estimates of the required hydraulic parameters. Detailed core logging and geophysical borehole logging data are available (e.g. Blikhuis, Oudtshoorn) or will most likely be available in time (City of Cape Town project, DWAF, WRC project) for a number of boreholes within the TMG, which can be used to extrapolate relevant parameters to other areas.

- It is envisaged for the regional scale model to apply reasonable average values of storativity for different aquifers, based on local knowledge, literature, geological reasoning and actual measurements.
- For the detailed model areas, existing field data, additional field measurements, local knowledge and geological reasoning will be used to provide reasonable estimates of the relevant parameters and to develop spatial distribution maps for these.
- Transmissivity or hydraulic conductivity will be calibrated during the detailed numerical models and become a model output.

Table 6-9: Aquifer Parameter Data

Data	Format		Scale	Source
Hydraulic Conductivity	Data		Lithology	Literature
	Raster	Scanned-Map		Gerber, 1980
	Text			Ninham Shand, 1987
	Data	Point	Pump test	Wessels and Greeff, 1980
Transmissivity	Raster	Data	1 km x 1 km grid	GRA II
	Data	Point	Borehole	NGDB/NGA
	Data		Pump test	Umvoto
Borehole Yield	Raster	Data	1 km x 1 km grid	GRA II
	Data	Point	Borehole	NGDB/NGA
Aquifer Yield	Vector	Polygon	1:500 000	1:500 000 Hydrogeological Map Series (DWAF)
Specific Yield	Data		Lithology	Literature
	Text			Gerber, 1980
Storage Coefficient	Data		Lithology	Literature
	Raster	Data	1 km x 1 km grid	GRA II
	Data	Point	Borehole	NGDB/NGA
	Data		Pump test	Umvoto



LEGEND

· Towns

Quaternary Catchments

Storage Co-efficient

0.0008

0.004

0.01

0.1

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

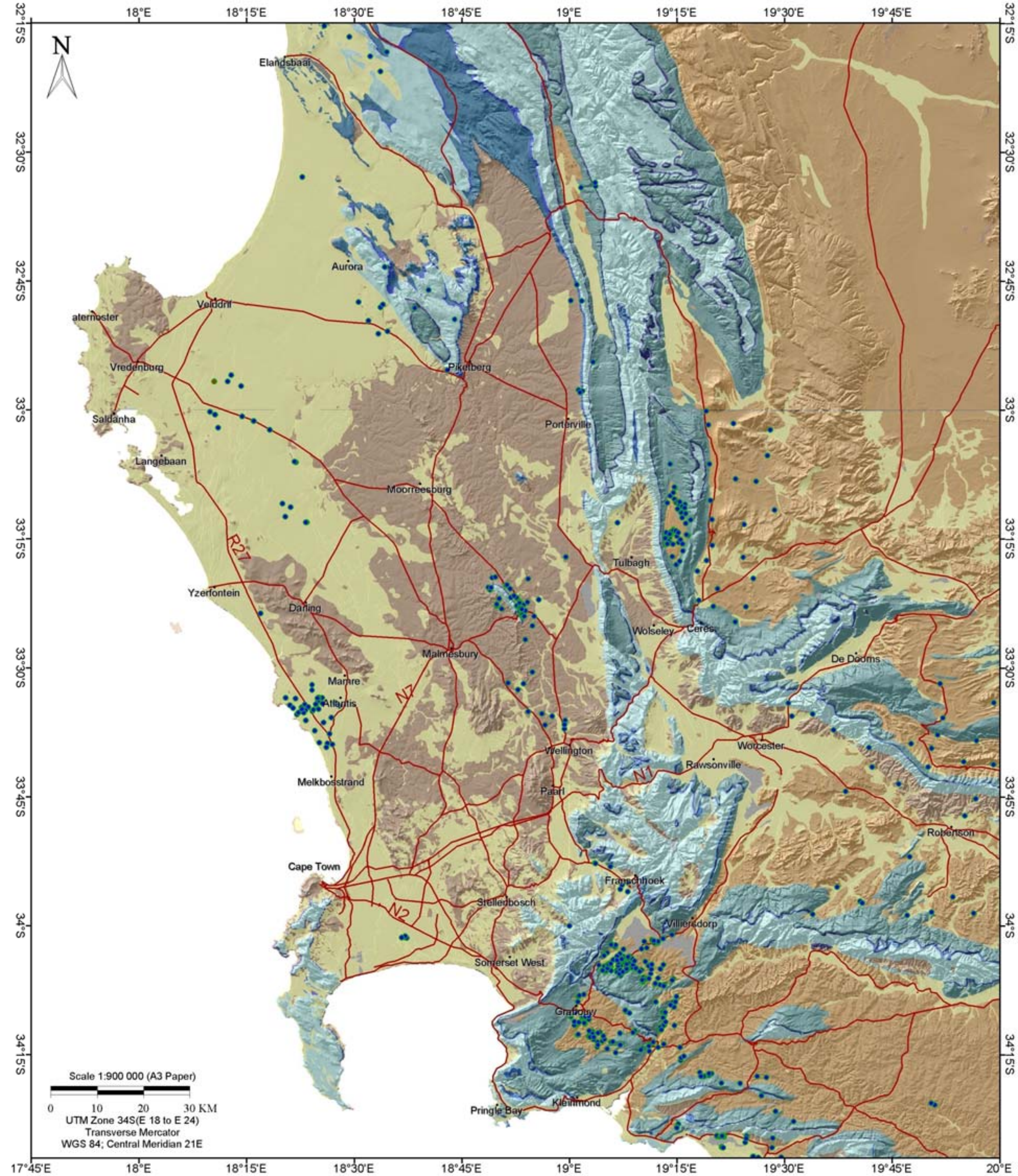
CONSULTANT

UMVOTO

TITLE

STORAGE COEFFICINT (After GRA II)

FIGURE 6.6



LEGEND

Towns

Boreholes

Springs

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

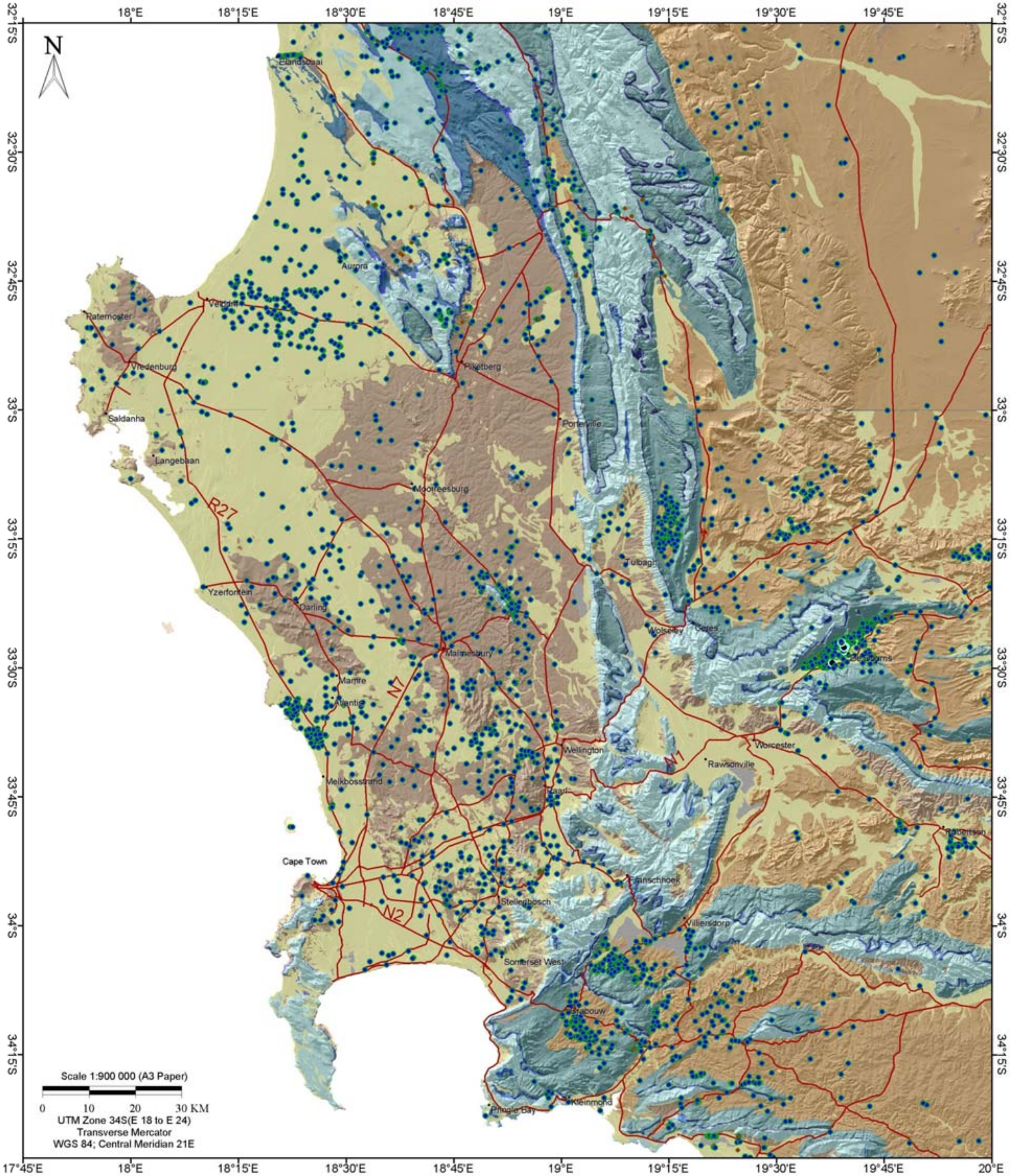
CONSULTANT

UMVOTO

TITLE

BOREHOLES WITH PUMPTEST DATA

FIGURE 6.7



LEGEND

· Towns

● Boreholes

● Springs

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

BOREHOLES WITH YIELD DATA

FIGURE 6.8

6.2.3 Recharge

There are a number of attempts to map recharge on a regional or national scale (see **Table 6-10**), most of which are based on single recharge calculation methods; e.g.

- baseflow separation method,
- chloride mass balance,
- Saturated Volume Fluctuation method,
- GIS model.

The baseflow separation method for recharge estimation is considered not feasible in the study area, as

- there is discharge to the ocean,
- the rate of recharge vary depending upon abstraction as the flow regime is pressure dependent, and
- there is in some areas lateral or vertical recharge to overlying primary aquifers.

The details of these patterns are contained in Volume 3 of this project report.

Table 6-10: Recharge Data

Data	Format		Scale / Extent	Source
Recharge percentage	Raster	Data	1 km x 1 km grid	GRA II
Recharge depth	Raster	Data	1 km x 1 km grid	GRA II
Recharge	Vector	Polygon	Per catchment	GRDM Software (DWAF)
	Vector	Polygon	1:7 500 000	Vegter (1995)
	Raster	Map	Langebaan	SRK, 2004
	Raster	Map	Breede WMA	DWAF, GCS (2002)
	Data		Cape Flats	Gerber, 1980
	Data		Cape Flats	SRK, 1996
	Data		Cape Flats	Vandoolaeghe, 1990
	Text		TMG area	UWC, SRK

The available spatial distribution of recharge, prepared at national scale, does not take into account the behaviour and infiltration capacity of the different aquifers. Furthermore, there is no distinction between recharge and discharge areas of the different aquifers. The estimates for the Langebaan Road Aquifer, the Cape Flats Aquifer and for the Breede WMA area use different methodologies, so that a comparison and extrapolation to regional scale is difficult.

There are a number of ways in which aquifer specific recharge can be estimated, given the available technology. Two proposed ways are;

- a simple spatially weighted GIS model using rates of recharge that are accepted in the industry and or have been measured in comparable environments in the field;
- a map centric model that integrates basic process relationships such as slope, temperature, altitude, rainfall and runoff.

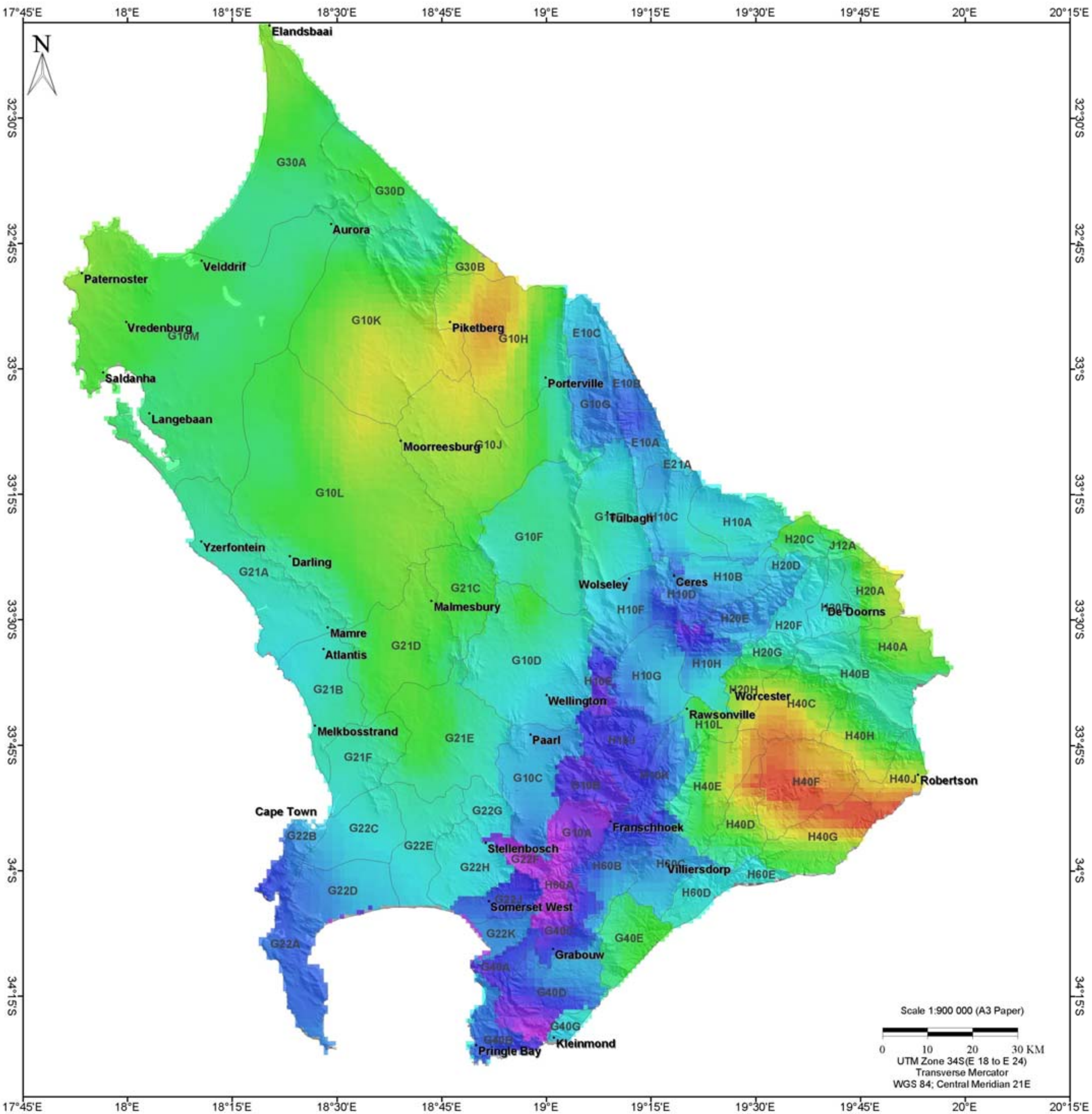
The use of isotopic data and hydrochemical data can further enhance the recharge estimations. It is advantageous when a model input parameter such as recharge can be estimated using a variety of methods and data as it increases confidence in the result if the amount of recharge estimated converges towards one number of a relatively narrow range regardless of the method used. It is advised to use the Saturated Volume Fluctuation (SVF) method to estimate recharge in selected areas where and if the spatial and temporal distribution of rainfall and water level data are adequate. Given the in-depth understanding of the aquifer geometries, the adequate rainfall data distribution and knowledge of the topography, soil cover, land use and vegetation type it is reasonable to estimate recharge in those areas of lesser data based on results from comparable catchments.

The approach adopted to estimate aquifer specific recharge values is scale dependent, as described in the Inception Report (DWAF, 2005a). The following steps will be undertaken to estimate recharge on a regional scale:

- Applying the aquifer specific recharge model, as developed for the ISPs (DWAF 2004).
- Applying map-centric recharge simulation model with modelled distribution of run-off and actual evapotranspiration. This type of model was originally developed in the CAGE project (DWAF, 2000) and calibrated in the recent Clanwilliam project (DWAF, 2006d). It is not yet known whether the model will be applicable in catchments of varying character.
- Create time series data for monthly recharge values, based on monthly rainfall data, and apply seasonal changes to spatial distribution from map-centric simulation.

Additionally, it might be required to refine the recharge estimation for the detailed model domains, based on:

- Recharge estimations from previous study reports,
- Applying chloride mass balance and or SVF method,
- Using recharge factors, based on land cover, land use, vegetation and soil type.



LEGEND

· Towns

Quaternary Catchments

Recharge Percentage (%)

22.2
17.8
13.4
9.0
4.6
0.2

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

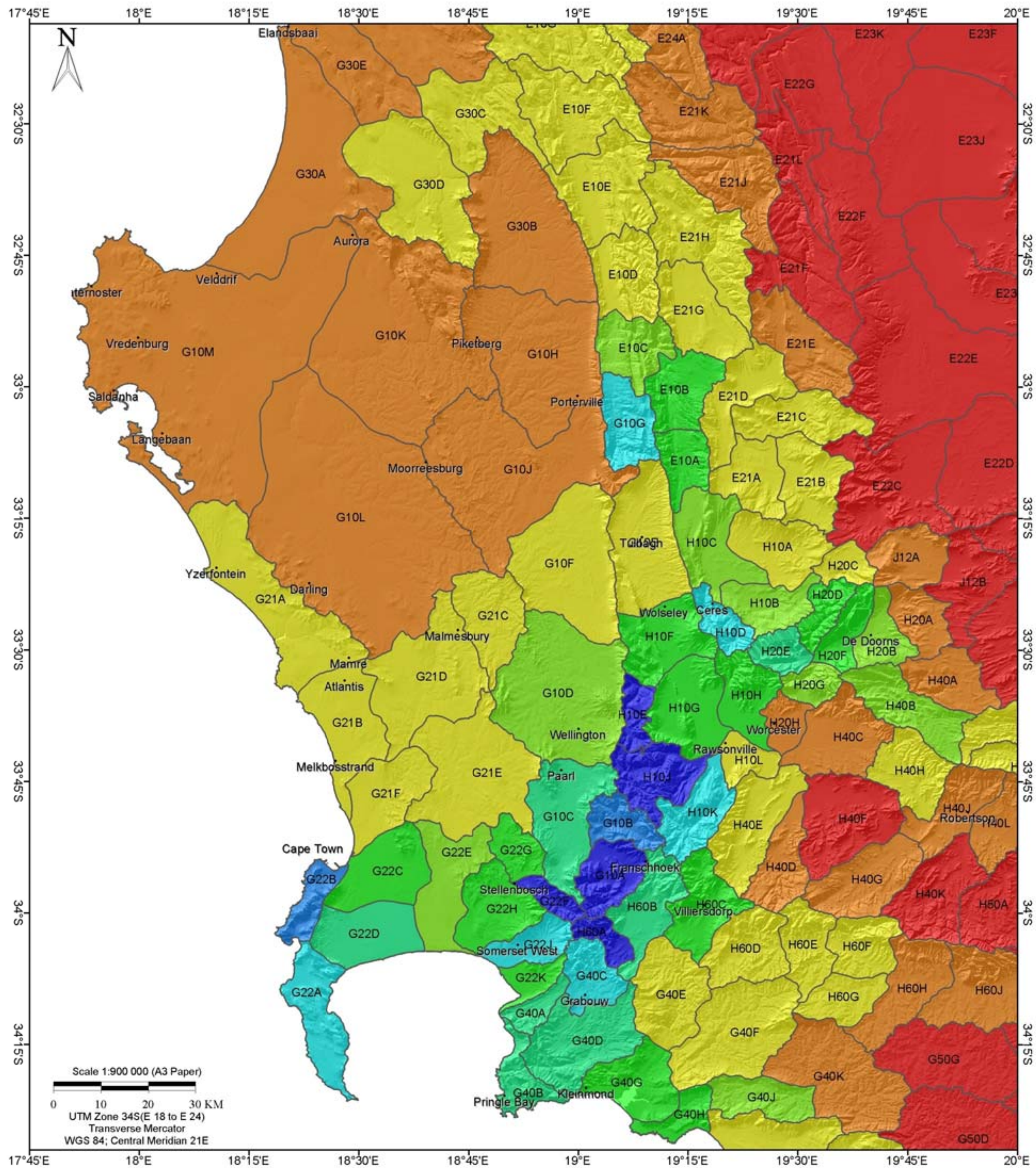
CONSULTANT

UMVOTO

TITLE

RECHARGE PERCENTAGE (after GRA II)

FIGURE 6.9



LEGEND

Towns

Quaternary Catchments

RECHARGE (mm/a)

	0 - 10
	10 - 20
	20 - 40
	40 - 60
	60 - 80
	80 - 100
	100 - 120
	120 - 150
	150 - 223

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

RECHARGE PER CATCHMENT (After GRDM)

FIGURE 6.10

6.2.4 Groundwater levels

Water level measurements will be used to determine groundwater flow directions and hydraulic gradients. Water-level data from different but neighbouring aquifers determine the possible interaction and leakage between the aquifers and can be clear indicators of hydraulic barriers.

In addition, detailed time series data over more than one hydrologic cycle in combination with monthly rainfall and abstraction data can be used for recharge estimation in the Saturated Volume Fluctuation (SVF) or Cumulative Rainfall Departure (CRD) models.

The borehole data with water level information was acquired from different sources and existing projects.

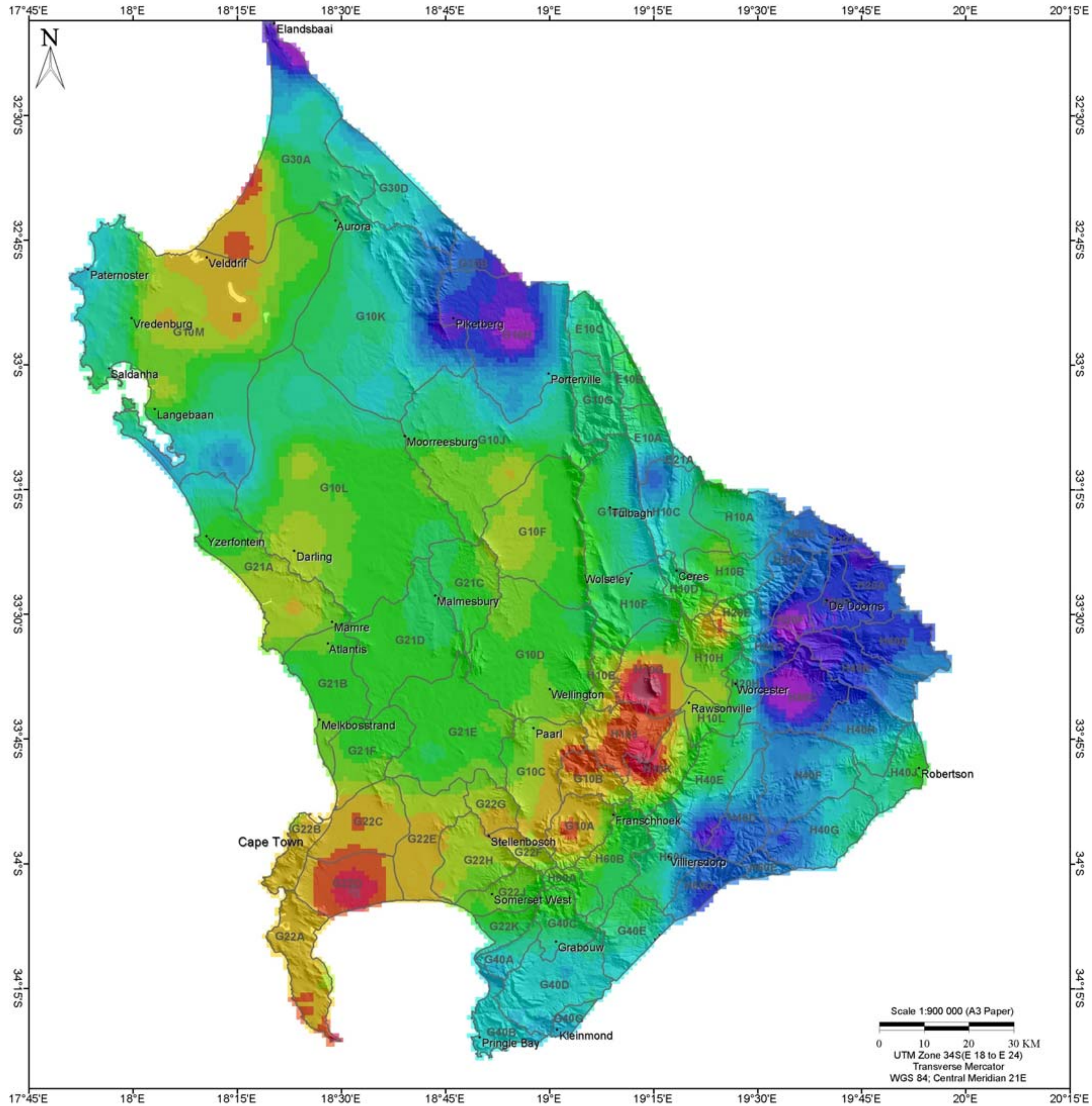
(a) National Groundwater Database (NGDB) of the Department of Water Affairs and Forestry (DWAF)
(b) Berg River Baseline Monitoring Project (Parsons et al, 2003)
(c) Table Mountain Group Aquifer Feasibility Study, hydrocensus data (City of Cape Town, 2004b, 2005b, 2006)
(d) Hex River Monitoring data by Hex River Irrigation Board
(e) Koo Valley Monitoring (Department of Agriculture)

Table 6-11: Groundwater level Data

Data	Format		Scale	Source
Water level	Data	Time series		NGDB
	Data	Time series	Seasonal	Hydrocensus (CAGE, TMGA, BRBS)
	Data	Time series		Wessels and Greeff, 1980
	Data	Time series		Hexriver Irrigation Board
	Data	Time series		Koo Valley (D:Agri)
	Raster	Data	1 km x 1 km	GRA II

The regional scale spatial distribution of groundwater levels from the GRA II is not realistic, and will not be used. However, there are sufficient data sources of groundwater level measurements for the detailed model domains.

- For the regional scale model it is envisaged to apply reasonable average values for different aquifers, based on local knowledge, literature, geological reasoning and actual measurements.
- For the local scale models a spatial distribution of average values, based on field measurements, local knowledge and geological reasoning will be established as input into the models.
- The time series data from field measurements will be applied to transient model runs.
- Both the spatial distribution and the time series data are then used as reference data for the calibration of the models.



LEGEND

· Towns

Quaternary Catchments

Water Level Distribution (mbgl)

23

19

14

10

5

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

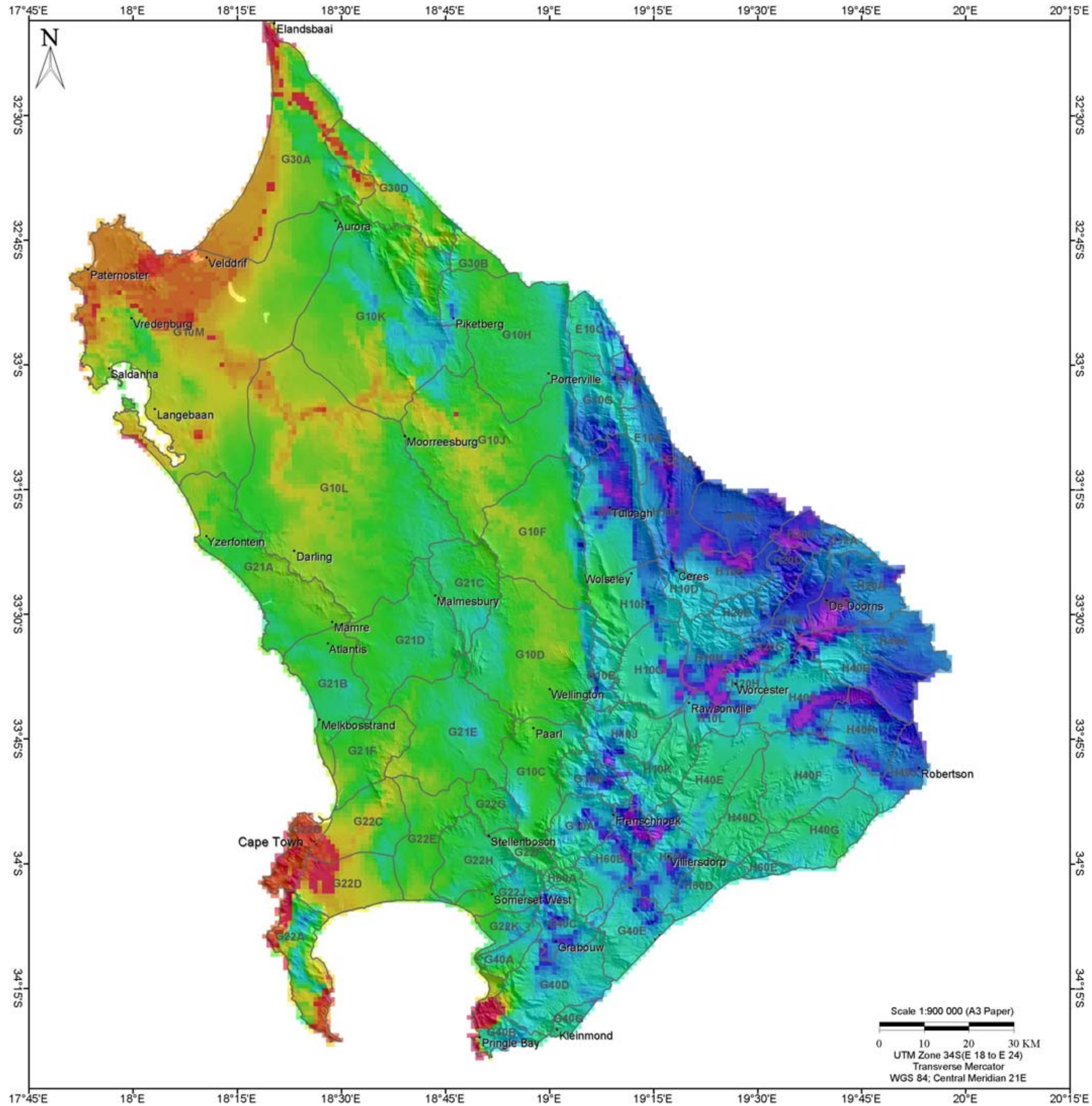
CONSULTANT

UMVOTO

TITLE

WATER LEVEL DISTRIBUTION (after GRA II)

FIGURE 6.11



LEGEND

· Towns

Quatemary Catchments

Water Level Distribution (mamsl)

1869
1140
898
655
412
169
-74

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

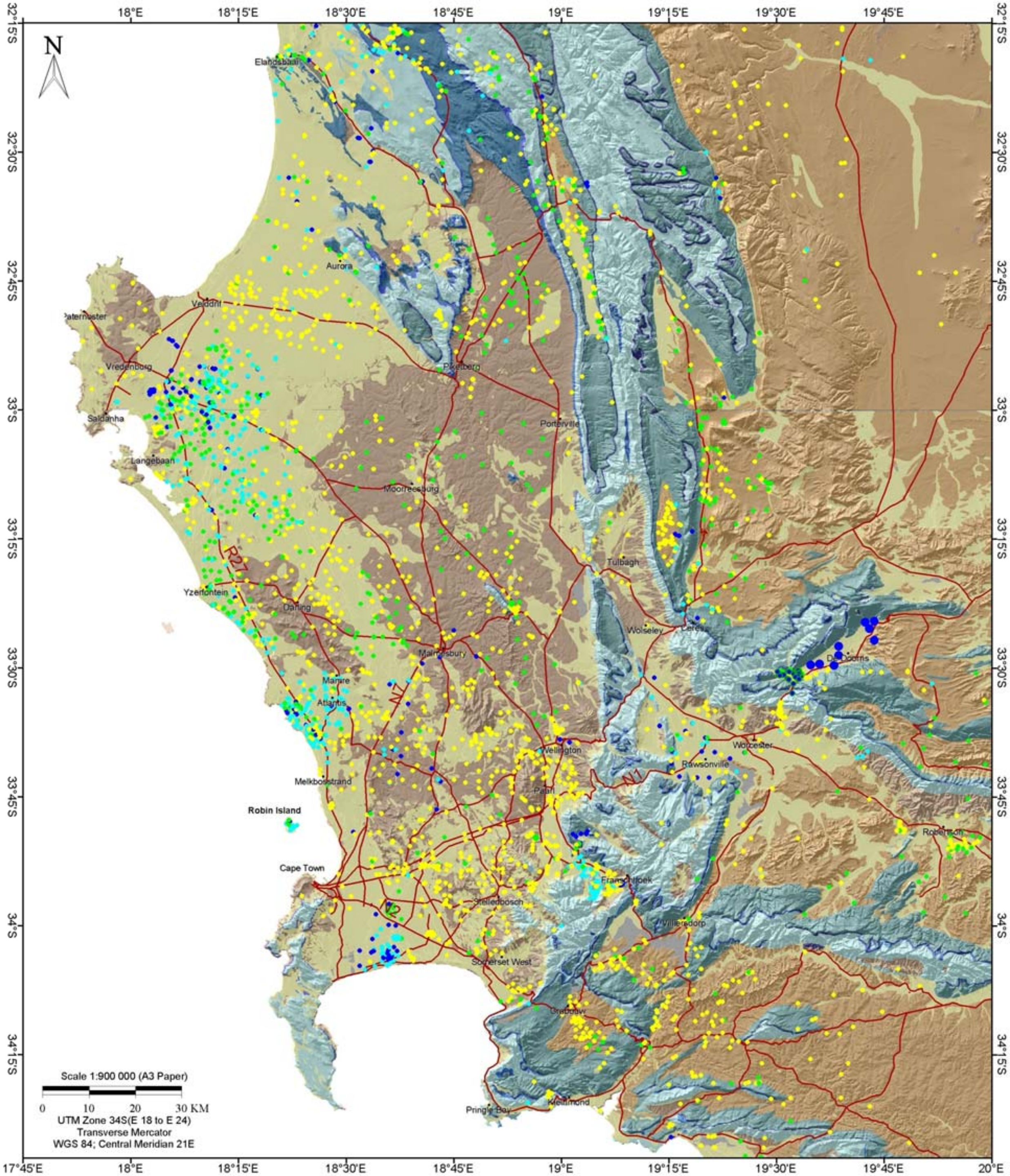
CONSULTANT

UMVOTO

TITLE

WATER LEVEL DISTRIBUTION (after GRA II)

FIGURE 6.12



LEGEND

· Towns

WATER LEVEL MEASUREMENT COUNT

- 1
- 1 - 5
- 5 - 100
- >100

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

BOREHOLES WITH WATER LEVEL DATA

FIGURE 6.13

6.2.5 Springs

Knowledge of the location of perennial and non-perennial springs provides supporting information to the investigation into the three-dimensional distribution of aquifer bodies and will be used to develop regional piezometric or water table contours. Information of the temperature and flow rate of water discharged at spring locations also assists in constraining the 3D flow path (specifically the depth of the flow below surface), and provides additional information to derive hydraulic parameters of the aquifer; e.g. the use of the geothermal gradient allows for the calculation of the likely rate of upward flow and therefore likely K values, using Darcy's law.

Table 6-12: Spring Data

Data	Format		Scale	Source
Springs	Vector	Point		NGDB
				WARMS
				Hydrocensus (TMGA)
			1:500 000	1:500 000 Hydrogeological Map Series (DWAF)

There is inadequate quantitative and time series information about the distribution of distinct discharge sites and the actual discharge at springs. Additionally, the use of water from springs is most often not registered with the DWAF and therefore the uptake is not recorded (see discussion in section 8.2). It is envisaged using the currently mapped springs and starting points of perennial rivers as 1st order indication of groundwater discharge sites. The discharge sites will be assigned to the different aquifers, based on geological mapping and reasoning.

6.2.6 Hydrochemistry

The importance of good hydrochemistry data is threefold:

- The fitness for use depends upon the chemical constituents in the water;
- Chloride and isotope data can be used to support recharge estimation as well as the residence time and therefore the water resource evaluation;
- Macro and trace elements and isotope data can be used to distinguish between water from different aquifers as well as between surface water and groundwater;
- Trace elements in particular and isotopes can reflect the geochemistry of the flow path as well as the recharge area.

The available regional data is sufficient as indicator for fitness for use and will be used to determine the amount of potable water. Sampling and analysis of groundwater and rainfall for Chloride is undertaken in several areas within the study domain and the data are considered sufficient at the regional scale.

Table 6-13: Hydrochemistry Data

Data	Format		Scale	Source
Chemical analyses	Data			NGDB
				Hydrocensus (CAGE, TMGA, BRBS)
	Data			Wessels and Greeff, 1980
	Data			SRK, 2004
Chloride concentration	Raster	Data	1 km x 1 km	GRA II
Groundwater quality	Vector	Polygon	1:500 000	1:500 000 Hydrogeological Map Series (DWAF)

6.2.7 Thermal Data

Thermal data include temperature measurements from springs and boreholes. Data are used to determine deep flow paths of groundwater and establish groundwater flow rates and recharge/discharge areas.

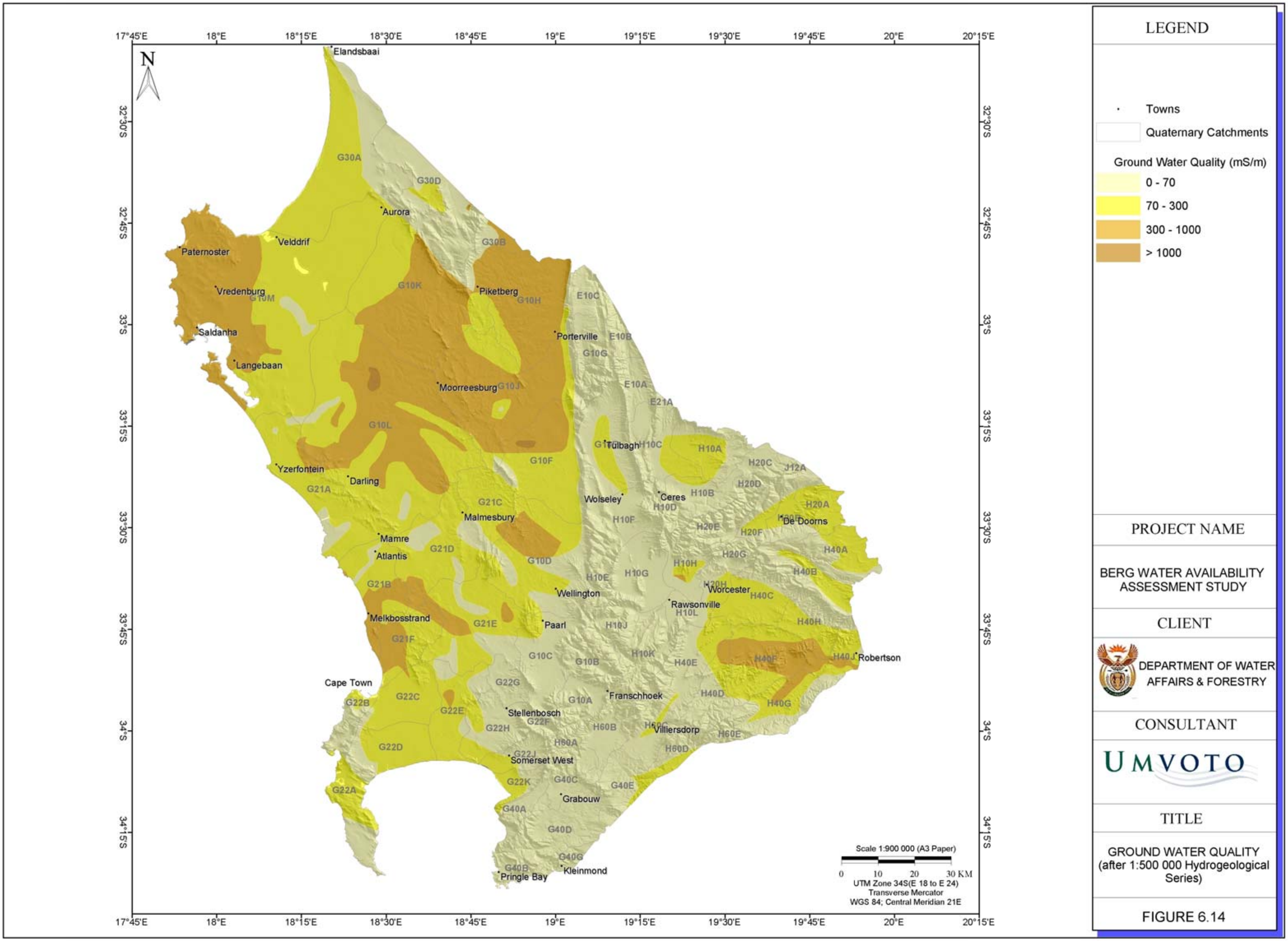
Table 6-14: Thermal Data

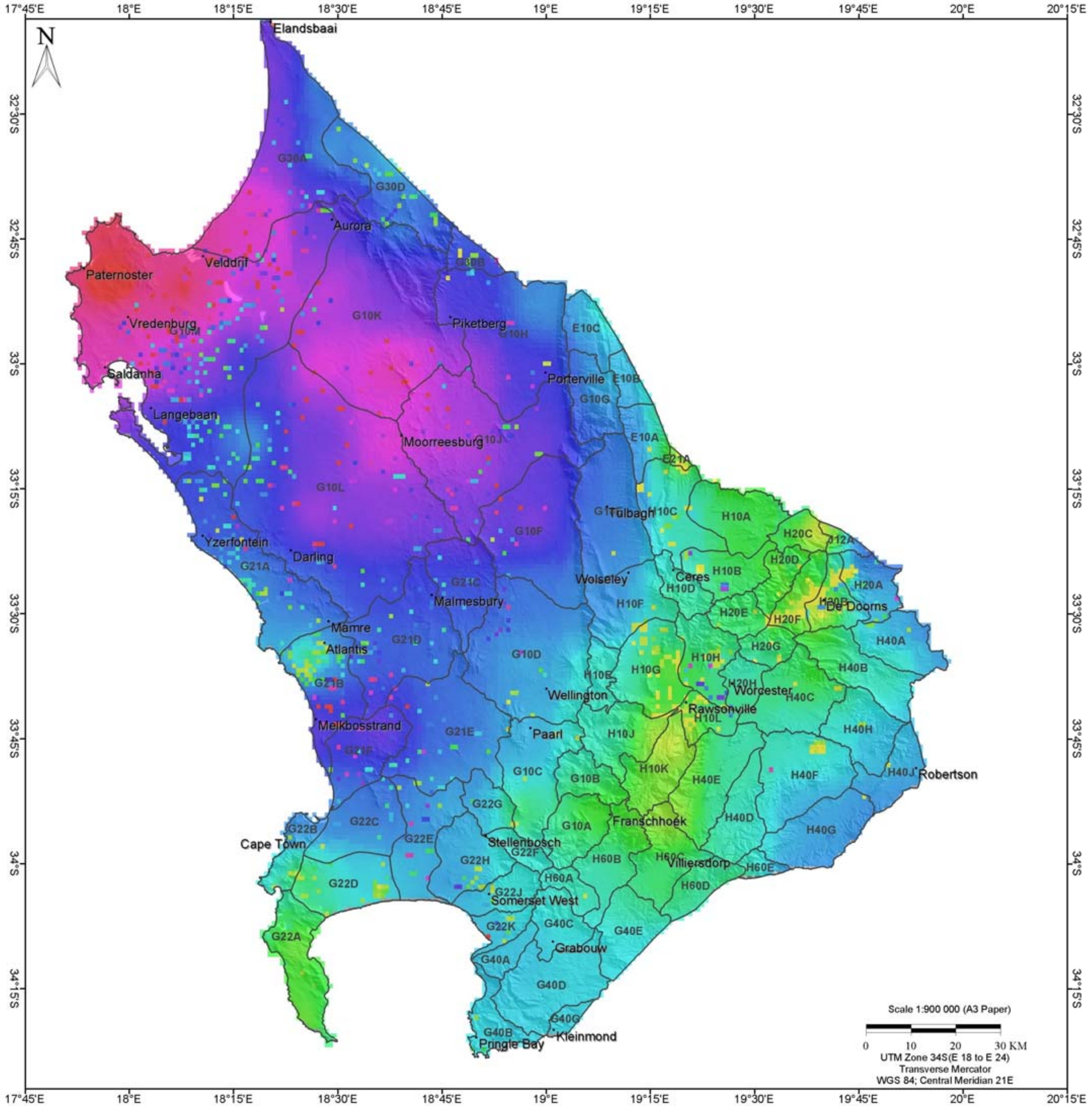
Data	Format		Scale	Source
Temperature measurements	Data			NGDB
	Data	Time series		Hydrocensus (CAGE; TMGA)

There is no comprehensive mapping of thermal springs available. There are also no time series data of temperature changes at hot springs. It is therefore envisaged to use the limited thermal data for the groundwater flow modeling as follows:

- Applying thermal data from the NGDB and TMGAA hydrocensus as indicators for the regional flow model
- Applying thermal data from selected boreholes and springs within the TMG Aquifer domain for calibration of heat and groundwater flow models.

It is further recommended to undertake a comprehensive spring hydrocensus to collect field data on spring flow, hydrochemistry and temperature of springs as well as selected river reaches (see Section 9.2).


LEGEND
Towns
Quaternary Catchments
Ground Water Quality (mS/m)
0 - 70
70 - 300
300 - 1000
> 1000
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS & FORESTRY
CONSULTANT
UMVOTO
TITLE
GROUND WATER QUALITY (after 1:500 000 Hydrogeological Series)
FIGURE 6.14
N
Elandsbaai
Aurora
Velddrif
Paternoster
Vredenburg
Saldanha
Langebaan
Piketberg
Porterville
Moorreesburg
Tulbagh
Ceres
Wolseley
De Doorns
Yzerfontein
Darling
Malmesbury
Mamre
Atlantis
Wellington
Worcester
Rawsonville
Melkbosstrand
Paarl
Robertson
Cape Town
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
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
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



LEGEND

Towns

Chloride concetration (mg/l)

9449
2364
1183
2

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

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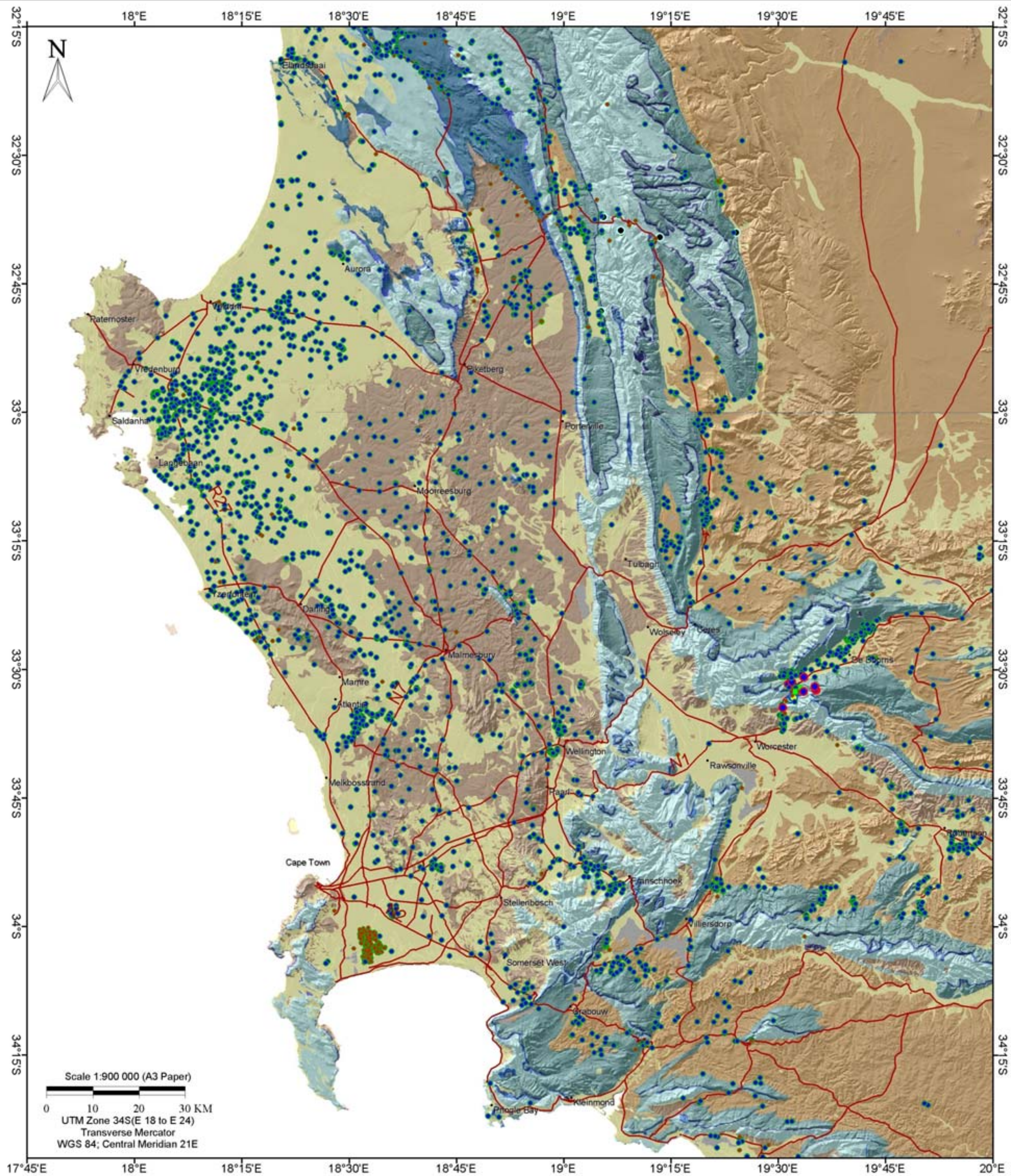
CONSULTANT

UMVOTO

TITLE

CHLORIDE CONCENTRATION IN GROUNDWATER (after GRA II)

FIGURE 6.15



LEGEND

- Towns
- Boreholes
- Springs
- Alluvium Pits
- Streams
- Other

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

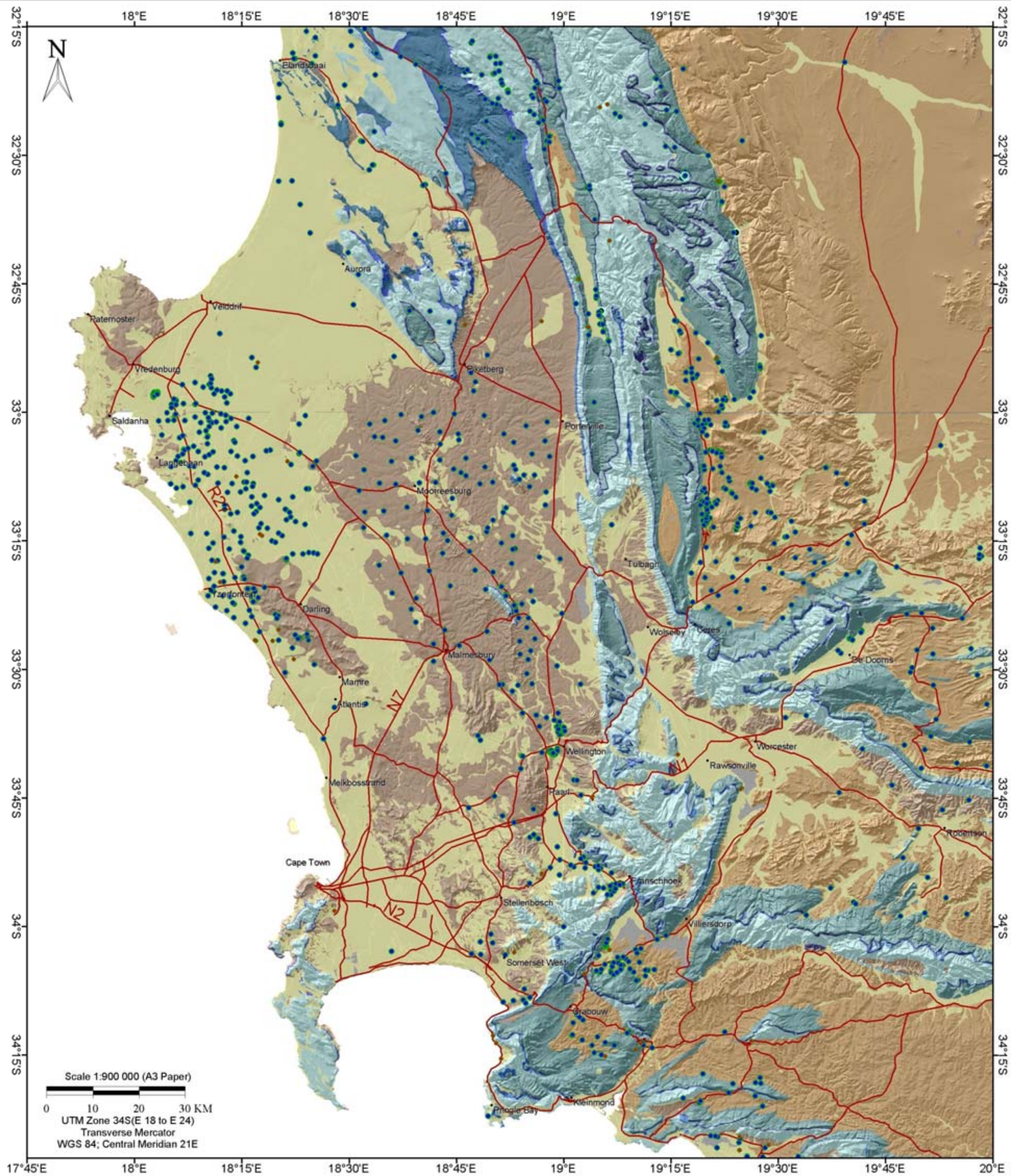
CONSULTANT

UMVOTO

TITLE

BOREHOLE AND SPRING DISTRIBUTION WITH WATER QUALITY DATA

FIGURE 6.16



LEGEND

Towns

Boreholes

Springs

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

BOREHOLE AND SPRING DISTRIBUTION WITH THERMAL DATA

FIGURE 6.17

7. LAND COVER

Land cover comprises both natural and agricultural vegetation, soils, as well as the urban or man-made environment. What concerns this project is primarily vegetation and soils, because these most directly relate to the catchment mass balance.

7.1 SOIL COVER

The development of specific soil types and the thickness above the host rock are linked to the underlying lithology, as well as to slope, altitude and climate condition. The soil types are governed by their content of sand, clay and loam and additional chemical constituents. In addition to soil type how the individual grains pack together directly impacts the ability of water to permeate through the soil horizons. Impermeable soil types will promote surface water run-off while permeable soils will encourage recharge.

The soil type data available in this project is summarised and illustrated below in **Table 7-1** and **Figure 7-1** respectively.

Table 7-1: Soil Type Data

Data	Format		Scale	Source
Soil type	Vector	Polygon	1:2 500 000	WR90 (Midgley et al., 1994)

The scale of the available soil type map is very coarse. This information will only be used as background information and to qualitatively evaluate the recharge model results.

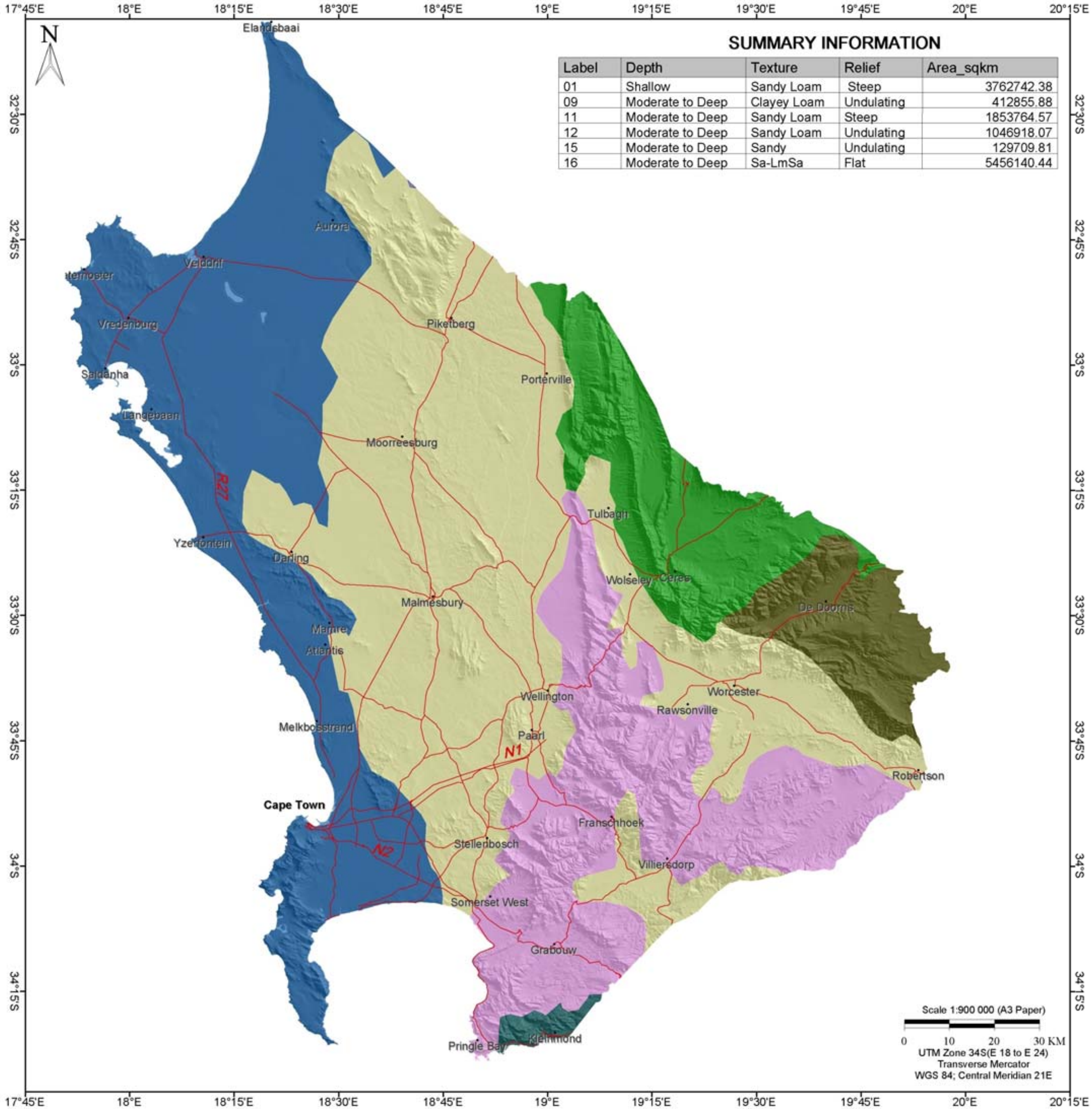
7.2 VEGETATION COVER

Different vegetation cover (type and density) affects the surface and groundwater or catchment mass balance, impacting upon the run-off efficiency and the amount of evapotranspiration, and therefore is considered relevant input data to the numerical models developed for the study area.

Table 7-2: Land Cover and Vegetation Data

Data	Format		Scale	Source
Natural vegetation	Vector	Polygon	1:500 000	Botanical Research Institute – Department of Agriculture and Water Supply, Acocks Veld Types of South Africa
National land cover	Vector	Polygon	1:50 000	CSIR, NLC 2000
Land use	Vector	Polygon	1:10 000	Ninham Shand

There are two different existing data sets with vegetation data available, viz. the natural vegetation cover after Acocks and the land cover from the NLC 2000 project. Since the land cover represents the most recent situation of vegetation cover and land use, the NLC coverage will be used as support parameter for the recharge estimation and water use calculation. The results of both estimations will be qualitatively checked against the pattern of land use.



SUMMARY INFORMATION

Label	Depth	Texture	Relief	Area_sqkm
01	Shallow	Sandy Loam	Steep	3762742.38
09	Moderate to Deep	Clayey Loam	Undulating	412855.88
11	Moderate to Deep	Sandy Loam	Steep	1853764.57
12	Moderate to Deep	Sandy Loam	Undulating	1046918.07
15	Moderate to Deep	Sandy	Undulating	129709.81
16	Moderate to Deep	Sa-LmSa	Flat	5456140.44

LEGEND

- Towns
- Roads

Soil Types

- 01
- 09
- 11
- 12
- 15
- 16

(see Summary Information for details)

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

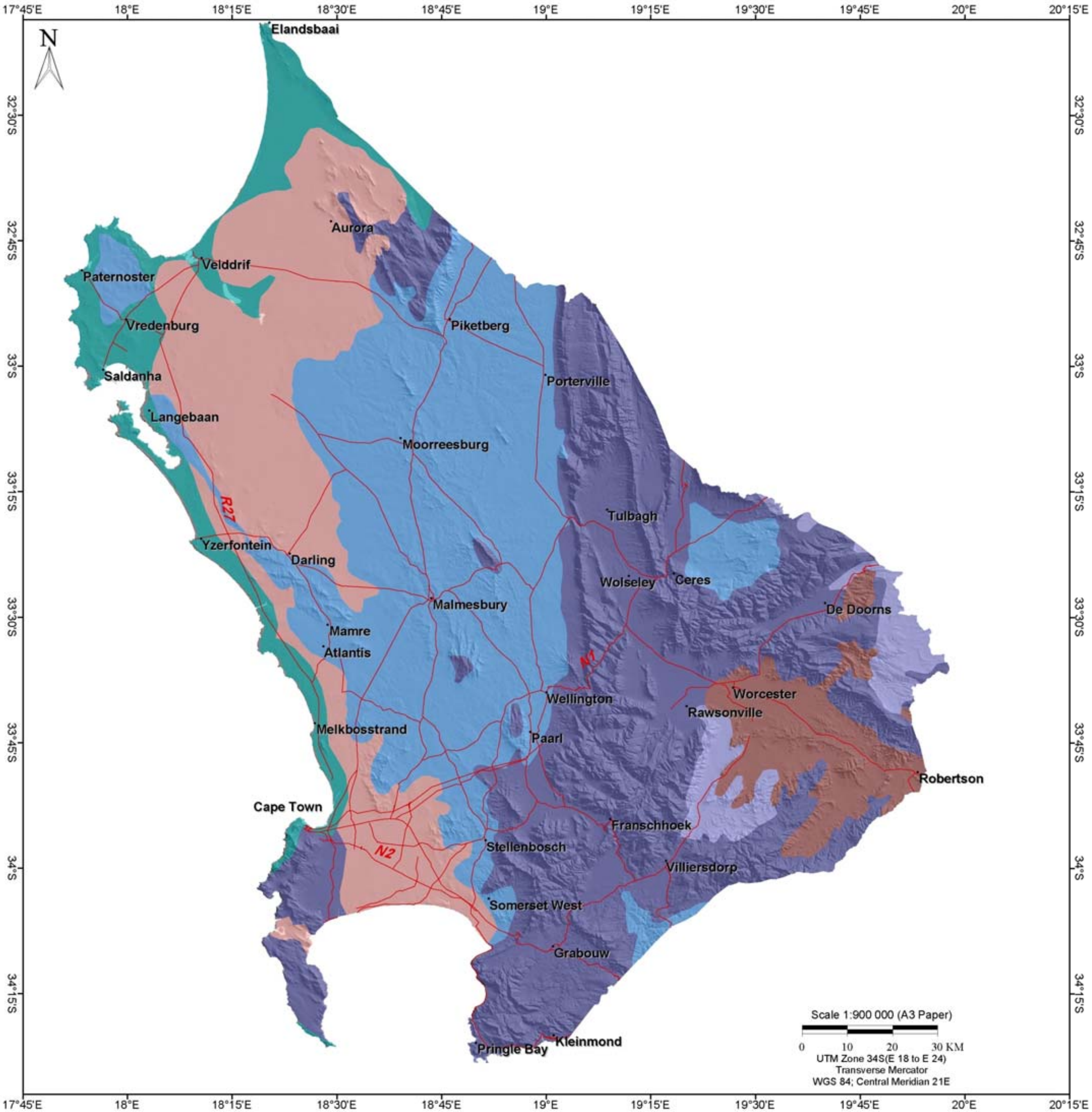
CONSULTANT

UMVOTO

TITLE

SOIL TYPES (WR90)

FIGURE 7.1



LEGEND

Towns
Roads

Natural Vegetation of Acocks

- CoastalL Macchia
- Coastal Renosterbosveld
- Karroid Broken Veld
- Macchia(Fynbos)
- Mountain Renosterbosveld
- Strandveld Of West Coast

PROJECT NAME

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CLIENT

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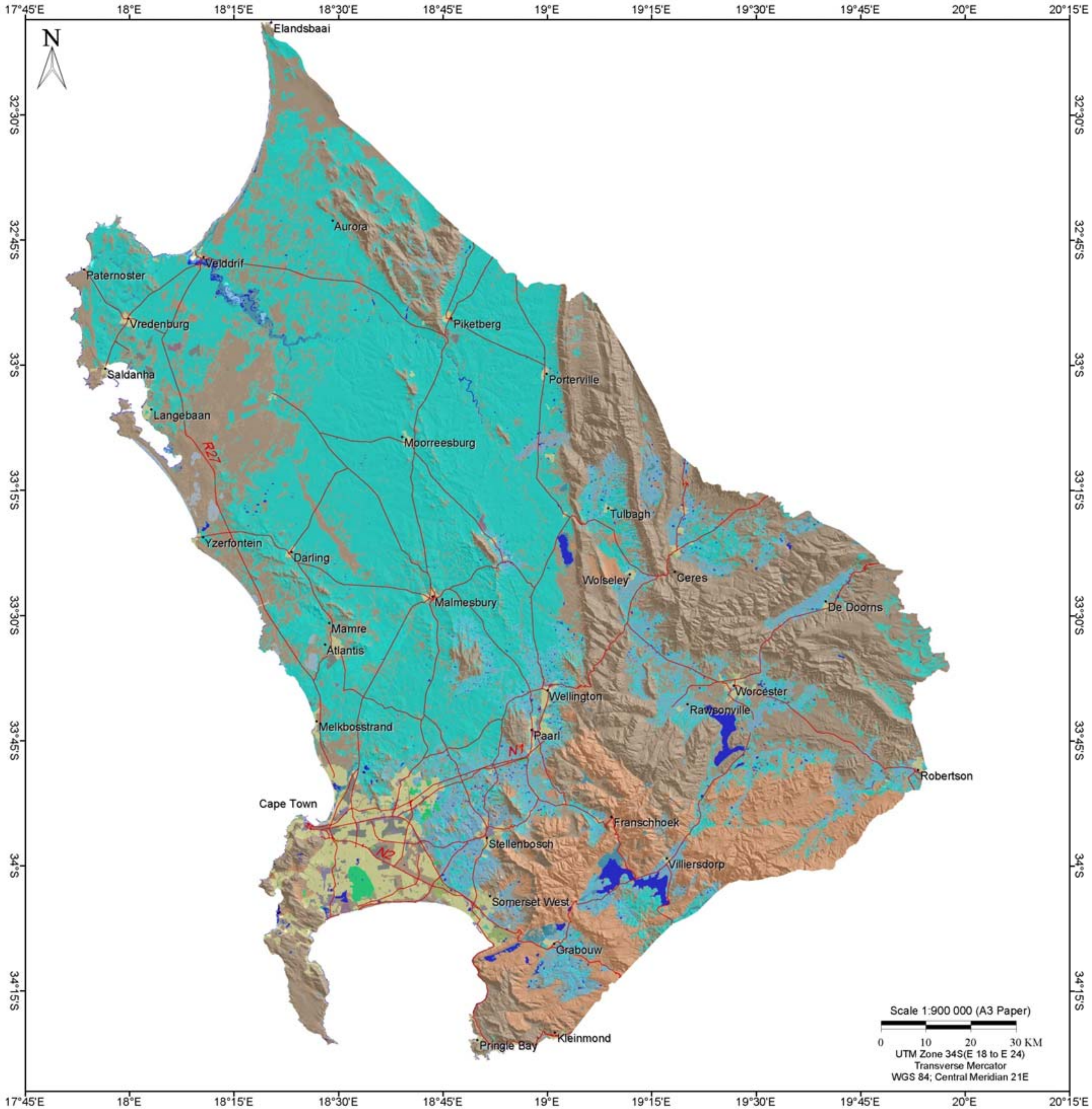
TITLE

NATURAL VEGETATION (After Acocks)

FIGURE 7.2



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 7.3

8. WATER USE

8.1 SURFACE WATER

The data on farm dam volumes, major dams, naturalised inflow and “current-day inflow” (i.e. less water usage) is a useful cross check on the common sense reality of regional aquifer specific recharge estimates. This data is available from the results of Task 6 of this study.

8.2 GROUNDWATER

Groundwater usage has only recently become regulated and many users neither monitor their abstraction nor keep records. The WARMS database provides usage data on registered use above Schedule 1. There is also usage data on the NGDB/NGA. This data is not necessarily current but depending upon the project on which the data was collected it can be a very useful cross check with the WARMS data.

Estimates for some areas are also available from hydrocensus surveys.

Table 8-1: Groundwater Use Data

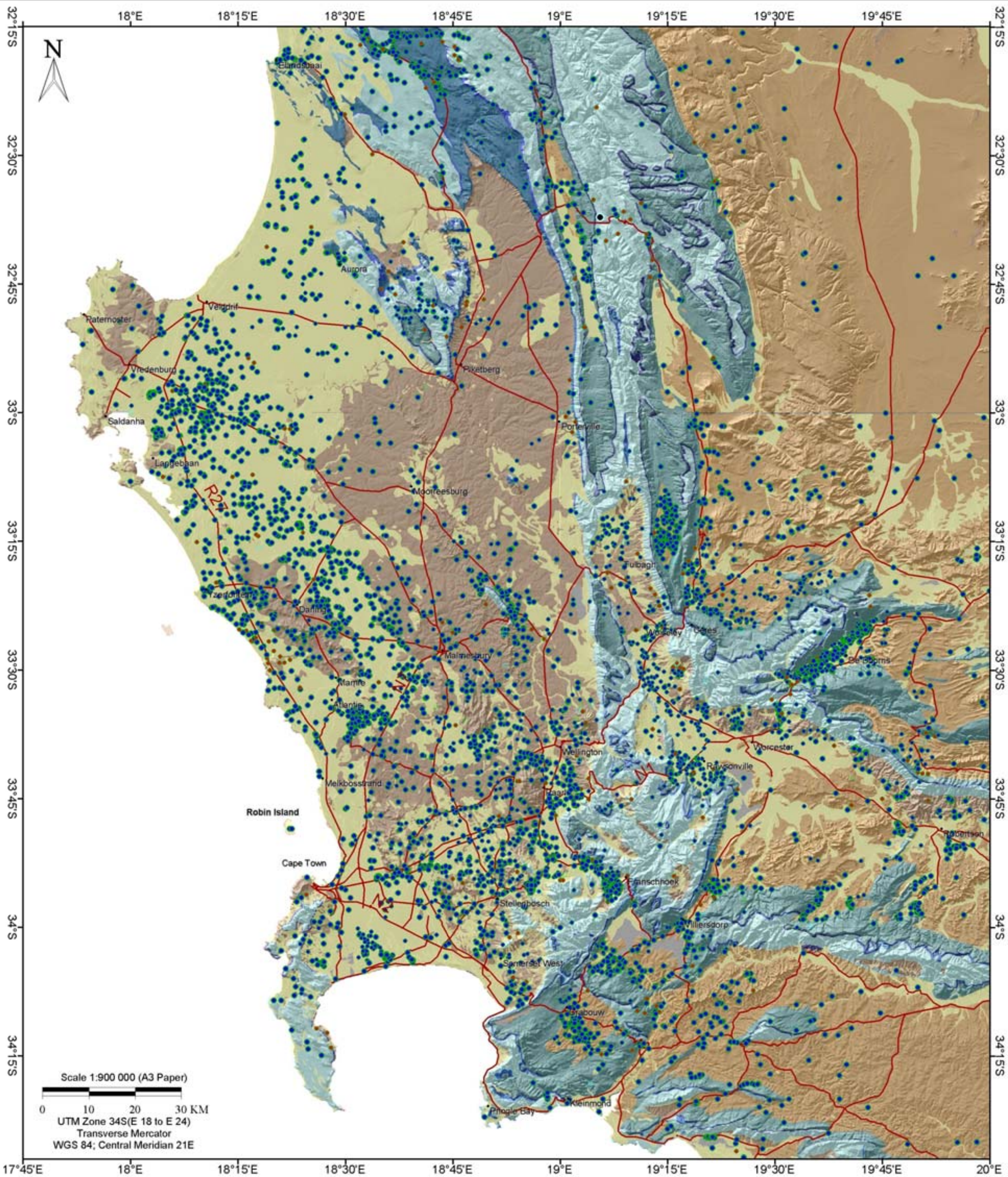
<table>
<tr><th>Data</th><th colspan="2">Format</th><th>Scale</th><th>Source</th></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="6">Groundwater use</td><td rowspan="3">Data</td><td></td><td></td><td>NGDB,</td></tr>
<tr><td></td><td></td><td>Vandoolaeghe, 1990</td></tr>
<tr><td></td><td></td><td>Hydrocensus (TMGA, CAGE, SRK, BRBS, Koo)</td></tr>
<tr><td>Vector</td><td>Points</td><td></td><td>WARMS</td></tr>
<tr><td>Vector</td><td>Polygon</td><td>1:500 000</td><td>1:500 000 Hydrogeological Map Series (DWAF)</td></tr>
<tr><td>Vector</td><td>Polygon</td><td>Quaternary catchment</td><td>GRA II</td></tr>
</table>

The information on groundwater use in its current format is not sufficient for the purpose of this project. The data are averaged or summed per quaternary catchment (GRA II) or per cadastral farm (WARMS) and are therefore not aquifer specific. Furthermore, the source data for these estimates, e.g. WARMS, do not contain geological information.

There is also no information in these sources that indicates the seasonal fluctuations of groundwater use, the historical growth (or decline) in groundwater use, or in the case of WARMS from which aquifer the water is being abstracted.

The following is envisaged to overcome these problems:

- Spatial disaggregation of water use data per catchment with respect to aquifers, based on registered usage, borehole distribution, land use, aquifer properties and local knowledge;
- Estimation of seasonal fluctuation of groundwater use, based on assessment of irrigation requirements and percentage split between sectors;
- Indication of historical change in groundwater use, based on boreholes drilled per year, increase in agricultural areas, population growth and general development.



LEGEND

· Towns

● Boreholes

● Springs

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

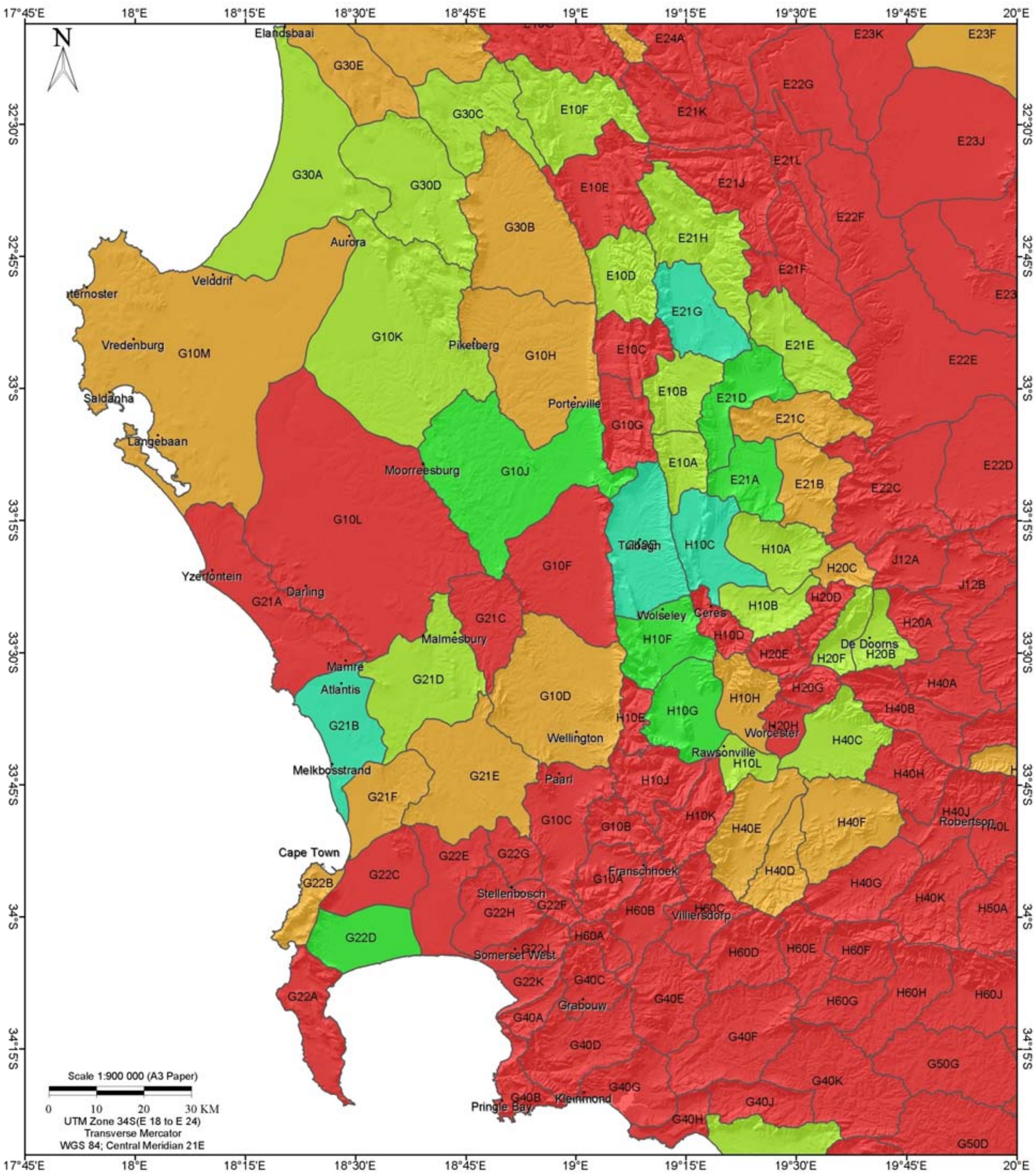
CONSULTANT

UMVOTO

TITLE

BOREHOLE AND SPRINGS DISTRIBUTION USED FOR ABSTRACTION (After NGDB & WARMS)

FIGURE 8.1



LEGEND

· Towns

Quaternary Catchments

GROUNDWATER USE (mm³/a)

- 0 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20

PROJECT NAME

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TITLE

GROUNDWATER USE (After GRA II)

FIGURE 8.2

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The main conclusion from the assessment of available data is that there is enough adequate data:

- to initiate modelling,
- to configure the proposed models, and
- to run these models to contribute to improved groundwater resource evaluation.

This conclusion is based on the following approaches and assumptions:

- modelling is essential to realise adaptive management,
- it is not necessary that a huge amount of data be available in order to start modelling,
- a sound 3D physical understanding of earth and flow-system processes supported by empirical evidence is necessary to overcome limited spatial distribution of data in some areas and for some aquifers by extrapolating data from comparable areas / aquifers,
- recommended process monitoring networks will in due course be installed,
- it is necessary and assumed that models will be upgraded as additional and new data become available,
- system behaviour is predicted for double the number of years for which there is temporal data available to calibrate the model and
- time-scale dependency effects are understood and time-averaged data is used.

Conceptual and semi-quantitative understanding can be tested against available field measurements and records of exploration results. If the conceptual model proves to be robust, careful selection of measured, derived and extrapolated data sets to configure, calibrate and test the model in a predictive mode will support:

- Sensitivity analysis of input parameters to model output, and
- Evaluation of uncertainties in model results.

This approach supports the management of uncertainties in groundwater assessment and it also allows the modeller to prepare a physically real mesh, especially with regards to volume and area, yet limit numerical instabilities. Ongoing upgrade and revision of the model configuration and calibration will provide a sound analytical tool to be used in a Model, Monitor and Manage strategy for groundwater resource evaluation, development and management.

This approach was one aspect of what is now more formally known and accepted as a strategy of adaptive management (Luger & Hay, 2002), sometimes described as a process of "learning by doing" (Lowry & Bright, 2002). An adaptive approach to groundwater management necessarily requires appropriate analytical tools or models to support it, which are (op. cit., p. 6):

- conceptually presentable and plausible to stakeholders, and expressive of a collective understanding of participants about the:
  - physical operation of the groundwater system,
  - assessment of uncertainties,
  - prediction of the effects of various management actions;
- capable of implementation in "real-time" mode consistent with the time scale of adaptive decision-making;

- suitable for use with (often sparse) available data.

Where little or nothing is known about the resource to begin with, the models must necessarily make initial assumptions that are conservative, so as to prevent irreparable harm. These initial constraints can be relaxed (or if necessary, tightened) as more information becomes available through monitoring and investigation, since the cause and effect of decisions can then be better predicted (Lowry et al., 2001). This is the approach that has been adopted for this study. It presupposes that critical data shortfalls identified in the modelling process will be addressed in order to increase confidence and certainty in subsequent modelling exercises.

The recommendations in this regard are summarised in the following section and the data available and selected for use in the model process are tabled in summary form in **Table 9-1**.

Table 9-1: Summary Table of Parameters and Data Sources used in the Project

Parameter	Data used	Comment
Topography		
Digital elevation model (DEM)	ComputaMaps	
Hydrology		
Quaternary catchments	WR90	
IWRM Domain		Model Output
Surface Water Bodies	CDSM	
Rivers	CDSM	
Flow gauges	WR90, NS	
Stream flow records	DWAF, NS	
Run off	WR90, NS	Model Output
Baseflow	Different Sources	
Groundwater contribution to Baseflow	GRDM	Model Output
Hydroclimatology		
Mean Annual Precipitation	NS	
Median monthly rainfall	Agrohydrology	Adjusted with NS MAP
Rainfall stations	SAWS, NS	
Rainfall time series	NS	
Mean Annual Temperature	Agrohydrology	
Mean monthly maximum Temperature	Agrohydrology	
Temperature time series	SAWS	
Mean Annual Evaporation	Agrohydrology	
Mean Monthly Evaporation	Agrohydrology	
Mean Annual Evapotranspiration		Model Output
Mean Monthly Evapotranspiration		Model Output
Geology		
1:50000 geology maps	Council for Geoscience	
1:250000 geology maps	Council for Geoscience	
Folds		Umvoto mapping
Faults	Council for Geoscience	Re-interpreted
Fractures		Umvoto mapping
Bedrock topography for Cape Flats	Different sources	Re-interpreted

Parameter	Data used	Comment
Bedrock topography for West Coast	Different sources	Re-interpreted
Bedrock topography for Breede Alluvium	Different sources	Re-interpreted
Porosity	Different sources	
Aquifer thickness	Different sources	Model Output
Hydrogeology		
Aquifer yield	Combined Database	Model Output
Groundwater Storage		Model Output
Transmissivity m^2/day	Combined Database	
Hydraulic conductivity	Combined Database	
Borehole yield	Combined Database	
Storage coefficient	Combined Database	
Specific Yield	Combined Database	
Spring locations	Combined Database	Re-interpreted
Recharge	Combined Database	Model Output
Waterlevel (mamsl)	Combined Database	
Waterlevel (mbgl)	Combined Database	
Water chemistry data	Combined Database	
Water temperature data	Combined Database	
Land Cover		
Land Cover	NLC 2000	Updated by NS
Soil Cover	WR90	Partially updated by NS
Water Use		
Groundwater abstraction, water use	Combined Database	Re-interpreted
Annual groundwater abstraction	DWAF / GRA II	

9.2 RECOMMENDATIONS

The assessment of available data and the approaches to overcome critical data gaps and shortcomings highlights the impact of limitations of existing data bases, particularly the baseflow and usage values. In the smaller aquifers and in those areas where significant or distinct seasonal surface and groundwater interaction is a feature, these relatively small numbers can introduce uncertainty to resource allocation decisions; viz., there is groundwater available for allocation or there is not. This illustrates the principle that resource evaluation and management is risk management, and that management and monitoring strategies must be directed towards reducing and or better defining the risks.

The assessment of the data available for use in this study and the development of the conceptual models and approach at a regional and at an individual aquifer scale (see Volume 3) have highlighted the following data gaps:

- location of perennial springs
- time series for spring flow
- spring hydrochemistry (macro and trace)
- isotopic characterization of springs and seep zones and groundwater
- thermal measurements of springs and groundwater
- event response changes in spring flow and groundwater level
- widely distributed hydraulic parameters for the TMG Aquifer
- bedrock topography along the West Coast
- volume and pattern of groundwater use per aquifer
- uniform scale of fracture mapping
- geological anomalies in the 1:50 000 geological field sheets.

It is therefore recommended to undertake the following data collection activities:

- Spring hydrocensus including diverse hydrochemical sampling
- Borehole hydrocensus
- Fracture mapping in TMG terrain
- Hydraulic testing in selected boreholes in both the Peninsula and Skurweberg Aquifer
- Mapping of paleo 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 review and revision of the monitoring network is required for the improvement of relevant data for future model upgrades. The other recommendations are suggested for immediate implementation to verify model assumptions and hence to increase the confidence and, in case of hydraulic parameters, the certainty in the model outputs. Since it is not expected that these data will be available for this study, preliminary assumptions will be made as part of this study.

The different recommendations are motivated for and detailed in the sections below.

9.2.1 Spring hydrocensus

The groundwater is discharged into the surface water via springs, seep zones and lateral or sub-vertical flow into rivers. The study area is unique in that there are ambient, warm to very hot springs in an area of relatively low seismic activity. The springs and seep zones also occur in distinct geological settings which allows comparison with borehole data (depth of water strike, geological formation, geological situation).

The temperature of these springs inform about the maximum likely depth through which the water has moved and therefore also the likely rate of movement from these depths to the surface. This combined with macro and trace chemistry and isotope data, different aquifers having a fairly distinct chemical signature, facilitates definition of flow paths, residence times.

There are currently only a handful of springs in the greater study area that are being monitored (see **Figure 9-1**). The information about the location of springs, their flow pattern and monitoring data are invaluable in groundwater studies as they provide a direct window into the aquifers themselves. For this reason a comprehensive spring hydrocensus is recommended in the Task 5 Report (DWAF, 2006a) with the aim of locating and identifying all perennial springs in the western portion of the Western Cape relevant to the study area.

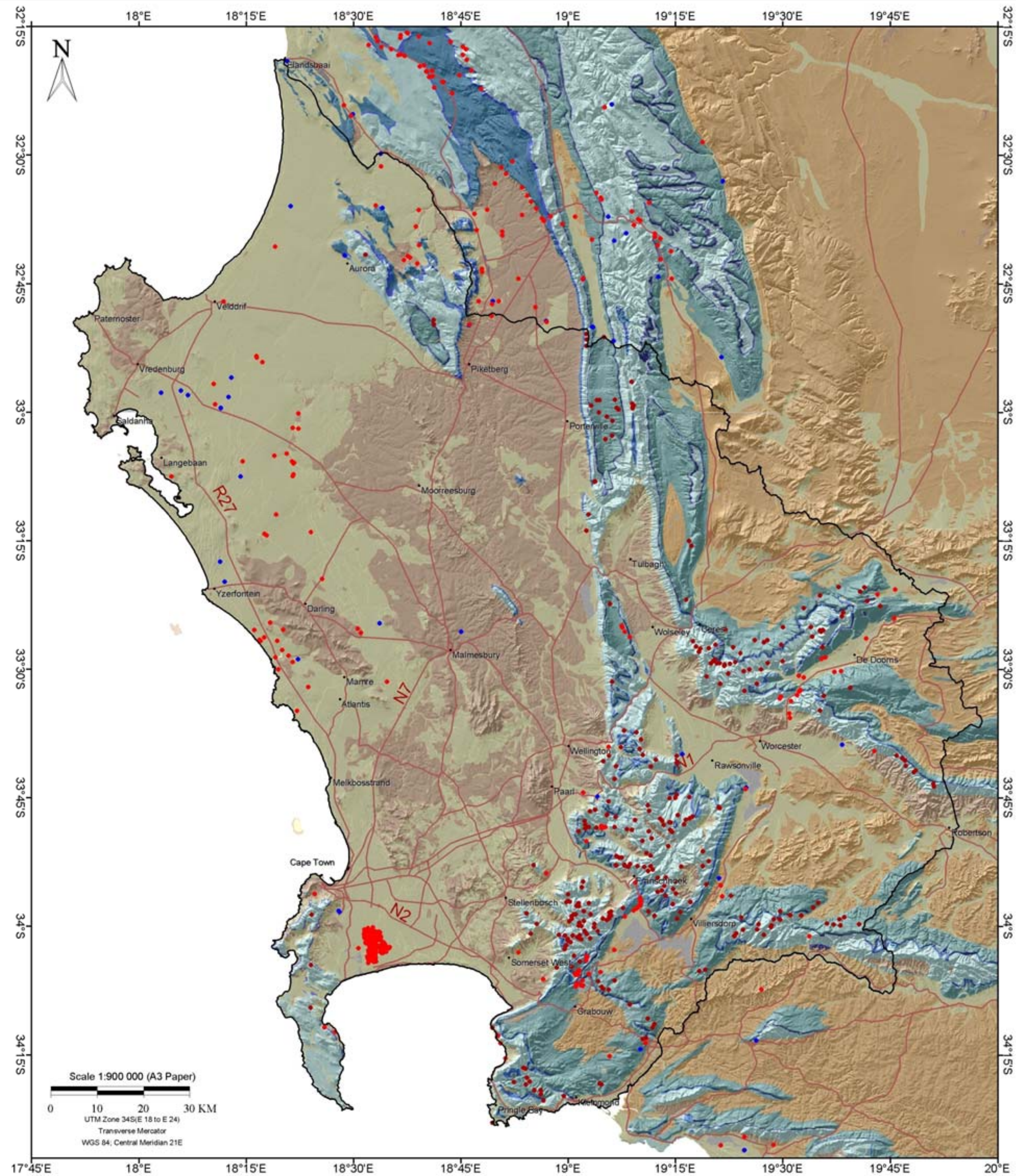
The recommendation in Task 5 relates to future investigations and improvement of the monitoring network for future model upgrades. However, it becomes evident from the assessment of available data that a comprehensive spring hydrocensus should be undertaken immediately in order to address some of the identified data gaps, listed above.

In summary a thorough and well-designed spring hydrocensus will increase confidence in model results because

- The conceptual models can be tested and revised against hard field data with regards to
  - Regional flow paths for different aquifers
  - Discharge areas for different aquifers
  - Linkage between recharge and discharge areas
  - Hydrochemical characterisation of aquifers and seasonal changes thereof.
- Correlate recharge and discharge areas and therefore upgrade catchment mass balance estimates and or prioritise those catchments into or from which water is being transferred either at a quaternary or up to secondary scale.
- Discharge estimations from the regional Water Balance Model can be calibrated.
- Residence times & flow rates for different levels/temperatures of flow can be established (from isotope and temperature data).

Ideally, the spring hydrocensus should be approached with an initial desktop study to identify key areas of interest, followed by field verification. The desktop study will entail a GIS based methodology combined with remote sensing techniques using high resolution satellite imagery to identify

- local geology,
- geological structures,
- aquifer characteristics,
- surface water patterns, and
- vegetation.



LEGEND

- Towns
- Monitored Springs
- Not Monitored Springs
- Inferred Springs
- Study Area

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

MONITORED AND OTHER SPRINGS

FIGURE 9.1

Subsequently field verification will be required as a next phase to determine the validity of the identified potential spring locations and the suitability for installation of automated flow measurements (e.g. weirs, v-notches or flumes), to take water samples for chemical and isotope analysis and to determine field parameters such as water temperature, EC and flow.

9.2.2 Borehole hydrocensus

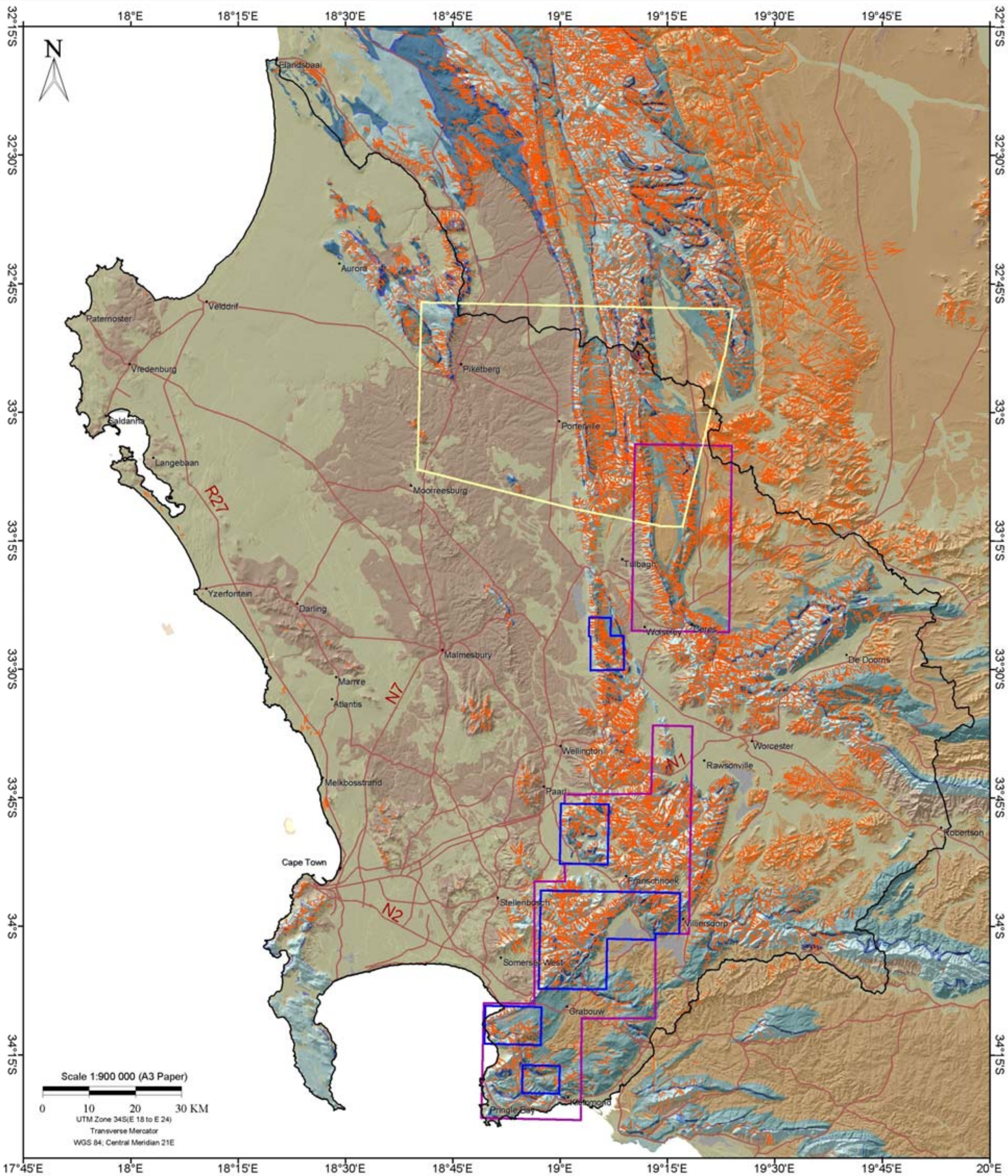
The assessment of the NGDB and WARMS databases indicates that there is some inconsistency in the data about groundwater use and the number of boreholes in some areas of the study domain. It is of utmost importance for the estimation of groundwater abstraction per aquifer to verify borehole locations and groundwater use. Furthermore, the hydrocensus allows for gathering additional vital information about the aquifer, such as water level, water chemistry, water temperature etc.

There has been a recent blanket hydrocensus undertaken in the Berg River catchment (Parsons, 2003) but no hydrocensus was undertaken during the Breede Basin Study. It is necessary to upgrade the NGDB with a particular focus on obtaining borehole abstraction rates and schedules from all private and municipal users, detailing the aquifer from which the groundwater is abstracted and undertaking selective comprehensive hydrochemical and isotope sampling and analysis. The temperature of different waters is necessary as is selective sampling and mapping of temperature and hydrochemical variations at certain river reaches selected on the basis of prior hydrogeological interpretation of flow paths.

9.2.3 Fracture mapping

The currently available data about the fracture network is very detailed in some areas of the study area, e.g. Hottentots Holland, Kogelberg, Du Toits Kloof, Hawequas, Winterhoek, Langeberg and Piketberg, while the data is not available at the required scale in other areas, especially in the northern part around Tulbagh, Ceres and Hex River (see **Figure 9-2**). The information about fracture distribution and density is crucial for determining hydraulic parameters, hydraulic relevant thickness and interaction with surface water bodies. It is therefore recommended to undertake a fracture mapping in the study area to fill these data gaps in all areas relevant for detailed modelling and for groundwater – surface water interaction.

Fracture mapping involves digitizing of linear features as identified on satellite imagery and aerial photos at different scales from 1:100 000 and 1:40 000 (satellite imagery and DEM) to 1:10 000 (aerial or orthophoto).



LEGEND

- Towns
- 1:100 000 Fracture Mapping
- 1:40 000 Fracture Mapping
- 1:20 000 Fracture Mapping
- 1:10 000 Fracture Mapping
- Study Area

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS

CONSULTANT

UMVOTO

TITLE

FRACTURE MAPPING DISTRIBUTION

FIGURE 9.2

9.2.4 Hydraulic Testing

Aquifer parameters for the Peninsula Aquifer are available from numerous pump tests conducted for up to three weeks in different areas, i.e. the Koo Valley, Hermanus, Citrusdal. There is also long-term data on groundwater level changes from the Olifants-Doring and the Gouritz Basin. Seasonal response to recharge (~1 m) is comparable in these areas. However these is limited pump test data or long-term water level monitoring data for the Skurweberg Aquifer.

The test pumping results indicate a range of values for transmissivity and storage coefficient (see **Table 6-8**). However, there is a need for a better spatial distribution of hydraulic parameter estimations for both the Peninsula and the Skurweberg Aquifer with regards to fracture patterns and hydrotects.

It is suggested that selected existing boreholes are test pumped, using tracer tests if appropriate and thereafter equipped with down-hole data loggers. These boreholes will be selected on the basis of the spring and borehole hydrocensus, fracture mapping, revision of flow path definition and the following criteria:

- Location within study domain with regards to model domains
- Geological profile of borehole log
- Proximity to hydraulically active faults
- Existing monitoring network.

The minimum requirements for the hydraulic testing are:

- Pumping at high abstraction rate over an extended period of time (minimum of 5 to 10 days) to stress the aquifer;
- Monitoring of hydraulic head in an abstraction borehole and at least two, strategically placed monitoring boreholes; and
- Identification of boundary conditions and flow regimes based on pumptest data.

Currently, the Overstrand Municipality embarks on a long-term abstraction from their Gateway wellfield, which is drilled into the Peninsula Aquifer. Results from several single-hole and wellfield tests are available and show the dependency between hydraulic parameters and the fracture network. It is recommended to utilise this test pumping by measuring changes to land surface elevation to determine the elastic parameters and therefore the storage coefficient for the Peninsula Aquifer.

9.2.5 Palaeochannel mapping

The location and depth of the palaeo channels along the West Coast and underneath the alluvium aquifers determine the groundwater flow pattern in these aquifers. Reasonable inference can be made in the Cape Flats and Langebaan Aquifers based on both offshore and onshore data. No detailed information is available about palaeo channels north of the Berg River estuary. These have previously been inferred from regional structural geology and 1:10 000 topography, as well as knowledge of sea level rise and fall.

Mapping of these palaeo channels would confirm and or refine the present model configurations. It is therefore recommended to undertake airborne or surface geophysical measurements along the West Coast and over the Breede River alluvium.

9.2.6 Surface water and groundwater sampling

The groundwater discharge to rivers along river reaches can be mapped with the aid of chemical and isotope analysis, as some trace elements and isotope signatures are aquifer specific. It is therefore recommended to sample the surface water along selected river reaches to verify whether groundwater discharges into the surface water body. It might be required to also take groundwater samples in the vicinity of the river to determine isotope and trace elements signatures for the relevant aquifers. This work should be planned together with the spring hydrocensus and interpretation of results must take spring localities and hydrochemistry into account.

9.2.7 Review and revise geological mapping

The mapping of structural geological features on the 1:250 000 and 1:50 000 geological maps is sufficient for the regional models, but is lacking detail and accuracy as required for detailed modelling. Furthermore, it recently became evident that the mapping of formations is incorrect in some areas. It is therefore recommended to review the geological mapping in the detailed model domains, especially in the TMG dominated domains, with respect to the structural features and stratigraphic detail. If required, the geological mapping will then be revised and updated.

9.2.8 Review and revise Monitoring Network

Groundwater monitoring programmes must involve regular measurements of:

- water levels,
- water quality (macro and trace elements and biological indicators),
- abstraction volumes,
- climatic variables - rainfall, temperature, potential evaporation and snowfall
- hydrologic variables – spring flow (altitude, volume, water quality, seasonal and or climate event- related variation), baseflow and water quality variations in rivers.

Such systematic programmes are generally implemented for particular groundwater or conjunctive-use schemes, mostly tied to production boreholes. There is an imperative need for strategically placed observation boreholes exclusively dedicated to groundwater monitoring in locations distant from production wellfields.

Groundwater level, as monitored at one or more observation wells (piezometers), is the most important indicator of the state of the resource. Even just one suitably located well, preferably placed furthest from outflow boundaries to surface waters and/or away from sites that are likely to be affected significantly by surface abstraction or by local (artificial) recharge from surface irrigation, can provide substantial information about the overall state of the resource, because the dynamic variability of groundwater levels observed in that suitably located well reflects that of the surrounding aquifer.

There is currently not one consistent monitoring network within the Berg WAAS study area. It is therefore recommended to review and revise the monitoring network and data collection process as well as the actual location (longitude, latitude, elevation, depth) of monitoring boreholes on basis of this project to ensure that the monitoring boreholes are in the right place and monitor different processes at different scales in relevant aquifers.

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APPENDIX A

GLOSSARY

APPENDIX A : GLOSSARY

Aquifer — a consolidated or unconsolidated geologic unit (material, stratum or formation) or set of connected units that yield a significant quantity of water of suitable quality to wells or springs in economically usable amounts.

Confined (or artesian) - an aquifer that is immediately overlain by a low-permeability unit (confining layer). A confined aquifer does not have a water table.

Unconfined (or water-table) - the upper surface of the aquifer is the water table. Water-table aquifers are directly overlain by an unsaturated zone of a surface water body.

Aquitard — a geologic material, stratum, or formation of low permeability (a confining unit) that transmits significant amounts of water on a regional scale or over geologic time.

Conceptual model — a clear, qualitative physical description of how a hydrogeological system behaves.

Drawdown — the drop in head from the initial head caused by pumping from a well or set of wells.

Hydraulic conductivity (K) — the volume of fluid that flows through a unit area of porous medium for a unit hydraulic gradient normal to that area.

Hydraulic head (h) — the elevation in a well in reference to a specific datum; the mechanical energy per unit weight of water [L].

Permeability — the ease with which a porous medium can transmit water or other fluids.

Porosity — the volume of the voids divided by the total volume of porous medium. Effective porosity is the interconnected porosity which contributes to groundwater flow. Often used synonymously with specific yield although the two terms are not synonymous.

Phreatic zone — layer of soil or rock below the water table, i.e. the saturated zone

Pump test — one of a series of techniques to evaluate the hydraulic properties of an aquifer by observing how water levels change with space and time when water is pumped from the aquifer.

Recharge — the process by which water enters the groundwater system or, more precisely, enters the phreatic zone.

Safe yield — the volume of water that can be withdrawn annually from an aquifer (or groundwater basin or system) without 1) exceeding average annual recharge; 2) violating water rights; 3) creating uneconomic conditions for water use; or 4) creating undesirable side effects, such as subsidence or saline water intrusion.

Specific storage (Ss) — the volume of water released per unit volume of aquifer for a unit decrease in hydraulic head.

Specific yield (Sy) — the volume of water that a saturated porous medium can yield by gravity drainage divided by the volume of the porous medium.

Storage — water contained within an aquifer or within a surface-water reservoir.

Storativity (S) — the volume of water released per unit area of aquifer for a unit decline in head. In a confined aquifer, S is essentially the specific storage (Ss) times aquifer thickness; in an unconfined aquifer, S is essentially equal to the specific yield or the effective porosity

Transmissivity (T) — the discharge through a unit width of the entire saturated thickness of an aquifer for a unit hydraulic gradient normal to the unit width, sometimes termed the coefficient of transmissibility [$L^2\ t^{-1}$]

Water table	a surface at or near the top of the phreatic zone (zone of saturation) where the fluid pressure is equal to atmospheric pressure. In the field this is defined by the level of water in wells that barely penetrate the phreatic (saturated) zone.
Yield	generically, the quantity of water pumped from a well (or bore) over a certain time. In Australia, there is a narrower definition - the maximum sustainable pumping rate such that the drawdown in a well after 24 hours does not exceed a specified percentage (typically ~2%) of the column of water above the base of the aquifer. This assumes that the well is fully penetrating and screened overall permeable intervals of the aquifer. The units of yield are volume per time.
Data	observations made from monitoring the real world.
Raster	system of tessellating rectangular cells in which individual cells are a represenation of point, line, area and network surfaces.
Vector	a spatial data model using two-dimensional Cartesian (x, y) co-ordinates to store the shape of spatial entities.

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APPENDIX B

LIST OF TOPOSHEETS

APPENDIX B : LIST OF TOPO-GEOGRAPHICAL SHEETS THAT COVER THE STUDY AREA

		3218ad						
		3218cb	3218da	3218db				
3217dd	3218cc	3218cd	3218dc	3218dd	3219cc			
	3318aa	3318ab	3318ba	3318bb	3319aa	3319ab	3319ba	
	3318ac	3318ad	3318bc	3318bd	3319ac	3319ad	3319bc	3319bd
		3318cb	3318da	3318db	3319ca	3319cb	3319da	3319db
		3318cd	3318dc	3318dd	3319cc	3319cd	3319dc	
		3418ab	3418ba	3418bb	3419aa	3419ab	3419ba	
				3418bd	3419ac	3419ad		

APPENDIX C

LIST OF QUATERNARY CATCHMENTS

APPENDIX C : LIST OF QUATERNARY CATCHMENTS

Table C-1: Catchment area in study domain, MAP, MAR and Run-off efficiency

Quaternary catchment	Area	MAP *WR90*	MAP *CCWR*	MAP *GRAII*	MAP *Berg WAAS*	MAR *WR90*	Run-off Efficiency *WR90*
	km²	*mm*	*mm*	*mm*	*mm*	*mm*	
E10A	133.73	899	743	907	966	458	0.51
E10B	197.15	736	648	724	869	346	0.47
E10C	189.98	587	552	581	840	259	0.44
E21A	183.09	620	475	582	718	184	0.30
E21B	92.50	497	336	540	666	121	0.24
E21D	108.22	627	620	771	851	188	0.30
E22C	91.22	324	394	426	603	27	0.08
G10A	171.78	1580	1218	1555	1603	1015	0.64
G10B	125.97	1245	893	1237	1306	726	0.58
G10C	328.07	1009	914	1000	874	448	0.44
G10D	687.55	625	574	640	690	168	0.27
G10E	394.10	640	656	660	767	173	0.27
G10F	539.36	515	549	533	581	113	0.22
G10G	185.58	912	672	935	995	668	0.73
G10H	674.52	411	404	406	404	31	0.08
G10J	867.50	447	454	450	494	40	0.09
G10K	1175.89	382	408	383	318	21	0.05
G10L	1754.55	390	387	390	305	29	0.07
G10M	2004.68	300	271	298	225	9	0.03
G21A	523.29	408	409	409	345	32	0.08
G21B	303.78	424	398	424	331	32	0.08
G21C	244.22	523	472	523	546	62	0.12
G21D	484.05	477	465	478	384	49	0.10
G21E	530.76	531	530	535	497	68	0.13
G21F	242.40	488	449	491	361	54	0.11
G22A	237.99	684	723	682	735	133	0.19
G22B	109.40	923	956	912	1073	296	0.32
G22C	254.25	605	609	610	651	92	0.15
G22D	246.01	738	823	732	824	165	0.22
G22E	270.68	572	562	575	562	77	0.13
G22F	65.69	1465	1421	1527	1620	868	0.59
G22G	106.36	754	717	750	785	155	0.21
G22H	227.30	669	678	680	814	111	0.17
G22J	128.19	1002	1027	1013	1152	459	0.46
G22K	79.82	769	854	815	906	300	0.39
G30A	761.28	260	261	262	309	6	0.02
G30D	438.59	384	345	384	398	22	0.06
G40A	71.52	1121	1017	1146	1053	538	0.48
G40B	122.42	937	1068	951	977	403	0.43
G40C	144.57	1367	1331	1312	1251	728	0.53
G40D	327.17	984	1042	986	899	436	0.44
G40E	252.59	722	609	735	764	135	0.19
G40G	108.82	724	724	808	745	136	0.19

Quaternary catchment	Area	MAP *WR90*	MAP *CCWR*	MAP *GRAII*	MAP *Berg WAAS*	MAR *WR90*	Run-off Efficiency *WR90*
	km²	*mm*	*mm*	*mm*	*mm*	*mm*	
H10A	233.67	512	473	550	651	168	0.33
H10B	162.46	708	424	653	778	288	0.41
H10C	259.60	674	722	668	862	266	0.39
H10D	96.96	1019	586	977	1146	520	0.51
H10E	84.81	1404	813	1440	1241	1064	0.76
H10F	247.88	784	627	799	883	349	0.45
H10G	270.43	788	703	804	816	353	0.45
H10H	187.49	886	381	864	753	423	0.48
H10J	213.78	1595	856	1612	1226	859	0.54
H10K	193.55	1225	678	1213	1106	573	0.47
H10L	95.79	476	403	464	542	94	0.20
H20A	140.46	357	281	356	375	34	0.10
H20B	124.39	590	312	539	488	33	0.06
H20C	80.57	643	503	627	674	44	0.07
H20D	100.67	696	383	697	945	277	0.40
H20E	95.20	906	301	957	967	423	0.47
H20F	116.58	797	322	757	714	97	0.12
H20G	85.08	680	347	684	765	55	0.08
H20H	89.03	300	276	294	365	29	0.10
H40A	184.39	426	293	435	383	35	0.08
H40B	240.54	577	357	649	542	15	0.03
H40C	271.79	375	269	356	380	52	0.14
H40D	181.76	557	318	587	672	136	0.24
H40E	285.43	539	398	541	590	126	0.23
H40F	339.92	293	251	292	427	27	0.09
H40G	263.37	417	326	468	554	66	0.16
H40H	207.91	461	342	417	415	88	0.19
H40J	152.24	417	307	358	372	52	0.12
H60A	72.64	1895	1569	1723	1695	1207	0.64
H60B	210.00	1127	904	1094	1161	564	0.50
H60C	216.89	891	631	879	869	386	0.43
H60D	137.75	652	512	751	809	184	0.28
H60E	84.52	640	412	814	849	174	0.27
H60F	115.52	582	418	677	731	141	0.24
H60H	35.64	464	402	549	600	78	0.17
J12A	127.96	437	326	469	731	38	0.09
J12B	38.72	268	258	274	322	10	0.04
Total	**22232.0**	**574.7**	**503.1**	**579.0**	**581.1**	**156.2**	**0.27**

Table C-2: Baseflow, Groundwater Contribution to Baseflow and Recharge per catchment

Quaternary catchment	Base Flow *GRDM*	Base Flow *HUGHES*	Base Flow *PITMAN*	Base Flow *SCHULZE*	GW Contribution to Base Flow *GW_BFLOW*	Recharge *GRDM*
	mm	*mm*	*mm*	*mm*	*mm*	*mm*
E10A	49.0	133.90	14.95	56.60	29.10	75.67
E10B	33.0	100.13	3.64	42.70	28.71	60.18
E10C	24.0	74.22	3.14	31.50	23.22	42.28
E21A	20.0	56.91	5.07	24.40	11.76	35.19
E21B	13.0	36.71	3.37	16.40	11.00	23.00
E21D	21.0	58.53	5.06	24.90	11.77	39.99
E22C	0.0	1.73	0.00	0.00	0.00	7.89
G10A	141.0	375.70	62.14	142.40	42.30	156.96
G10B	97.0	259.26	40.78	101.50	42.53	125.44
G10C	51.0	141.90	15.26	58.60	6.91	99.58
G10D	19.0	53.75	5.84	22.70	7.50	43.49
G10E	20.0	55.21	5.78	23.90	13.62	39.70
G10F	13.0	36.18	4.12	15.20	8.03	25.80
G10G	71.0	207.40	16.44	84.90	14.75	117.96
G10H	2.0	9.36	0.75	0.00	5.23	13.07
G10J	2.0	12.11	0.93	0.00	5.96	17.70
G10K	0.0	2.14	0.00	0.00	0.00	14.47
G10L	0.0	2.83	0.00	0.00	0.00	18.03
G10M	0.0	0.56	0.00	0.00	0.00	16.18
G21A	0.0	2.28	0.00	0.00	0.58	31.38
G21B	0.0	2.09	0.00	0.00	0.00	34.20
G21C	7.0	18.85	1.60	8.60	7.98	26.68
G21D	5.0	14.84	1.37	7.00	7.63	23.56
G21E	7.0	20.89	1.92	8.90	8.31	32.75
G21F	6.0	16.84	1.61	7.30	8.10	34.46
G22A	14.0	41.00	3.55	15.90	13.66	111.81
G22B	29.0	87.90	6.63	33.40	14.48	144.34
G22C	10.0	28.73	2.94	12.00	10.08	60.20
G22D	17.0	50.13	4.04	19.30	10.40	97.71
G22E	9.0	24.20	2.43	10.60	9.87	49.76
G22F	136.0	342.63	72.25	127.70	40.70	164.20
G22G	17.0	47.49	4.51	20.50	10.35	68.72
G22H	13.0	35.04	3.69	15.00	9.17	64.53
G22J	69.0	174.55	36.32	66.70	12.39	102.22
G22K	45.0	113.64	23.22	43.20	13.22	70.78
G30A	0.0	0.07	0.00	0.00	0.00	14.04
G30D	0.0	1.72	0.00	0.00	0.00	21.97
G40A	85.0	215.07	44.22	79.70	44.07	99.49
G40B	62.0	157.19	31.70	59.70	43.73	99.12
G40C	116.0	296.58	60.83	108.10	43.24	111.83
G40D	67.0	171.36	34.10	64.80	44.20	82.06
G40E	13.0	40.73	3.13	13.60	16.84	39.64
G40G	13.0	41.10	2.99	13.70	16.97	64.48

Quaternary catchment	**Base Flow** *GRDM*	**Base Flow** *HUGHES*	**Base Flow** *PITMAN*	**Base Flow** *SCHULZE*	**GW Contribution to Base Flow** *GW_BFLOW*	**Recharge** *GRDM*
	mm	*mm*	*mm*	*mm*	*mm*	*mm*
H10A	17.0	50.43	3.58	20.70	3.23	26.19
H10B	30.0	87.98	6.65	36.70	20.66	58.66
H10C	28.0	81.97	5.98	33.60	20.50	42.78
H10D	55.0	162.69	11.69	65.30	21.15	103.44
H10E	139.0	374.80	53.57	149.70	37.63	180.17
H10F	37.0	109.06	7.75	43.80	21.06	61.77
H10G	37.0	110.68	7.95	44.20	21.14	66.38
H10H	45.0	133.11	9.50	53.00	21.14	64.30
H10J	112.0	302.19	43.55	119.90	38.96	165.31
H10K	77.0	202.15	31.98	82.40	39.94	114.74
H10L	0.0	9.17	0.00	0.00	0.00	23.44
H20A	0.0	0.00	0.00	0.00	0.00	15.11
H20B	3.0	9.54	0.97	3.80	4.51	48.48
H20C	6.0	12.68	3.60	4.80	7.82	36.01
H20D	31.0	86.52	9.83	35.50	22.16	60.61
H20E	49.0	136.00	15.47	54.80	22.82	84.87
H20F	9.0	28.74	2.06	8.30	11.91	76.65
H20G	5.0	15.61	1.41	5.60	9.50	50.29
H20H	0.0	0.27	0.00	0.00	0.00	11.59
H40A	0.0	2.49	0.00	0.00	0.00	18.13
H40B	3.0	6.28	1.74	3.60	4.37	41.64
H40C	0.0	4.65	0.00	0.00	0.00	12.34
H40D	0.0	18.09	0.00	0.00	0.68	19.95
H40E	0.0	17.30	0.00	0.00	0.69	23.13
H40F	0.0	1.49	0.00	0.00	0.00	3.22
H40G	3.0	12.81	0.80	0.00	0.96	11.54
H40H	0.0	9.80	0.00	0.00	0.63	21.04
H40J	2.0	9.13	0.44	0.00	0.90	16.13
H60A	147.0	416.16	47.61	161.80	34.08	173.39
H60B	65.0	187.64	20.15	72.10	34.66	92.66
H60C	46.0	128.49	14.13	51.50	9.10	61.34
H60D	20.0	58.77	6.06	22.70	4.17	37.42
H60E	19.0	55.33	5.48	21.90	4.20	34.38
H60F	15.0	44.08	3.98	17.50	4.19	28.00
H60H	9.0	25.65	3.44	9.80	4.50	16.51
J12A	0.0	4.08	0.00	0.00	0.00	15.28
J12B	0.0	0.38	0.00	0.00	0.00	6.03
Total	**17.2**	**49.2**	**6.0**	**18.8**	**8.9**	**41.2**

APPENDIX D

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APPENDIX D : BIBLIOGRAPHY

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APPENDIX E

EVALUATION OF DATA SETS FROM GRA II PROJECT

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GRA II DATA SETS

The Groundwater Resource Assessment Phase II (GRA II) project comprised five different tasks to develop a general methodology for groundwater resource evaluation and provide an estimate of groundwater potential on a national scale. The five tasks are:

- Task 1 – Groundwater Quantification
- Task 2 – Planning Potential Map
- Task 3a – Recharge Estimation
- Task 3b – Groundwater surface water Interaction
- Task 4 – Aquifer Classification
- Task 5 – Groundwater use

"The key objective of the GRA II project is to provide an approach to quantifying groundwater resources in South Africa. Together with the approach (or method), the project must provide generic data sets that can be used for rapid and regional-scale groundwater resource assessments. The main purpose for quantifying groundwater in the GRA II project is to provide guidance on how much water can be allocated for use." (DWAF, 2004c)

Although one of the criteria for the GRA II methodology is that the approach should be applicable at various scales, this is not achieved. In preparing the GIS layers for the quantification of groundwater resources, they averaged input data across aquifer boundaries. The 3rd dimension of geology and aquifer geometry is often neglected and the differences in confined and unconfined aquifers are not considered. The resulting data sets are therefore not aquifer specific and often not relevant to the aquifer under investigation.

Different data sets on a 1km grid were obtained from the GRA II project. The data sets discussed below were made available by the DWAF from the database within the GRDM software. The data quality and usability of the data sets for the modelling study are discussed in the following sections.

Topography

The topography data are provided on a 1km grid to be consistent with the other data sets. The main use of topography data is to recalculate the water level in meter above mean sea level (mamsl) from the water level data set. However, there is an area of erroneous data in the G10F catchment.

This data set is not used further due to the data errors and the coarse grid cell size.

Rainfall

The mean annual rainfall (MAP) data are similar to the data set from the CCWR (see Section 3) and the total MAP for the study area is equal for both data sets (viz. 12.5 billion m^3/a). However, there are small shifts resulting in differences in actual values per cell of up to 921 mm/a.

Since an updated rainfall surface is developed as part of Task 6 of this study, the MAP data from the GRA II and the CCWR will not be used further.

Recharge Percentage

The data set of recharge percentage is mainly based on the Chloride Mass Balance method, which requires the chloride concentration in the rain and the groundwater. The input data sets were not available to check the distribution of input values. However, several aspects are relevant and need to be considered:

- The chloride concentration in the rain varies significantly depending upon the proximity to the sea and will vary with proximity to industrial sources.
- The influence of dry deposit of chloride is most relevant in closed proximity to the sea, but also in generally dry areas.
- The chloride concentration in the groundwater depends upon several factors; recharge being an important but not the only one. It can be influenced by irrigation, contamination, rock water interaction etc.
- The spatial distribution of recharge and discharge areas is not taken into account in this method.
-
- Aquifer specific recharge data is therefore not available. It appears from the distribution that there is a close correlation between recharge percentage and rainfall. A comparison of recharge values from the GRA II with other studies indicate some discrepancies:
- The recharge values given for the Cape Flats Aquifer are more than 50% lower than previous studies assumed (Vandoolaeghe, 1990).
- Recharge in the Agter-Witzenberg area was estimated by Weaver et al. (1999) to be up to 40% of rainfall. The GRA II data set suggests less than 20%.
- Recharge in the Breede valley below Worcester and in the Robertson area is given as below 1%, which is unrealistically low.

It is always problematic to base the recharge estimation on one single method. Depending upon the area of interest, the scale, the geological and hydroclimatological conditions, and the available data a variety of methods should be employed to estimate the aquifer recharge.

Waterlevel

Two data sets of average water levels in the study area were provided; viz.

- Water level in mamsl
- Water level in mbgl

It was discovered that the first data set (water level in mamsl) has a shift of approximately 16km southwards. It is therefore not usable for the study. The second data set (water level in mbgl) contains several areas with unreasonable values:

- Deepest water level in centre of basin; e.g. in G10H, H40C and H20F
- Shallow water level on top of high mountains; e.g. in H10G, H10J, H10K and G10B

The Langebaan Road Aquifer and the Cape Flats Aquifer are the only areas where the distribution of water levels and the values are reasonable. This shows one of the major shortfalls of the approach adopted in the GRA II project. The aquifers are not separated and data from different aquifers are compared. The grid values are calculated by interpolation and averaging across aquifer boundaries despite significant hydraulic property and even hydroclimatic changes at some of these boundaries.

Storage Coefficient

The data set of the storage coefficient is grouped into four classes, viz.

- 0.0008 for fractured rock aquifers, assigned to the TMG
- 0.004 for different low yielding aquifers and aquitards, e.g. assigned to the Malmesbury
- 0.01 for regolith aquifers, assigned mainly to granites
- 0.1 for primary aquifers, such as Langebaan Road and Cape Flats

Given available field data and internationally published data for different aquifer types (Freeze & Cherry, 1979), these values are considered too low for the TMG aquifers and for coarser grain primary aquifers. A value of 8E-4 for the TMG is even smaller than the range of storage coefficients estimated from pumptest analysis in comparable TMG terrain.

It also appears that the storage coefficient as applicable for confined aquifers and the specific yield or porosity as applicable for unconfined aquifers are confused in this parameter. Since this parameter is used in the GRA II for calculation of water in storage (see below), it should rather be equal to porosity. The porosity within the TMG is at least two orders of magnitudes higher. Similarly the other values are considered too low and not applicable for the purpose of this study.

Saturated Thickness

The data set of saturated thickness is grouped into five classes, viz.

- -1 m for primary aquifer
- 10 m for the lower part of the Breede River Alluvium
- 25 m for selected regolith aquifers in the eastern part of the study area
- 40 m for regolith aquifers, assigned to granites and Malmesbury
- 75 m for fractured rock aquifers from the TMG

These values were taken from suggested drill depth (Vegter, 1995). 10 years later this approach is not applicable anymore, as the drilling techniques and the knowledge of deep and confined aquifers have evolved significantly since 1998. The average drill depth planned for production boreholes is now no less than 250m.

The strike-density curves for the TMG Aquifer, as used in the GRA II, clearly indicate that there is no depth dependency of strike-density. Analysis of borehole data and experience with drilling in the TMG Aquifer shows that the yield increases steadily with depth (Weaver et.al, 1999), indicating that contribution of yield from the aquifer to the borehole continuous with depth. The thickness of the Peninsula Formation within the TMG Aquifers varies between 800 m along the coast and up to 1500 m within the mountain ranges. The thickness of the Skurweberg Aquifer is approximately 120m. Based on the structural analysis of the stress regimes it can be assumed that the full thickness of both the Peninsula and Skurweberg is fractured and capable of storing water within the confined zones. The altitude of springs and seep zones on valley slopes indicate the regional elevation of the water table in the unconfined areas of both aquifers and therefore (with previous knowledge of the total thickness of the unit) is also a reasonable approximation of the unconfined aquifer thickness.

Furthermore the GRA II aquifer parameter values are only assigned to the outcrop areas of the TMG, so the confined areas of the TMG that are overlain by Bokkeveld, Karoo sandstones and primary aquifers are ignored.

Groundwater Storage

These data sets on groundwater storage were not provided but a description of them is available in the GRA II report (DWAF, 2004c). The groundwater storage is derived from the data sets above, i.e. topography, waterlevel, storage coefficient and saturated thickness, whereby

- Maximum storage = (Top – Bottom) x Storage Coefficient
- Average storage = (Water level – Bottom) x Storage Coefficient
-

The final report of the GRA II project states that “a number of anomalies are evident … e.g. the Eastern Karoo aquifer systems appear to have a greater maximum volume of groundwater stored per unit area than the Table Mountain Sandstone aquifer systems.”

The groundwater storage data will not be used further in this study since:

- the input parameters to the above equations are already questionable and not considered usable for the purpose of this study;
- aquifer storage should be calculated using aquifer dimensions and porosity, not storage coefficient as stated above; and
- based on simple field measurements of rock volume and text book values of equivalent porosity as well as available pumptest data, it is simply unrealistic that the amount of water stored per unit area in the TMG is less than that of the Eastern Karoo aquifer system.

Borehole Yield

The distribution and values of borehole yield over the study area is not consistent with the distribution of aquifers and the yield map of the 1:500 000 hydrogeological map series. The borehole yield is most often a function of the insight and knowledge of the person siting the borehole, therefore interpolating between boreholes without taken cognisance of the meta information for the specific boreholes and the geological conditions at the borehole site results in a wrong distribution of the data. Examples for erroneous interpretation of the borehole data are:

- Area of very high borehole yield at St Helena Bay lies within granite outcrops.
- Area of very high borehole yield in G10K lies north of the Langebaan Road Aquifer at the edge of a paleo channel. Higher yields would be expected within the paleo channel
- Area of low borehole yields along the mountain range is situated on the TMG Aquifer.
- Breede River Alluvium is indicated as high yielding, while the surrounding TMG Aquifers are indicated as much lower yielding.

Transmissivity

The transmissivity data set was derived from the borehole yield. The report indicates that this approach is based on that of van Tonder and Kirchner and used by Murray (1996) working in the Eastern Cape Karoo rocks. There is no documented basis for extrapolating this relationship to other aquifer types and hydroclimatic settings. Furthermore the distribution of transmissivity values over the study area does not match the different high yielding aquifers (e.g. primary, TMG) and low yielding aquitards (e.g. Malmesbury). It appears that the distribution is based on single borehole yields (see above), which over-represent localised high yielding boreholes and does not account for the geological control of these boreholes.

Groundwater use

The groundwater usage information, as implemented in the GRDM software, is based on the methodology and assessment from the GRA II project. The methodology utilises different sources of information for the different sectors of water use; viz.

- Agriculture – Livestock Department of Agriculture,
- Agriculture – Irrigation Department of Agriculture, NLC
- Domestic – Rural CWSS
- Domestic – Urban DWAF
- Mining WARMS
- Industry WARMS

Most of these sources have inherent uncertainties, but are the best data available. Due to the different sources of information and applied estimation methods, it is not possible to compare the results for the different sectors but it is assumed that the relative orders of magnitude are correct. Some of the inherent critics on the methodology are:

(a) "A fundamental concern is that many data sources are or were created using inferred data, rather than measurement. The WARMS is incomplete and only captures registered water use. Until this registration is near completion it is never going to be a true reflection of actual water use and will therefore continue to be misleading at best. This being said, the WARMS is one of the only sources of data available that is based on actual current reporting." (DWAF, 2004g)

(b) The method for rural domestic water use is based on census figures for 2003, an estimate of groundwater reliance per village and an average consumption of 25 L/day. Depending upon the livelihood situation in the village, the value for consumption appears to be under estimated.

(c) The water use for agriculture is based on theoretical irrigation requirements and a percentage groundwater dependency of the agricultural sector, obtained from the Department of Agriculture.

APPENDIX F

DATA INVENTORY

APPENDIX F : DATA INVENTORY

Category	Description	Source
Hydrology	Quaternary catchments	WR90
	dams	CDSM
	rivers as lines	CDSM
	flow gauges from NS	WR90, NS
	stream flow records	DWAF, NS
	Digital eleveation model (DEM)	ComputaMaps
Geology	1:50K geology maps	Council for Geoscience
	1:250K geology maps	Council for Geoscience
	Bedrock topography for Cape Flats	Different sources
	Bedrock topography for West Coast	Different sources
Hydrogeology	1:500k hydrogeological map series	DWAF
	Waterlevel meters above sea level	DWAF / GRA II
	Waterlevel(mbgl) meters below grd level	DWAF / GRA II
	NLC hazard ratings	DWAF / GRA II
	Reclassified ADE vegetation zones	DWAF / GRA II
	Recharge percentage	DWAF / GRA II
	Storage coefficient	DWAF / GRA II
	Reclassified saturated thickness	DWAF / GRA II
	Transmissivity m^2/day	DWAF / GRA II
	Borehole yield	DWAF / GRA II
	Vulnerability	DWAF / GRA II
	Transmissivity m^2/day	Different sources
	Hydraulic conductivity	Different sources
	Borehole yield	Different sources
	Recharge	Different sources
	Storage coefficient	Different sources
	Porosity	Different sources
	Berg River Project Monitoring data	DWAF / R Parsons
	TMGA Hydrocensus monitoring data	CCT / Umvoto / GEOSS
	Monitoring data from Hex River Valley	Hexriver Irrigation Board
	Borehole logs, yield, depth etc.	DWAF / NGDB
	Borehole logs, yield, depth etc.	Different sources
	Borehole water level data	DWAF / NGDB
	Borehole water level data	Different sources
	Borehole chemistry monitoring data	DWAF / NGDB
	Borehole chemistry monitoring data	Different sources
	Groundwater abstraction, water use	DWAF / WARMS
	Groundwater abstraction, water use	Different sources
	Annual groundwater abstraction	DWAF / GRA II
Hydroclimatology	mean annual precipitation (mm)	Agrohydrology
	Mean annual precipitation	CCWR
	Mean annual precipitation mm/a	DWAF/GRAII
	Mean monthly evaporation	Agrohydrology
	Mean_daily_max temperature	Agrohydrology
	Median_month_rainfall	Agrohydrology
	rainfall stations	SAWS
	patched rainfall data	Ninham Shand
Land use	National Land Cover 2000	NLC 2000
	Aerial photographs	DWAF / CDSM