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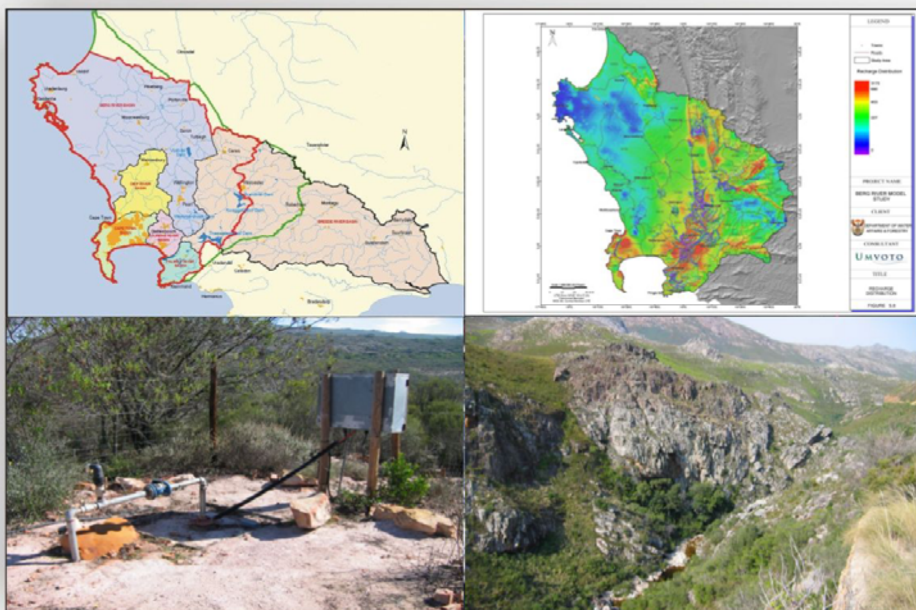
Directorate: National Water Resource Planning

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

GROUNDWATER MODEL REPORT VOL. 4
REGIONAL WATER BALANCE MODEL



Final **April 2008**

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

NINHAM SHAND CONSULTING SERVICES

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DEPARTMENT OF
WATER AFFAIRS AND FORESTRY

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

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APPROVAL

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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 4
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EXECUTIVE SUMMARY

INTRODUCTION

The Assessment of Water Availability in the Berg Catchment (WMA19) by means of Water Resource related Models (short title: Berg 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). 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.

This report is Volume 4 in the project series. Volume 3 and 4 are to be read in conjunction with each other as the conceptual model has informed the delineation of IWRM domains and the breakdown into aquifer types, as used in the water balance model.

STUDY DOMAIN

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

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

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

REGIONAL WATER BALANCE MODEL

It is imperative in this study to establish a groundwater balance that can be reasonably linked to the surface water balance. The main elements of the groundwater balance are recharge, storage and discharge, while the surface water balance comprises rainfall, run-off, evaporation and abstraction. The approach adopted in this study ensures that the input parameters for the estimation of the different components are the same as for the surface water modelling.

Storage

The storage capacity, viz. the total available storage of the different aquifers, is calculated with an in-house developed GIS model based on aquifer geometry calculated using first principles of structural geology and estimated values (based on text book and measured data) for effective porosity and storage coefficient.

The model of the aquifer storage intentionally makes use of low, geologically reasonable values for porosity and aquifer compressibility, so as to provide *minimum estimates of potential yields*. However, as new data accumulate from the TMG aquifers in the study area, these initial porosity and compressibility assumptions will probably be revised upwards.

The results indicate a storage capacity within the Peninsula Aquifer alone of 366,705 million m^3 (see **Table E-1**), which are 2 to 3 orders of magnitude higher than the capacity of the surface water storage facilities in the study domain.

Table E-1 Rock Volume vs Pore Volume for Peninsula Aquifer, given a porosity of 0.05 (5%)

Peninsula Aquifer	**Area (km^2)**	**Rock Volume (Mm^3)**	**Pore Volume (Mm^3)**
Unconfined portion	1,750.27	1,414,52	70,726
Confined portion	5,112.44	5,919,58	295,979
Whole Peninsula Aquifer	**6,862.71**	**7,334,10**	**366,705**

Recharge

Aquifer specific recharge is estimated using a GIS-based Water Balance Model that takes rainfall, run-off and evapotranspiration into account. The results are compared with other GIS models. In addition, other recharge estimation methods, such as the Chloride Mass Balance method and the Saturated Volume Fluctuation method, are applied in localised areas to compare with the regional estimation.

From the comparison of the different recharge methods, as shown in **Table E-2**, it is evident that the map-centric simulation results in very conservative estimates for the TMG aquifers, while the recharge for the intergranular-fractured and intergranular aquifers appears to be relatively high. On the other hand, the water balance method developed for the ISP studies results in high recharge to the TMG aquifers and lower recharge to the intergranular and intergranular-fractured aquifers. For comparison, the results of both methods will be used for further analysis in the water balance and yield model, as best and worst case, respectively.

Table E-2 Comparison of recharge estimations

Aquifer type	Recharge [million m^3/a]					
	Fixed %	BRBS	ISP	GRA II	Map-centric	SVF conf
Peninsula	404	406	511	433	214	384
Nardouw	140	215	275	241	196	N/a
Fractured	7	7	10	6	11	N/a
Intergranular-fractured	123	223	222	323	348	N/a
Intergranular	147	375	363	326	350	N/a
Total aquifer specific	**822**	**1,227**	**1,381**	**1,328**	**1,119**	**N/a**

Discharge

Discharge from the aquifer systems occurs as natural discharge via springs or baseflow, and as groundwater abstraction. For both, the currently available regional estimates are disaggregated into aquifer specific values, using assumptions and knowledge about distribution of discharge sites and boreholes. A comparison between the GRA II data sets on groundwater use and the WARMS database shows significant differences in both the aquifer specific distribution and the total volume (see **Table E-3**). The data from the WARMS are considered conservative and will be used in determining the groundwater potential.

Table E-3 Estimated groundwater use per aquifer

Source and Method	Peninsula Aquifer *Mm^3/a*	Nardouw Aquifer *Mm^3/a*	Other Fractured Aquifers *Mm^3/a*	Intergranular fractured Aquifers *Mm^3/a*	Intergranular Aquifers *Mm^3/a*	**Total Groundwater use** *Mm^3/a*
Disaggregating of GRA II	14.57	23.83	1.48	51.40	58.48	**149.76**
WARMS / NGDB	8.58	20.60	0.60	58.44	92.63	**180.86**

YIELD MODEL

The water balance and yield model suggests a total remaining long-term averaged groundwater potential of 741 million m^3/a within the study area, based on a comparison of the map-centric recharge estimation, baseflow and current groundwater use (see **Table E-4**). The results for applying the recharge estimation based on the water balance method developed for the ISP studies suggest a total groundwater potential of 1003 million m^3/a. Using the average of the different recharge estimations, the total groundwater potential is estimated at 869 million m^3/a. A significant part of the groundwater potential is lost either to the sea or as rejected recharge, if not utilised.

Table E-4 Summary results of groundwater potential per aquifer [million m^3/a]

Aquifer	Method	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
Intergranular	Map-centric	350	41.1	309	92.6	217
	ISP	363	36.6	327	92.6	234
	Average	**355**	**41.1**	**314**	**92.6**	**222**
Intergranular fractured	Map-centric	348	54.1	294	58.4	236
	ISP	222	28.5	194	58.4	135
	Average	**267**	**39.2**	**228**	**58.4**	**170**
Fractured	Map-centric	10.8	0.6	10.2	0.6	9.6
	ISP	9.6	0.9	8.7	0.6	8.1
	Average	**8.0**	**0.7**	**7.3**	**0.6**	**6.7**
Nardouw	Map-centric	196	43.2	152	20.6	132
	ISP	275	49.3	226	20.6	205
	Average	**226**	**46.2**	**180**	**20.6**	**159**
Peninsula	Map-centric	214	57.9	156	8.6	148
	ISP	511	81.6	429	8.6	420
	Average	**390**	**69.7**	**320**	**8.6**	**312**
Total	Map-centric	1119	197	922	181	741
	ISP	1381	197	1184	181	1003
	Average	**1247**	**197**	**1050**	**181**	**869**

However, the impact of abstraction and acceptable drawdown within the aquifer determine the groundwater yield on shorter time frames. By utilising the storage capacity of the confined portions alone, the Peninsula Aquifer can deliver a yield of between 158 and 633 Mm^3, depending upon the acceptable average drawdown of between 5m and 20m respectively.

The results of the water balance and yield model will be used as input to the WRSM and WRYM. The review of the applicability of the Sami Module (DWAF, 2007d) revealed that the module has inherent assumptions that are not met in most of the study area. There are only few catchments within the Berg WAAS area, where most of the assumptions are met and the module therefore might work. The assumptions are summarized as follows:

1. Single homogenous aquifer in catchment, with uniform gradient and isotropic parameter distribution
2. Shallow aquifer, water table near surface, that is connected to surface water body along the whole length of the river reach
3. Unconfined aquifer
4. Well-established initial water level for starting month of simulation period
5. Groundwater flows directly towards single main stem; no asymmetry in perennial tributary pattern
6. Catchment free of endorheic drainage areas.

CONCLUSIONS

A robust water balance and yield model was developed to estimate the groundwater potential from different aquifers within the study area as well as to produce reasonable values for input parameters to the groundwater modules of the WRYM and WSAM. The model is based on the following components:

- Aquifer specific recharge, calculated with a variety of GIS-based methods and compared to / verified with results from previous studies;
- Modelled overland flow, based on slope distribution, as input to the recharge model;
- Modelled evapotranspiration, using the Turc (1954) approach, as input to the recharge model;
- Storage capacity in the Peninsula Aquifer, based on three dimensional modelling of the geological structure;
- Aquifer specific natural discharge, based on groundwater contribution to baseflow and recharge per quaternary catchment;
- Aquifer specific groundwater use, based on registered use on the WARMS database;
- Storage yield for the confined portion of the Peninsula Aquifer, based on the modelled storativity and reasonable values for specific storage;
- Groundwater potential, based on recharge, baseflow and groundwater use.

RECOMMENDATIONS

The results of the Water Balance Model shows that the uncertainty of the data input as well as the applied method has a significant impact on the reliability of the output and any decision that would be based on these results. It is therefore strongly recommended to initiate a data collection and monitoring programme, as outlined below.

In addition to the data collection activities as recommended in the Data Availability Report (DWAF, 2007a) long-term monitoring should be initiated for the following aspects:

- Rainfall sampling and chemical / isotope analysis in selected recharge areas for calibration of recharge model with Chloride Mass Balance and Isotopes;
- Seasonal and event response sampling of rainfall, spring flow and groundwater for calculation of residence time and interflow/rejected recharge;
- Monitoring of key abstraction points for aquifer response to abstraction for considering the impact of existing groundwater use with regards to refining unused potential estimates;
- Monitoring of ambient boreholes in different aquifers to establish seasonal fluctuation of water levels for calibration of recharge estimation.

It is suggested to develop a comprehensive monitoring programme for the Berg WAAS area that comprises all relevant aspects in an integrated and optimised manner.

It is also evident that the groundwater – surface water interaction and the integration of groundwater potential and use into the water resource planning cannot be achieved reliably with the current groundwater modules in the Water Resources Simulation Model (WRSM) and Water Resources Yield Model (WRYM). Hence, the development of alternatives to these modules is strongly suggested that comprises:

- Applying the aquifer specific distribution of groundwater contribution to baseflow in the Pitman model
- Applying the aquifer specific storage volumes in the WRYM as per scheme spatial and operational definition.

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

GROUNDWATER MODEL REPORT VOLUME 4
REGIONAL WATER BALANCE MODEL

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ABBREVIATIONS AND ACRONYMS

ASR	Aquifer storage and recovery
BRHS	Breede River Hydrological Study
CAGE	Citrusdal Artesian Groundwater Exploration
CDSM	Chief Directorate: Survey and Mapping
CMA	Catchment Management Agency
CRD	Cumulative Rainfall Departure
CSIR	Council for Scientific and Industrial Research
CVA	Change Vector Analysis
CWSS	Community Water Supply and Sanitation
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
EVT	Evapotranspiration
FAO	Food and Agricultural Organisation
FE	Finite Element
GIS	Geographical Information System
GRA	Groundwater Resources Assessment
IFR	Instream Flow Requirements
ISP	Internal Strategic Perspective
IWR	Integrated Water Resources
IWRM	Integrated Water Resources Management
km	kilometre
LRA	Langebaan Road Aquifer
Ma	Million annums
m	metre
mamsl	metres above mean sea level
MAP	Mean annual precipitation
MAR	Mean annual run-off
MOF	Modelled overland flow
N-S	north-south
NEMA	National Environmental Management Act
NEMP	National Eutrophication Monitoring Programme
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
SAWS	South African Weather Service
SFRA	streamflow reduction activities

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
VAS	Voëlvlei Augmentation Scheme
VHIMS	Vaal Hydrological Information Management System
WAA	Water Availability Assessment
WAAS	Water Availability Assessment 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
WRYM	Water Resources Yield Model
WR	Water Resources
WSAM	Water Situation Assessment Model

Codes for IWRM domains

ATL	Atlantis IWRM Domain
AWT	Agter-Witzenberg IWRM Domain
BRV	Brandvlei IWRM Domain
CFP	Cape Flats - Peninsula IWRM Domain
HEX	Hex River IWRM Domain
KGB	Kogelberg IWRM Domain
NUY	Nuy River IWRM Domain
PKT	Piketberg IWRM Domain
PUB	Paarl – Upper Berg IWRM Domain
RBT	Robertson IWRM Domain
THK	Theewaterskloof IWRM Domain
TWR	Twenty-four River IWRM Domain
VVT	Voelvlei – Tulbagh IWRM Domain
WBK	Warm Bokkeveld IWRM Domain
WCT	West Coast IWRM Domain

Codes of Pitman Model Parameters

FT	Pitman Model Parameter
POW	Pitman Model Parameter
SL	Pitman Model Parameter
ST	Pitman Model Parameter
ZMAX	Pitman Model Parameter
ZMIN	Pitman Model Parameter

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) initiated two major water resource management and planning undertakings in the environment of the WCWSS:

a. Compulsory licensing in terms of the National Water Act (NWA) - Act 36 of 1998 - is due to be piloted in the Berg WMA, in response to concerns that growing water user demands, as well as stream flow salinity increases, might place parts of the WCWSS in a water-stress condition during the foreseeable future.
b. A Reconciliation Strategy Study was completed in 2007, 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.

The Berg 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, 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.
- 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.

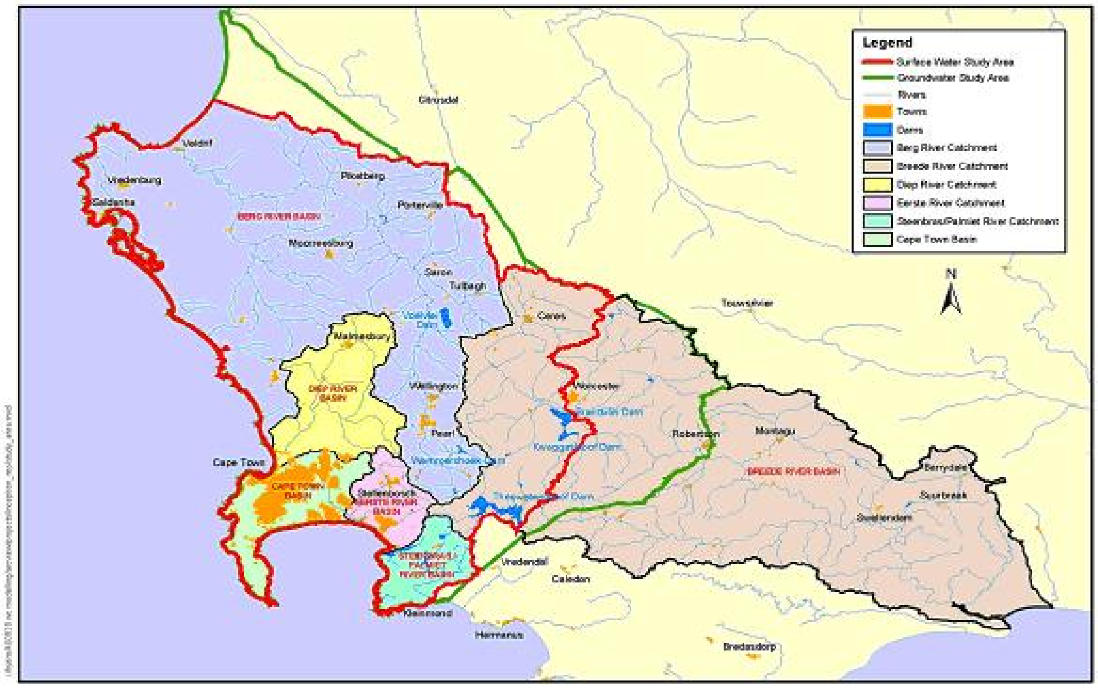


Figure 1-1: Study Area Locality

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 Water Management Area (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 North-South and East-West 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, 2004) 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 two dimensional (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 three dimensional (3D) problem in the study domain.

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

- total quantity 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 activities impact on the resource from a source directed and a water quality 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 may 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 4 of the groundwater model report and documents the model results of Task 12 and Task 15. It should be read in conjunction with Volume 3 (DWAF, 2007b), which describes the study area and conceptual model.

1.2 REGIONAL WATER BALANCE REPORT

The ultimate purpose of the present Berg WAAS modeling study is to provide a sound quantitative basis for resource assessment into the future. The Groundwater Resource Assessment Phase II (GRA II) project (DWAF, 2005b; -, 2005c; -, 2006b; -, 2006c; -, 2006d) proposed a general methodology for groundwater resource evaluation in order to provide an estimate of groundwater potential on a national scale. For generic estimates and broad based planning it is possibly adequate.

However, as described in more detail in Volume 2 (DWAF, 2007a) and Volume 3 (DWAF, 2007b) of this report, the methodology and data sets from the GRA II project are not completely applicable to the aquifers in the Cape Fold Belt, which cover most of the area in the Berg and Breede WMAs. It is therefore required to develop and apply an alternative methodology for groundwater resource evaluation on a regional scale.

1.2.1 Purpose of this Volume

The primary purpose of this volume is to describe the development and results of the regional groundwater balance model at the scale of the study domain. Although the modelling scale is the whole study domain, the results will be aggregated on an aquifer specific basis to quaternary catchment and or IWRM domain scale, as defined in Volume 3 (DWAF, 2007b).

A refinement of the aquifer specific water balance at the scale of selected IWRM and model domains will be undertaken and reported on in subsequent report volumes for this study (see above). These reports will provide an overview of water availability and identification of stressed catchments and aquifers once integrated with the comparable results from surface water models.

The output from this model suite will be:

- First-order results of aquifer recharge, storage, discharge and abstraction:
- GIS-based recharge estimation on an aquifer specific basis or per aquifer per quaternary catchment.
- Model estimation of natural aquifer discharge on an aquifer-specific basis or per aquifer per quaternary catchment.
- Estimation of aquifer abstraction using WARMS or related data, and possible identification of inaccuracies in this database.
- Estimation of storage capacity using geological knowledge.
- Identification of un- or under-utilised groundwater storage options as well as areas vulnerable to over-abstraction.
- Identification of key data gaps and uncertainties in quaternary-scale resource evaluation.

1.2.2 Structure of this Volume of the Report

This volume of the report is structured into eight sections with several sub-sections each.

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

Section 2 provides a general description of the regional model domain in terms of topography, drainage, hydroclimatology, hydrogeology and water use.

Section 3 describes the general approach and methodology adopted in this study for the water balance model.

Section 4 describes the storage model methodology and results for the TMG aquifers

Section 5 describes the aquifer specific recharge models.

Section 6 describes the approach to and results of the discharge estimation, which includes both the natural discharge via springs and along rivers and the groundwater abstraction.

Section 7 uses the principles and results described in the previous chapters to give a first order estimate of aquifer yield and potential.

Section 8 summarizes the conclusions and recommendations.

2. GENERAL DESCRIPTION OF THE STUDY AREA

A detailed description of the study domain, its physiography, hydrology, hydroclimatology and geology, is given in Volume 3 of this report (DWAF, 2007b). The following section gives a summary description as relevant to the purpose of this report. In addition further analysis is reported on.

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

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

2.1 TOPOGRAPHY

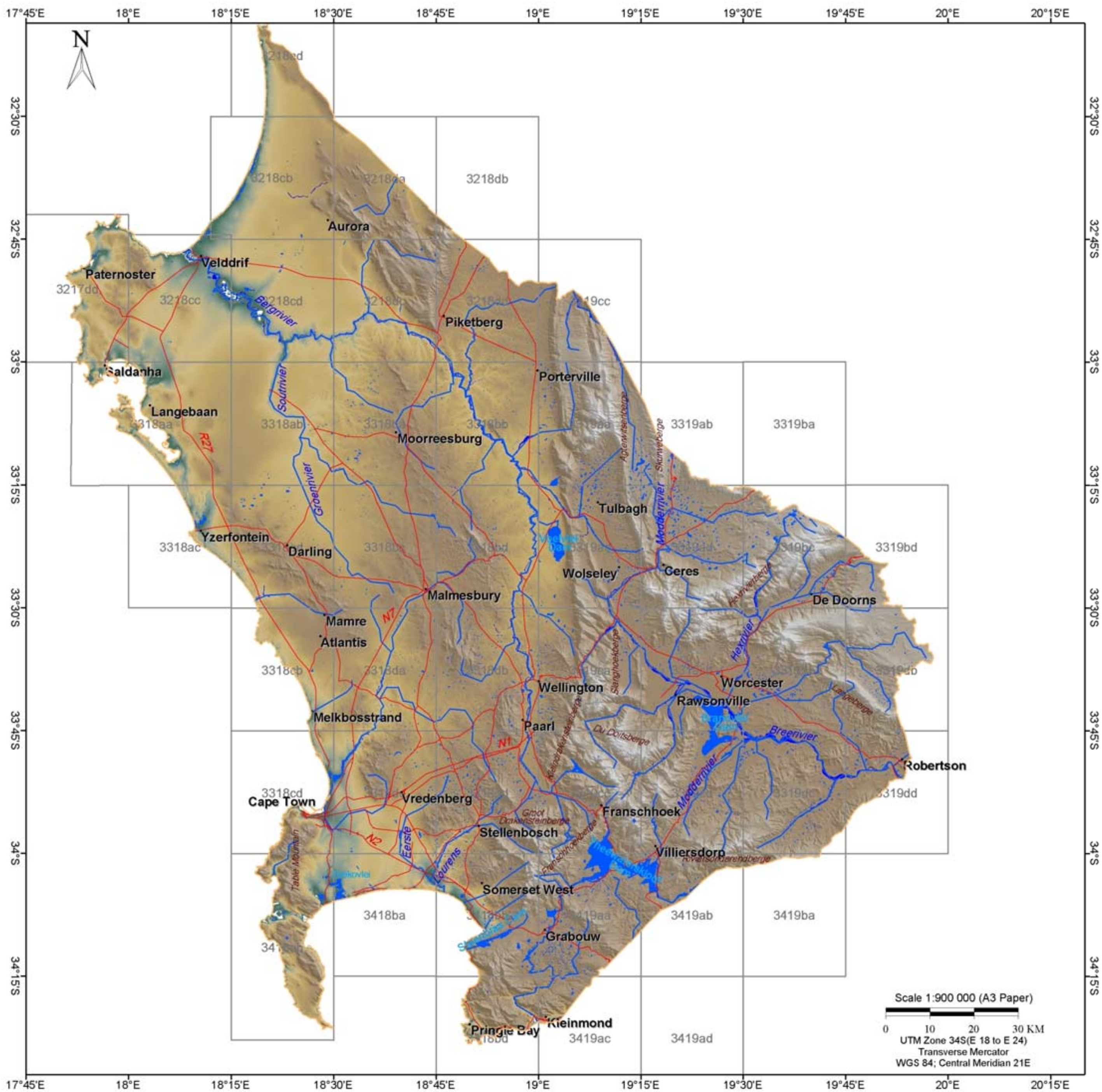
The topography of the study area in the east varies greatly from that in the west (**Figure 2.1**). The high and rugged mountains and valleys of the Table Mountain Group (TMG)-dominated Cape Fold Belt and their foreslopes define the eastern area. These extend the full length of the study area in the east, and grade westwards into the lower rolling hills of the Swartland, underlain by the Malmesbury Group bedrock. Between the Swartland and the Atlantic Ocean is the flat coastal plain known as the Sandveld. In the northeastern portion of the study area, north of the Swartland, the Piketberg range is a TMG outlier that separates the Boland from the Sandveld. In the extreme southwest, the study area also covers the Cape Peninsula, another outlier of the TMG rocks.

The Sandveld topography is characterized by extensive endorheic and ephemeral drainages due to the dominance of aeolian processes and parabolic dune formation in its recent (i.e. post-late Pliocene) geological history.

2.1.1 Slope Analysis

A model of slope gradients was produced (**Figure 2-2)** from the high-resolution (20 m pixel resolution) digital elevation model. At this scale, the areas of moderate (~30-50°) and high (>50°) slope angle are associated with TMG-dominated areas, in the ranges of the Cape Fold Belt, and also the Peninsula (G22A-B), Piketberg (G10K-G30D) and Riebeeck Kasteel (G10F-G21C) outliers.

As discussed in **Section 4.2.3** below, the slope angle θ is an important factor determining the run-off potential for individual slope elements in the digital slope model, and is used in the derivation of an overland-flow relationship within particular subcatchments and IWRM domains.



LEGEND

- Towns
- Roads
- Major Rivers
- Dams
- 1:50 000 Toposheet

Elevatiom (mamsl)

2101
1401
1167
934
700
467
233
0

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

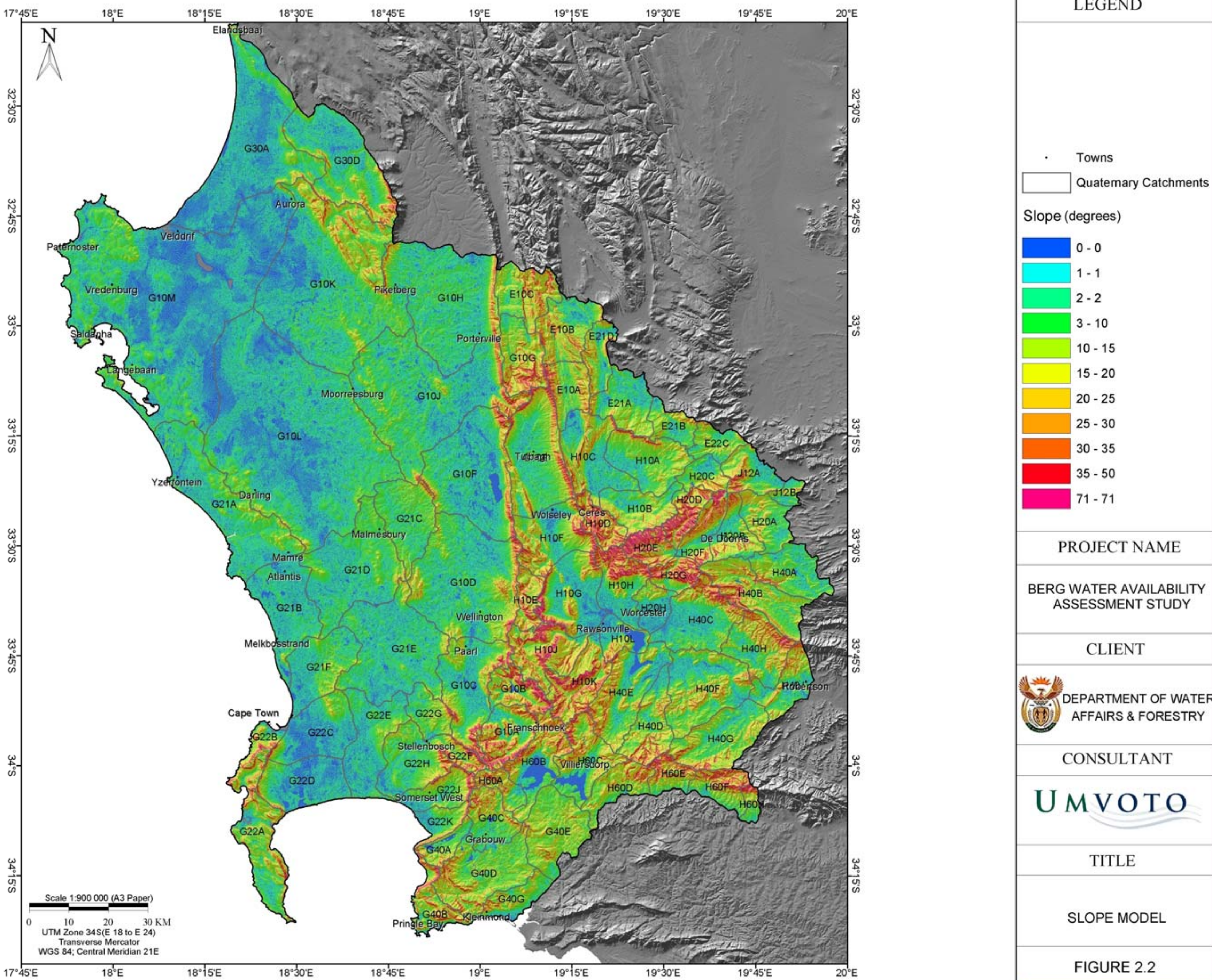
CONSULTANT

UMVOTO

TITLE

TOPOGRAPHY AND INFRASTRUCTURE

FIGURE 2.1



PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

SLOPE MODEL

FIGURE 2.2

2.1.2 Slope Histograms

The spatial distribution of slope varies widely within the study domain. This is easily and visually evident from the topography (**Figure 2-1**) and the slope model (**Figure 2-2**). The statistical analysis of the slope distribution shows a log-normal distribution, while the cumulative histogram depicts a general exponential function (**Figure 2-3**) indicating a high percentage of flat areas and fewer areas of steep slopes. The median slope is ~2.5 degrees and the maximum slope (based on the slope model) is 74 degrees.

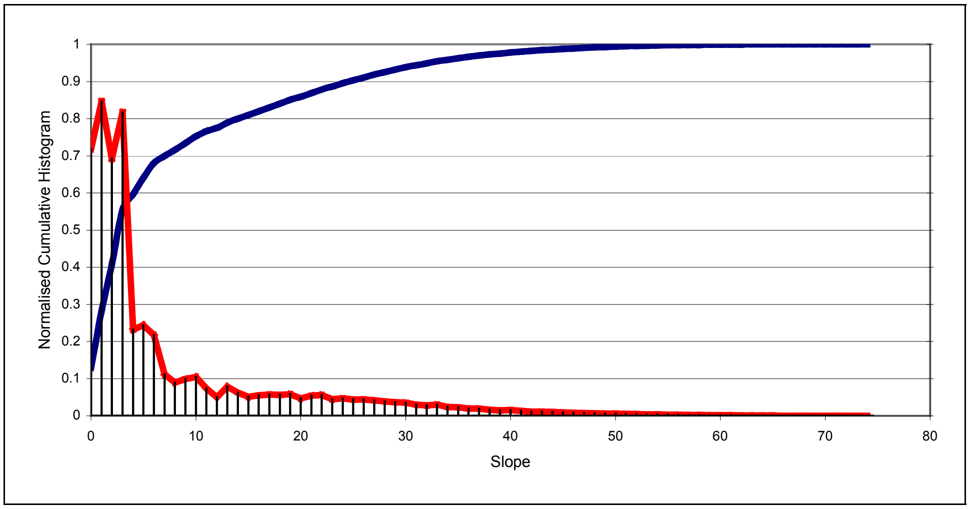


Figure 2-3 Slope distribution in study area; Histogram (red curve) and Normalised Cumulative Histogram (blue curve)

The statistical analysis of the slope distribution and its relationship to geology, hydroclimatology as well as hydrology and hydrogeology is considered relevant, since slope is one of the main factors determining run-off. **Figure 2-4** shows the relationship between mean and maximum slope per catchment and the run-off efficiency (after WR90; Midgley et al, 1994). Although this relationship is not sufficient to generate a direct formula for calculating run-off from the slope distribution, it clearly shows the general dependency between the two factors.

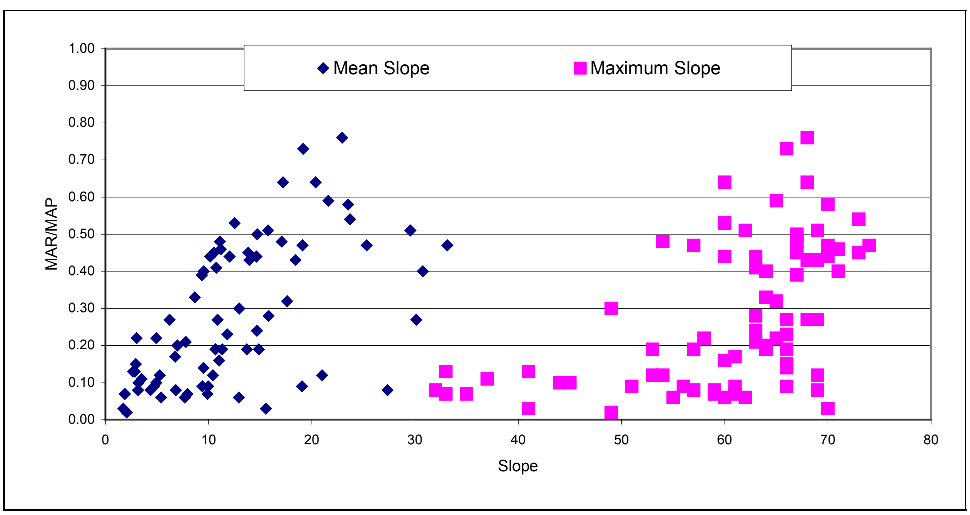


Figure 2-4 Mean Slope and Maximum Slope vs. Run-off Efficiency (WR90)

The shape of the cumulative histogram varies significantly between different catchments. Based on different slope distribution, the catchments can be grouped into up to 10 distinctive groups, numbered from Group 1 for predominantly steep areas to Group 9 with predominantly flat areas; Group 0 comprises catchments with a bimodal distribution. Further analysis showed that the catchments in Group 7 also have a bimodal slope distribution. The different normalised cumulative histograms are shown in **Figure 2-5**.

The spatial distribution of these groups is shown in **Figure 2-6**, highlighting the relationship between slope distribution and topography. However, it also illustrates that catchment boundaries do not necessarily align with geological and earth-process boundaries. This is especially obvious in the Breede River valley and the Piketberg area, both of which are within the bimodal groups 7 (Piketberg) and 0 (Breede River valley). The bimodality in these catchments arises from a combination of large flat areas and steep mountain ranges, such as found in the Breede River valley with the Du Toits mountain range in the south (H10G, H10L) and the Hexriver mountain range in the north (H10H) or the lower Berg River catchment with the Piketberg in the north (G10K).

Group 1 comprises small catchments in the Hex River Mountain chain, including the head waters of the Sand River (H20D, H20E). These catchments are characterised by steeply incised valleys (average slope of about 30°) within a high mountain range and contain very few flat areas.

Group 2 comprises the catchments of the Slanghoekberge (H10E) and Du Tois Berge (H10J and H10K), and is characterised by high mountain peaks and steeply incised valleys, but less steep than Group 1 (average slope of about 25°).

Group 3 comprises the catchments in the Hottentots Holland Mountain range and include the headwaters of the Wemmershoek (G10B), Berg River (G10A), Riviersonderend (H60A) and Jonkershoek (G22F). Other catchments include the Table Mountain (G22B) and the Twenty-Four River (G10G). These catchments are characterised by high mountains with larger flat areas, either in the valleys or as mountain plateaus.

Group 4 and 5 comprise a variety of catchments with a mixed character, mostly situated downstream of catchments of Group 1 to 3. These catchments consist of mountain ranges with lower slopes and larger flat areas.

Group 6 comprises catchments with low slopes along steeper mountain ranges, especially in the head waters of the Breede River (H10A) and the adjacent catchments in the Tankwa Karoo (E21A, E21B, E22C).

Group 7 comprises mainly the catchments of the Middle Berg and Piketberg, as well as the Hex River confluence with the Breede River (H20H). These catchments are all characterised by large flat areas, but show a bimodal character in that they also comprise a component of very steep slopes, mainly along TMG outcrops.

Group 8 comprises the catchments of the Diep River and the Cape Flats with large flat areas and the rolling hills of the Malmesbury outcrops.

Group 9 comprises the coastal catchments G30A, G10L, G10M and G21B that are characterised by very flat areas and few undulating hills due to bedrock outcrop (highest slope of 50°).

Group 0 comprises the catchments of the Breede River valley (H10G, H10H, H10L and H40C), showing a distinct different slope distribution with a bimodal character, indicating that at least two different physiographic settings, viz. large flat areas in the valley and steep mountain ranges at the catchment boundaries, are combined within each catchment.

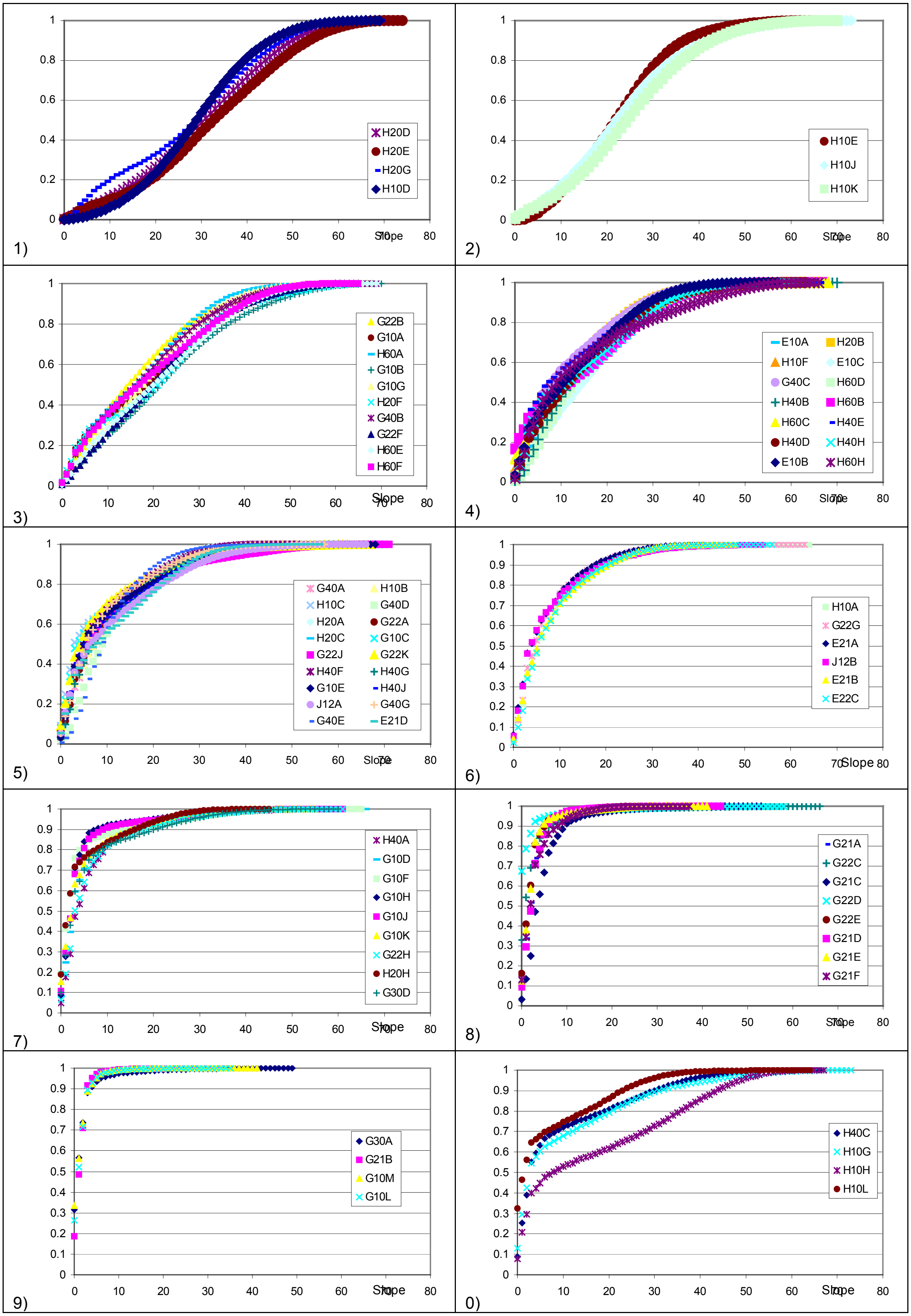
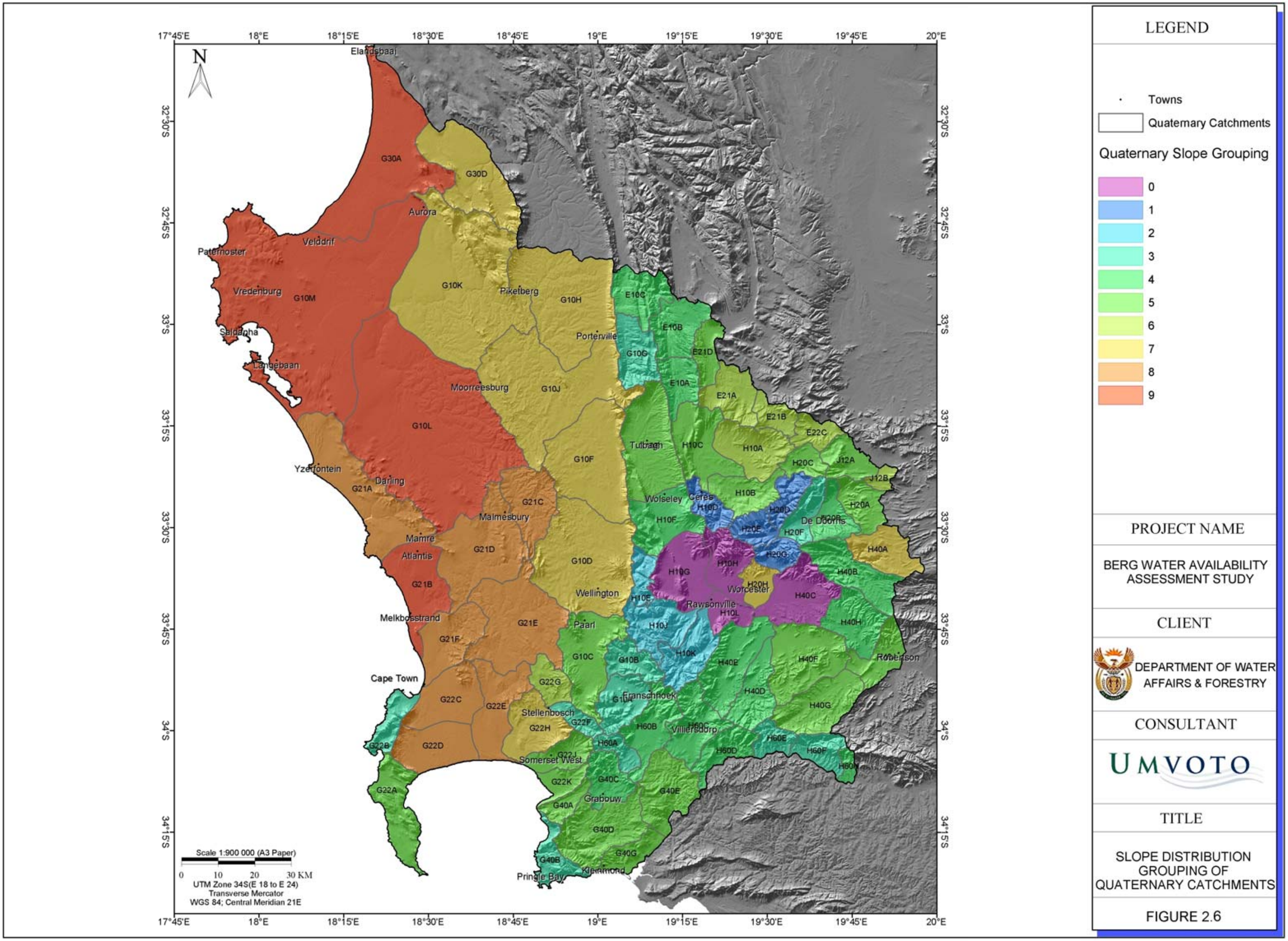


Figure 2-5 Slope distribution for groups 1 – 9 and 0



LEGEND
Towns
Quatemary Catchments
Quaternary Slope Grouping
0
1
2
3
4
5
6
7
8
9
PROJECT NAME
BERG WATER AVAILABILITY ASSESSMENT STUDY
CLIENT
DEPARTMENT OF WATER AFFAIRS & FORESTRY
CONSULTANT
UMVOTO
TITLE
SLOPE DISTRIBUTION GROUPING OF QUATERNARY CATCHMENTS
FIGURE 2.6
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
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
32°30'S
32°45'S
33°S
33°15'S
33°30'S
33°45'S
34°S
34°15'S
Elandsbaai
Aurora
Veldrif
Paternoster
Vredenburg
Saldanha
Langebaan
Piketberg
Porterville
Moorreesburg
Tulbagh
Yzerfontein
Darling
Malmesbury
Mamre
Atlantis
Wolseley
Ceres
De Doorns
Wellington
Worcester
Rawsonville
Melkbosstrand
Paarl
Robertson
Cape Town
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Grabouw
Pringle Bay
Kleinmond
G30A
G30D
G10K
G10M
G10H
G10J
G10L
G10F
G10D
G10C
G10G
G10B
G21A
G21B
G21C
G21D
G21E
G21F
G22A
G22B
G22C
G22D
G22E
G22F
G22G
G22H
G22J
G22K
G40A
G40B
G40C
G40D
G40E
G40G
E10A
E10B
E10C
E21A
E21B
E21D
E22C
J12A
J12B
H10A
H10B
H10C
H10D
H10E
H10F
H10G
H10H
H10J
H10K
H10L
H20A
H20B
H20C
H20D
H20E
H20F
H20G
H20H
H40A
H40B
H40C
H40D
H40E
H40F
H40G
H40H
H60A
H60B
H60D
H60E
H60F

As described in detail in the Conceptual Model Report (Volume 3; DWAF, 2007b), the concept of IWRM domains accounts for both the surface water processes and the groundwater processes. 15 distinct IWRM domains were defined (see **Figure 2-7** and **Table 2-1**).

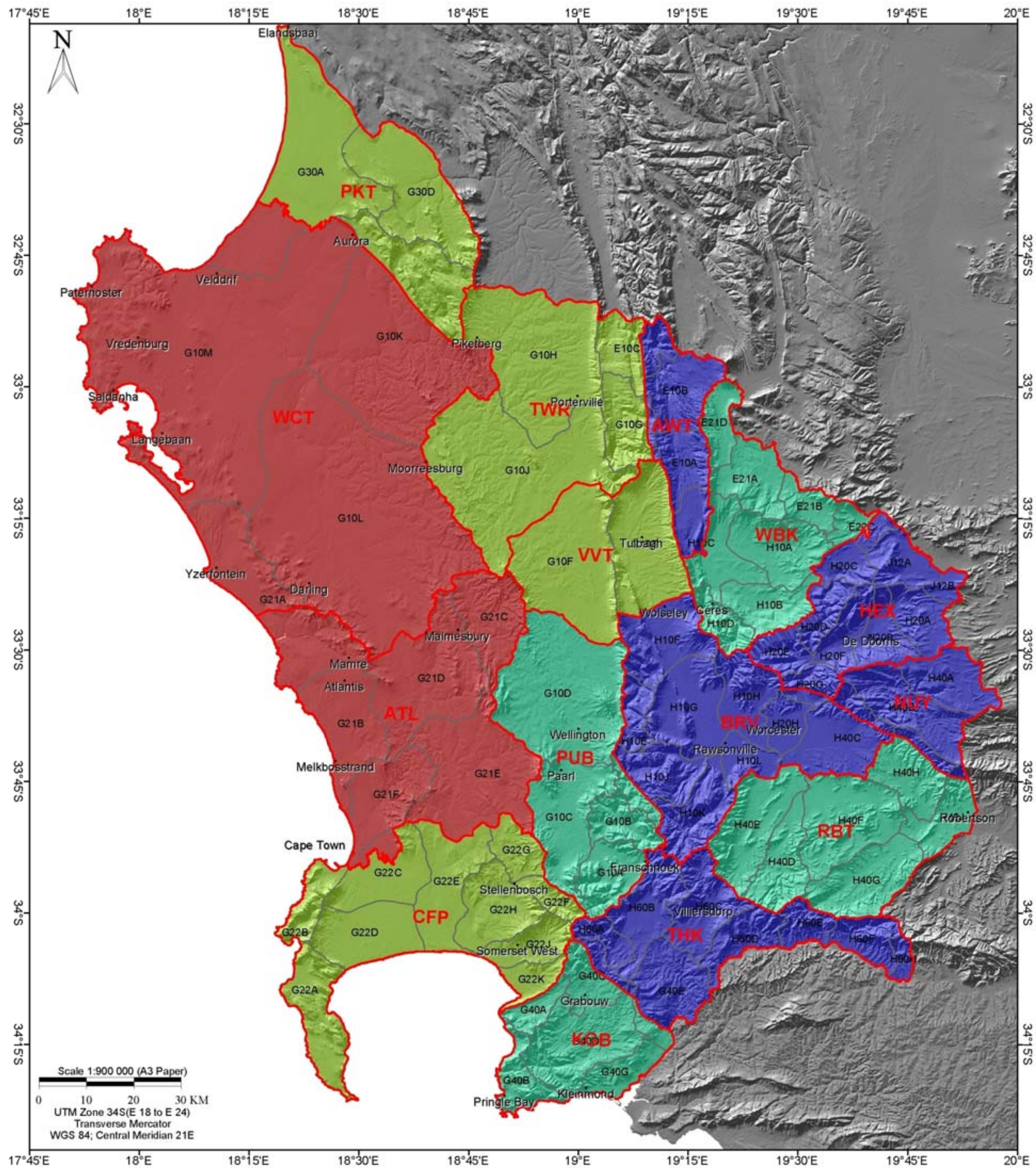
Table 2-1 IWRM Domain Classification

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

Based on the spatially averaged slope distribution throughout an IWRM domain, 4 distinct IWRM groups can be identified, as shown in **Figure 2-8**:

- IWRM Group A comprises largely quaternary catchments of Group 1, Group 2, Group 4 and Group 0 character in Peninsula dominated, high lying mountains with steep slopes in the Hex River, Agter Witzenberg, Nuy, Brandvlei and Theewaterskloof IWRM domains.
- IWRM Group B comprises largely quaternary catchments of Group 3, Group 5 and Group 6 character in mountains dominated by both Peninsula and Nardouw, surrounding the Group A areas in the Kogelberg, Warm Bokkeveld, Paarl-Upper Berg and Robertson IWRM domains.
- IWRM Group C comprises largely quaternary catchments of Group 7 and Group 8 as well as some catchments of Group 3 and Group 5 character in the TMG outliers in PKT and CFP as well as the western limb of the Cape Fold Belt in the 24 Rivers and Voëlvlei-Tulbagh IWRM domains.
- IWRM Group D comprises largely quaternary catchments of Group 8 and Group 9 character in the dominantly flat coastal areas in the West Coast and Atlantis IWRM domains.

The relationship between slope frequency and aquifer type is further discussed in Section 2.3.3.



LEGEND

· Towns

Quatemary Catchments

IWRM Slope Grouping

A

B

C

D

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

SLOPE DISTRIBUTION GROUPING OF IWRM DOMAINS

FIGURE 2.7

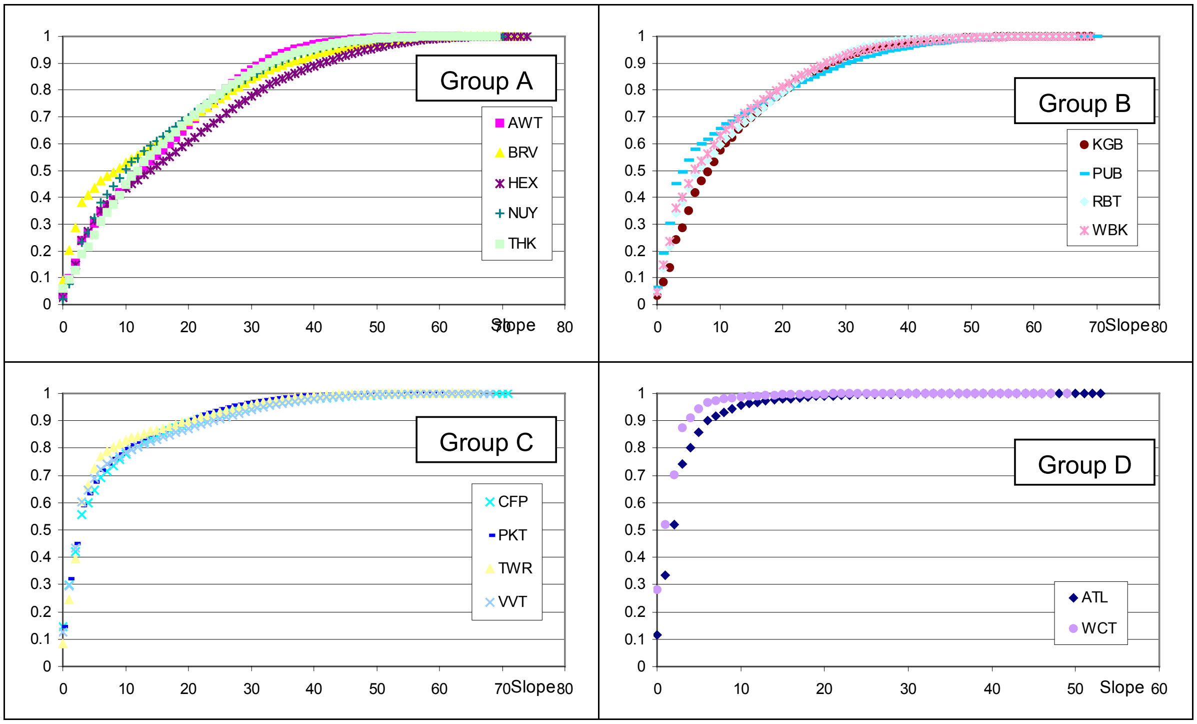


Figure 2-8 Slope distribution per group of IWRM domains

2.1.3 Terrain Roughness

From the 3-arc-second (~90 m) resolution digital elevation model obtained from the Shuttle Radar Topography Mission (SRTM-03 model), a terrain roughness map was constructed in the following steps:

(a) the SRTM-03 data covering the study area are smoothed using a 21 x 21 Gaussian filter;

(b) the smoothed Digital Elevation Model (DEM) is subtracted from the original data, and

(c) the result is squared to remove negative values.

As the horizontal dimension of the low-pass filter is roughly 2 km, the resulting map provides a measure of terrain roughness at the kilometric scale.

The Gaussian filter that was used for smoothing the SRTM data consisted of a 21 x 21 matrix of values between 0.01 and 1 in a 2D Gauss normal distribution (see **Figure 2-9**). The spatial filter operation calculates a weighted average of the cell value for each cell using the weighting factors assigned in the matrix. The weight factors are calculated for a Gaussian bell by

$$\mathbf{W(x,y) = e^{-a}}$$

with

$$\mathbf{a = (x^2\ y^2)/(2r^2)}$$

where x and y are cell numbers and r is the standard deviation sigma (i.e. 0.465).

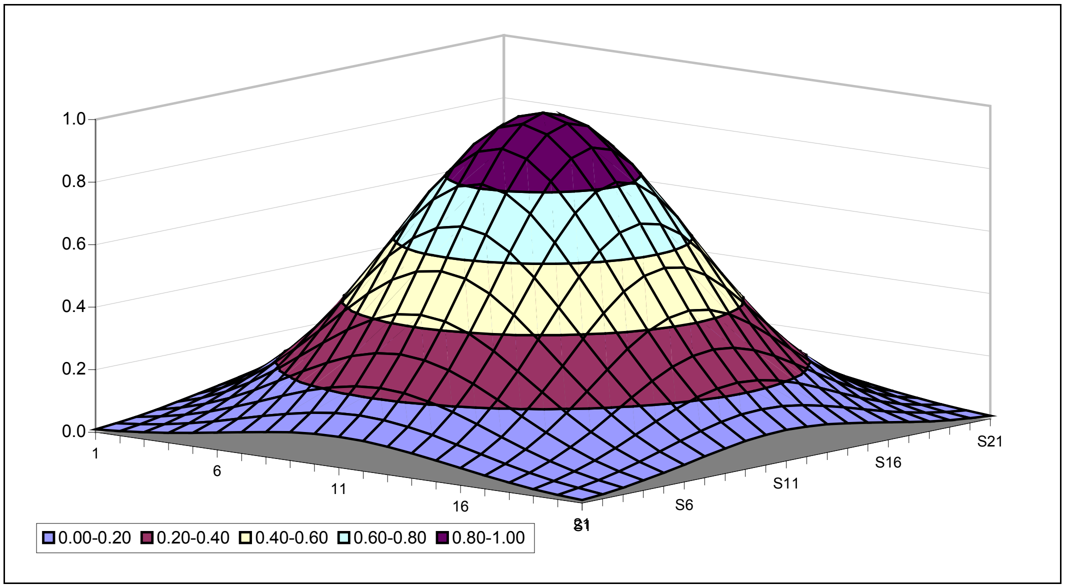


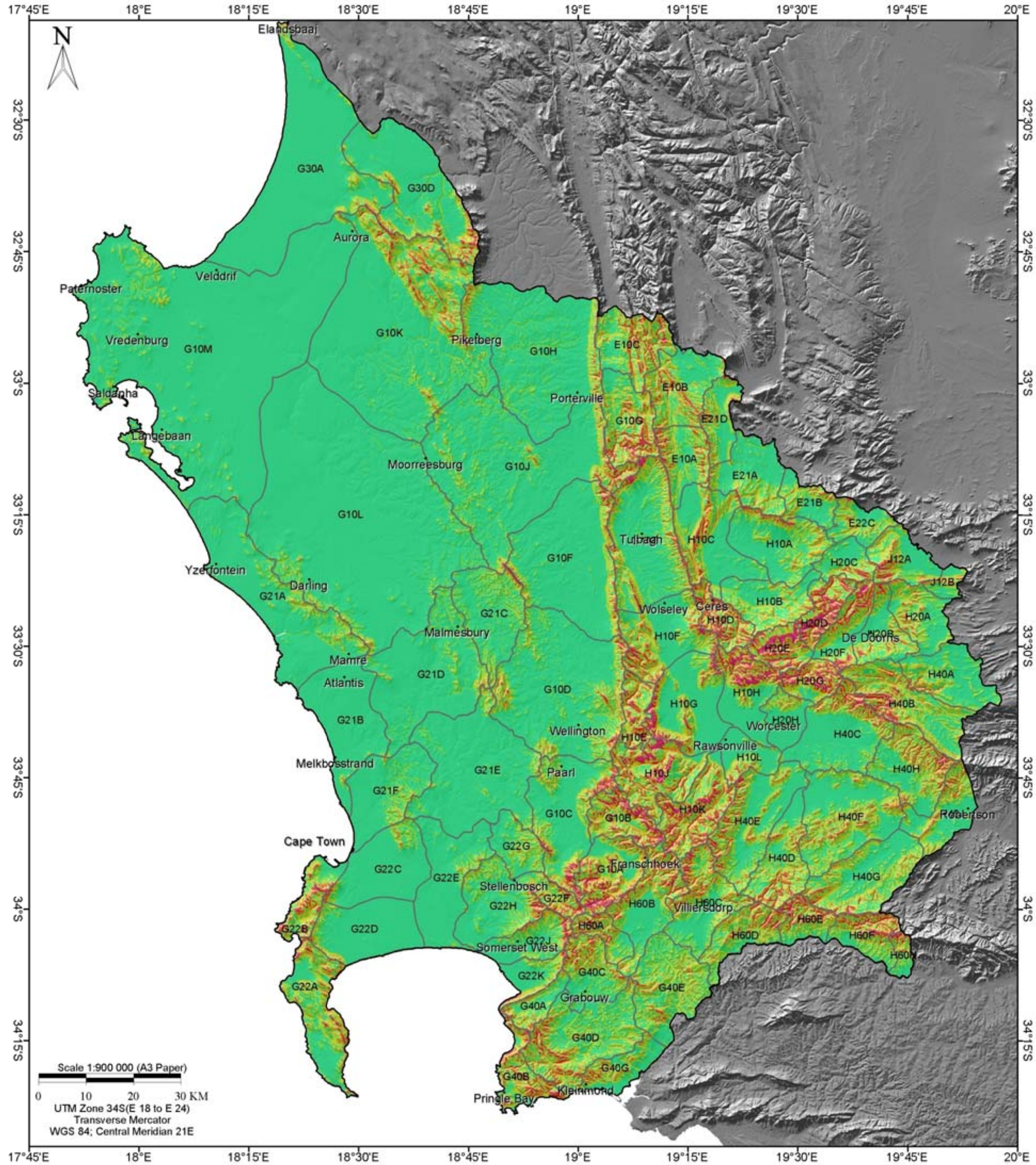
Figure 2-9 Value distribution of Gaussian filter in 21 x 21 matrix

As expected the map clearly shows that the roughest terrain is located in the TMG-dominated, high-mountain areas, which are also the areas of higher orographic rainfall (**Figure 2-10**). The intuitive expectation is that recharge and/or run-off relationships may be affected by terrain roughness, and that a roughness index may be useful in the derivation of run-off model relations in the subcatchments and IWRM domains of the study area.

In addition the relative relief was calculated from the Digital Elevation Model (DEM), following the steps a) and b) above, but omitting step c), to obtain a distinction between areas above and areas below the smoothed surface. The result is a map similar to the terrain roughness map showing positive values in the high mountain peaks and negative values in the valleys.

The relative relief clearly indicates areas within the valleys that can be considered discharge areas. For the application in the run-off and recharge model these areas are delineated with a threshold value of –40 (**Figure 2-11**), as this appears to be the best fit across the study domain. The recharge in these areas is then set to zero, as it is assumed that no recharge occurs in these clearly delineated discharge areas.

Similarly, areas outside of these discharge zones are considered recharge areas with the areas of positive relative relief, i.e. highlying and rough terrain, contributing most probably higher recharge, as these areas also coincide with the high rainfall areas.



LEGEND

· Towns

Quaternary Catchments

Terrain Roughness

65000
10263
6842
3421
0

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

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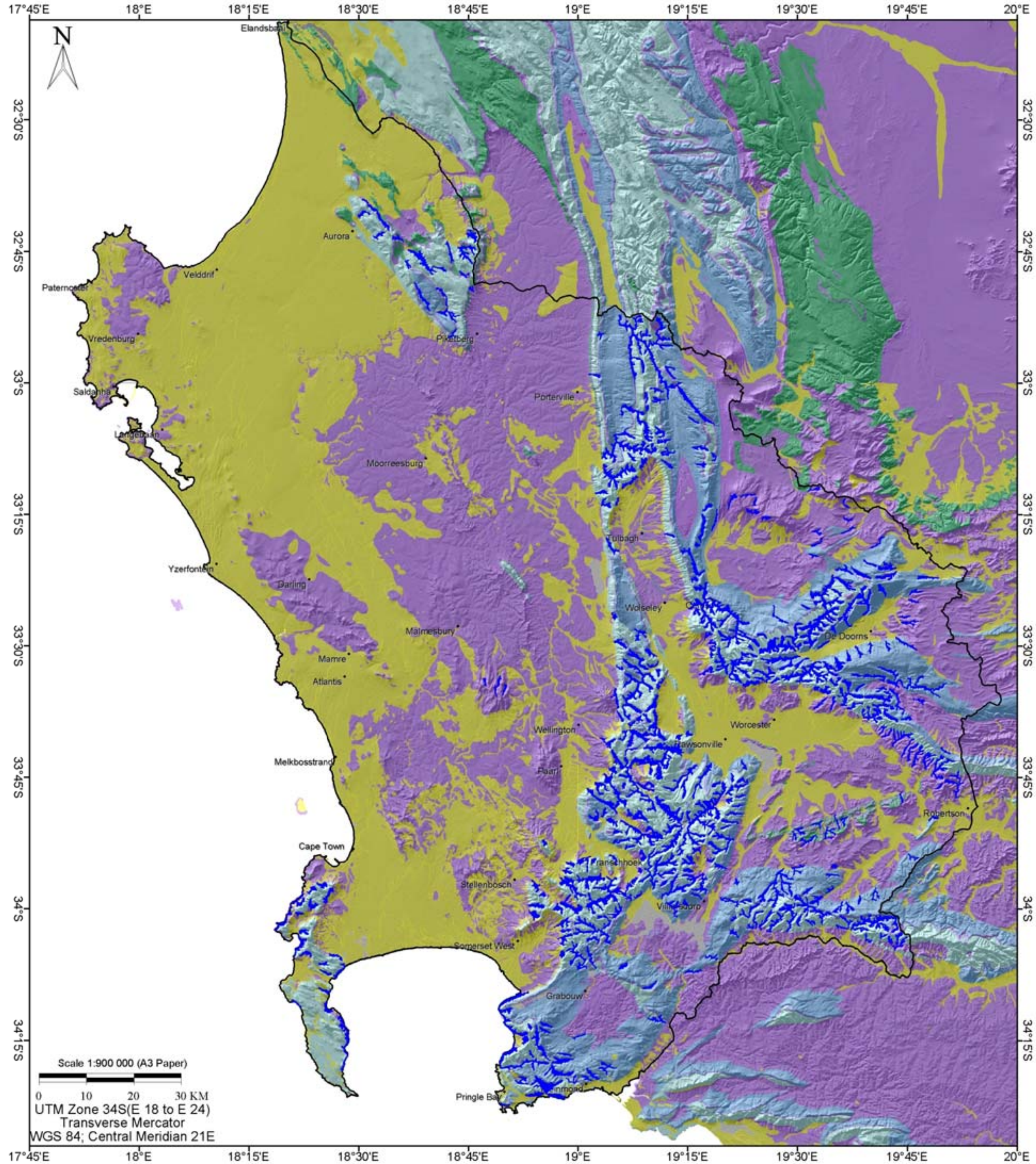
UMVOTO

TITLE

TERRAIN ROUGHNESS

FIGURE 2.10



LEGEND

- Towns
- Relative Relief
- Dam

AQUIFER TYPES

- Intergranular
- Fractured
- Intergranula Fractured
- Nardouw
- Peninsula

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

RELATIVE RELIEF

FIGURE 2.11

2.2 HYDROLOGY AND HYDROCLIMATOLOGY

2.2.1 Hydrology

The Berg WMA comprises the G10, G21, G22 and G40 tertiary catchments. The parts of the study area in the Breede WMA fall within the H10, H20, H40 and H60 tertiary catchments (see **Figure 2-12**). The northern boundary of the study domain falls within the Olifants Doorn WMA and straddles the G30, E10, E21 and E22 catchments.

The G10 tertiary catchment covers the Berg River catchment from its source in the Groot Drakenstein Mountains to the Berg River mouth at Laaiplek on the West Coast. Main storage reservoirs in the Berg River catchment include the Wemmershoek and off-channel Voëlvlei dams, while the construction of the Berg River Dam near Franschhoek was completed in 2007 (DWAF, 2005a).

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

The southern and southwestern areas of the study are within the Berg WMA but the rivers drain primarily southwards into the Indian Ocean and comprise the G22 and G40 tertiary catchments. The larger rivers in G22 also known as the Cape Town Basin (DWAF, 2005a) are the Eerste River, the Lourens River and Sir Lowry's Pass River which drain into False Bay. The Eerste River has tributaries originating in the Jonkershoek Mountains and transects the Cape Flats west of Stellenbosch, while the latter two rivers have their headwaters in the Hottentots Holland Mountains and drain into False Bay east of the Strand.

The Steenbras River and the Palmiet River fall within the G40 tertiary catchment and flow in a westerly direction to the Indian Ocean. The head waters of the Palmiet River are in the Hottentots Holland Mountains, close to the origin of the Jonkershoek, Upper Berg and Riviersonderend. The Upper and Lower Steenbras dams are situated in the catchment.

The Breede River originates in the Ceres Valley and flows in a southeasterly direction until its confluence with the Hex River (H20 catchments) near Worcester (DWAF, 2005a). The H10 catchments comprise the Upper Breede River upstream of the Brandvlei Dam, while the H40 catchments comprise the middle Breede and its tributaries. The Riviersonderend (H60 catchments) however has its origins in the Groot Drakenstein and Franschhoek Mountains and flows eastward into Theewaterskloof Dam, which falls within the study area.

2.2.2 Hydroclimatology

The study area experiences a typical Mediterranean climate with moderate temperatures and winter rainfall. Hydroclimatology data is further addressed in Volume 2 of this report (DWAF, 2007a) and in the area specific modelling reports. Key hydroclimatology data and patterns used in the regional water balance model are discussed and illustrated below.

Precipitation

As can be expected in an area where the rainfall is orographically controlled and the altitude range is from 0 mamsl in the west and the south to a maximum of 2249 mamsl on the Matroosberg Peak in the northeast, the Mean Annual Precipitation (MAP) varies significantly across the study area. It is highest in the high mountains in the east where the average rainfall is greater than 1000 mm/a, while it is less than 200 mm/a along the flat-lying coastal plain.

As illustrated in Volume 2 (DWAF, 2007a), it was required to develop a revised spatial distribution of MAP, based on additional rainfall data and rainfall stations (DWAF, 2007c). The revised MAP distribution as shown in **Figure 2-13** is used in this study.

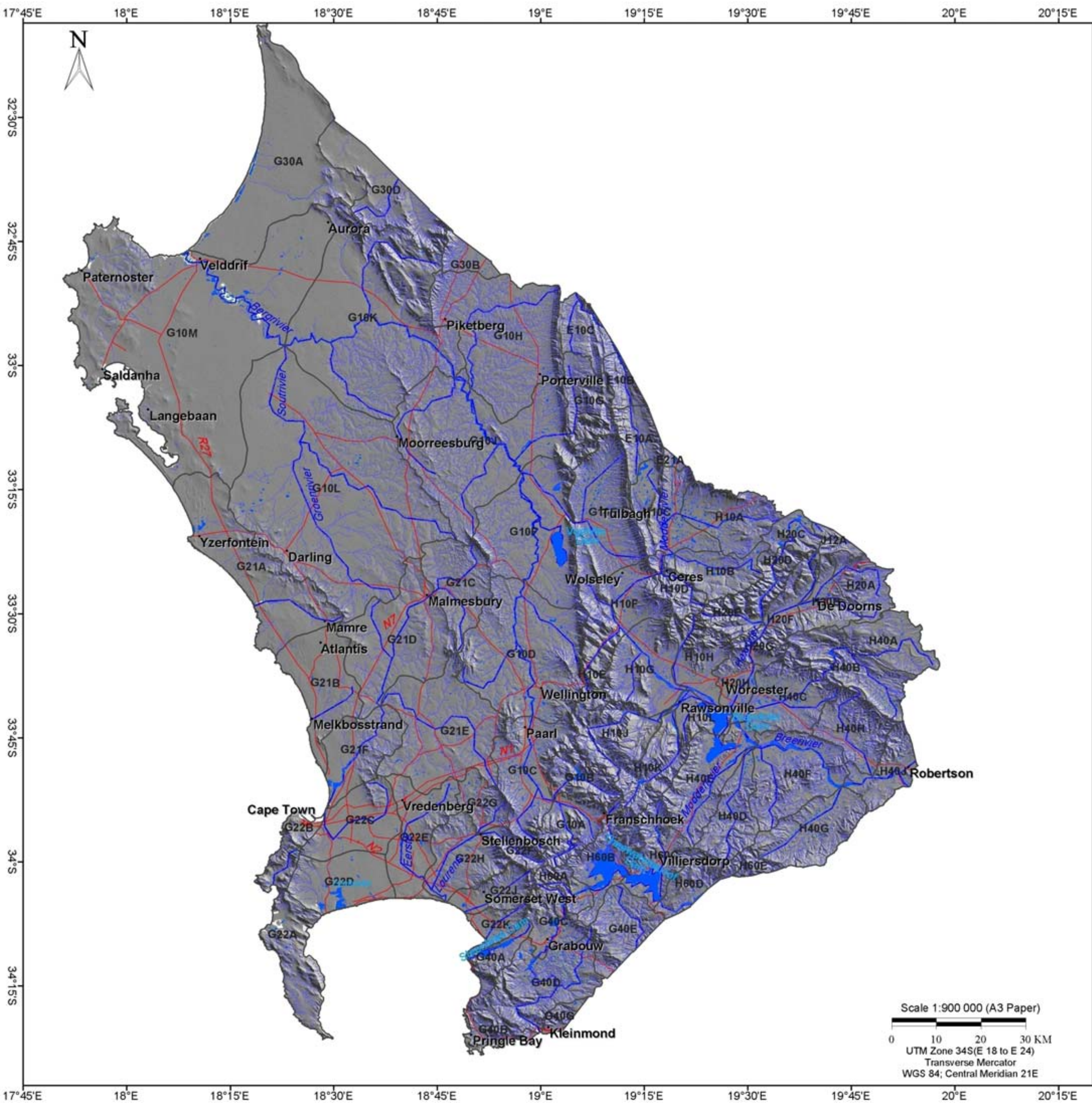
The seasonal pattern of rainfall is critical in the estimation of recharge since the aquifers are recharged in winter when the temperature and therefore evapotranspiration are also very low.

Run-off

The mean annual run-off (MAR) parallels the trend of mean annual rainfall with most river flow originating in the high-lying mountains. More than 200 mm of water is discharged as run-off in these mountains every year. These values decrease towards the coast to less than 5 mm of run-off per annum. The MAR values per quaternary catchment, as published in the WR90 report (Midgley et al., 1994a), are documented in Appendix A. These are currently updated in the WR2005 study, and preliminary results for the G and H basins are used in conjunction with the WR90 values. Appendix A contains a comparison of the different MAP and MAR values.

Evaporation

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



LEGEND

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

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

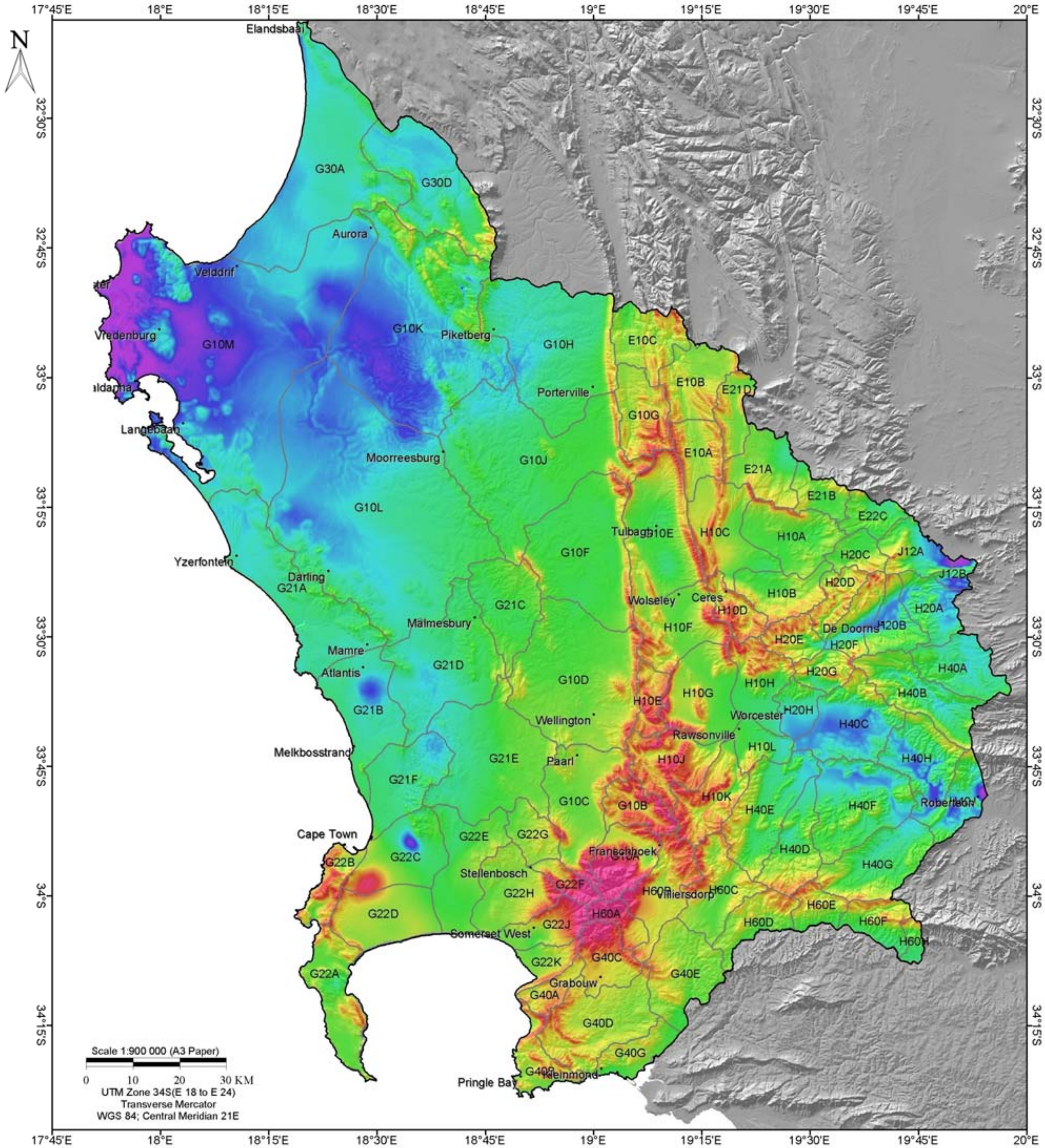
CONSULTANT

UMVOTO

TITLE

DRAINAGE

FIGURE 2.12



LEGEND

- Towns
- Quaternary Catchments
- Study Area

Rainfall (mm/a)

3238
1252
855
457
60

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

RAINFALL DISTRIBUTION (MAP)

FIGURE 2.13

2.3 STRATIGRAPHY AND AQUIFER CLASSIFICATION OF THE STUDY AREA

2.3.1 Geology and Stratigraphy

The topography, drainage, hydroclimate, land-use and even the agricultural crops are largely determined by the underlying rock type and its structural character. The strong correlation between geology and terrain, illustrated on the DEM topographic base in **Figure 2-14** and further discussed in **Section 2.3.3**, implies a strong geological control also of local climate and land-use potential, through orographic control, over precipitation and the widely variable geochemical composition of the different formations.

Underlying the younger cover strata along the West Coast, on the Sandveld and the Cape Flats in the western part of the study are, the oldest rocks, namely the **Malmesbury Group** (>555 million years [Ma]). The **Cape Granite Suite** (555-510 Ma), are also exposed as rolling hills in the geographic region known as the Swartland.

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

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

2.3.2 Aquifer Classification in this Study

The hydrostratigraphic scheme adopted for the present study is based on **Table 2-2**, and focuses on the three main “coincident” or stratabound aquifer units; namely, the Peninsula, Nardouw and Sandveld Aquifers. The non-coincident aquifer units, which correspond to the intervening “fractured-and-weathered” or regolith zones, are largely disregarded in this approach, except where they might interface laterally with, or grade into, TMG and/or Sandveld aquifer compartments. In these cases, the near-surface regolith zone may provide a diffuse or preferred flowpath between the different aquifers.

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

Table 2-2 Simplified hydrostratigraphic units of the study area and associated aquifer types

Superunits	Units	Aquifer Type
	Sandveld Aquifer	Intergranular
Aquicludes of	[Cape Granite Suite] [Malmesbury Group]	Fractured-and-weathered (regolith)
	Witteberg Aquifer	Fractured
Bokkeveld	Gydo Mega-aquitard	Fractured-and-weathered (regolith)
Table Mountain Superaquifer	Nardouw Aquifer	Fractured
	Peninsula Aquifer	Fractured
	Piekenierskloof Aquifer	Fractured
Aquicludes of the	[Klipheuwel Group] [Cape Granite Suite] [Malmesbury Group]	Fractured-and-weathered (regolith)

Intergranular aquifers

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

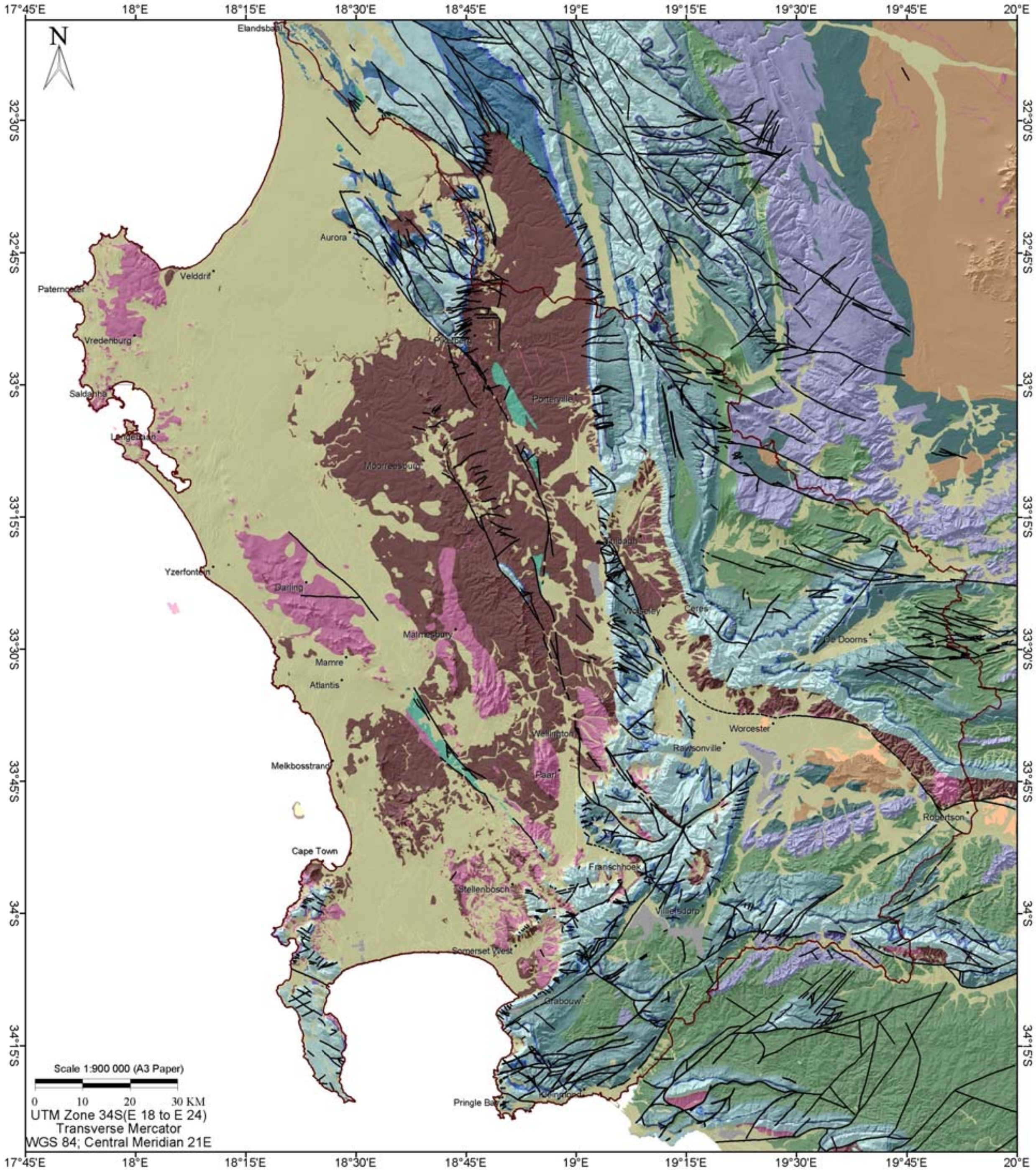
Fractured-rock aquifers

The TMG quartzites are stratabound aquifers (i.e. having significant fracture porosity and a permeability greater than $10^{-16}\,m^2$), and therefore constitute "coincident" hydrostratigraphic units, as defined by Al-Aswad and Al-Bassam (1997), in that the hydrostratigraphic boundaries generally coincide with those of the lithostratigraphic units. The **Table Mountain Superaquifer**, which is composed of the larger **Peninsula Aquifer** (apparent thickness approximately 1,1 km in this area) and the lesser **Nardouw Aquifer** (with its component subaquifers), are the principal focus of the present study.

Fractured-and-weathered (regolith) aquifers

The type d (or "intergranular and fractured") aquifers as currently mapped (DWAF, 2000a) coincide with exposures of the **Cape Granite Suite**. The only part of the **Bokkeveld** worth hydrogeological consideration is the "weathered and fractured" zone (categorically distinguished from true fractured-rock aquifers on the 1: 500 000 DWAF hydrogeological map series), which may also be termed a "regolith" aquifer.

The spatial distribution of the different aquifer types is illustrated in **Figure 2-15** below. The detailed vertical distribution within each aquifer type can best be illustrated using local-scale cross sections on which it is possible to highlight the hydrostratigraphic units and relationships which are not necessarily easy to conceptualise in plan view.



LEGEND

- Towns
- Faults
- Dam
- Study Area

SIMPLIFIED LITHOLOGY

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

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

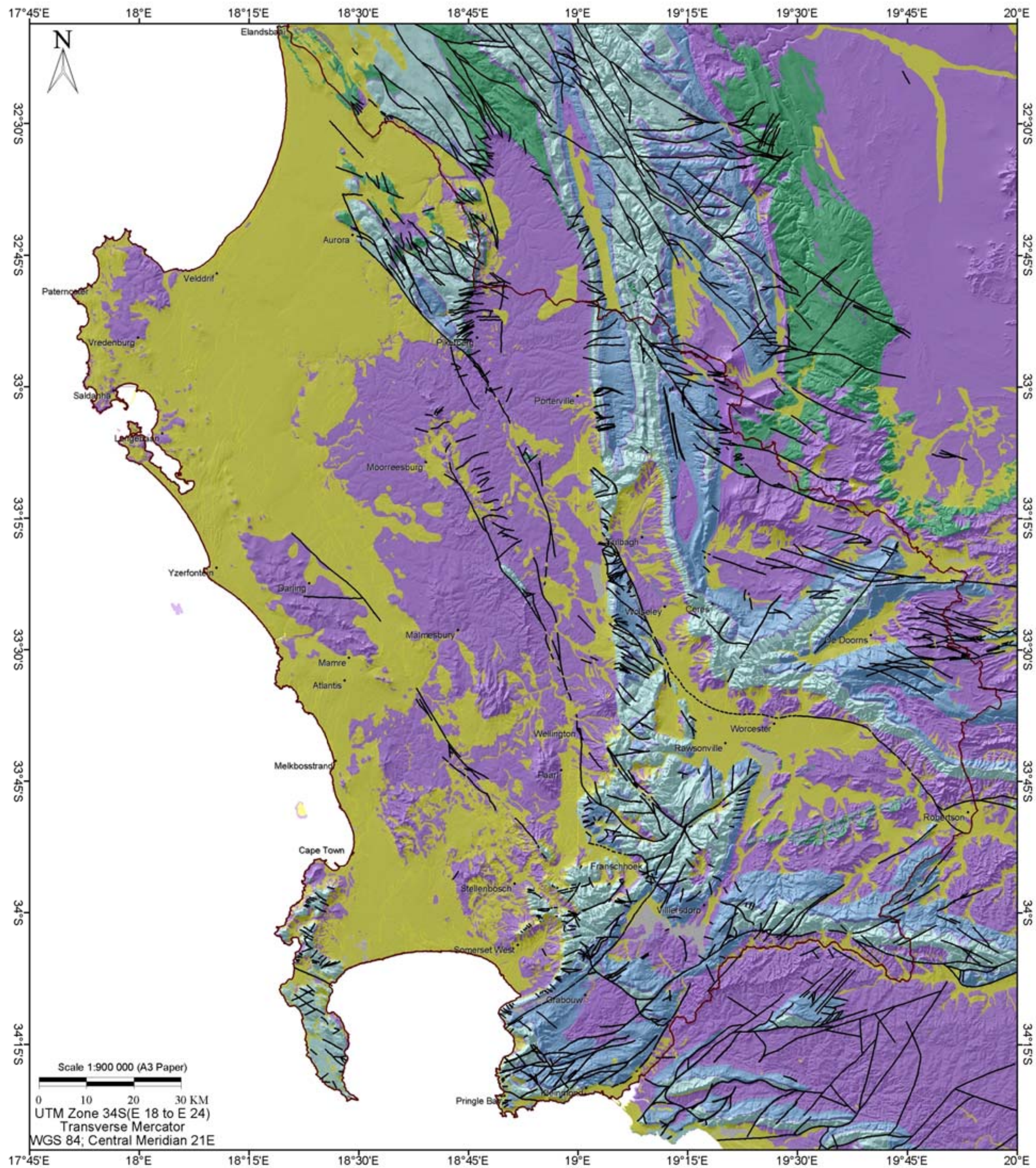
CONSULTANT

UMVOTO

TITLE

SIMPLIFIED GEOLOGY MAP OF THE STUDY AREA (1: 250 000)

FIGURE 2.14



LEGEND

- Towns
- Faults
- Dam
- Study Area

AQUIFER TYPES

- Intergranular
- Fractured
- Intergranula Fractured
- Nardouw
- Peninsula

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

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CONSULTANT

UMVOTO

TITLE

SPATIAL DISTRIBUTION OF AQUIFER TYPES

FIGURE 2.15

2.3.3 Relationship between Aquifer Type and Topography

As mentioned in Section 2.1, it is assumed that a strong relationship between the topography, slope distribution and aquifer type exists. The statistical analysis of the slope distribution in the quaternary catchments and IWRM domains indicates that the Peninsula Formation generally outcrops in higher terrain and generates steeper slopes than weathered fractured rock formations or intergranular formations. **Figure 2-16** shows the cumulative histograms of the slope distribution per IWRM domain for the different aquifer types, which clearly supports the above statement.

- The intergranular aquifers predominantly form the flat areas, with slopes of less than 10° in more than 80% of the outcrop area, except for the Kogelberg IWRM domain. The histograms resemble the Group 8 and Group 9 character, as shown in **Figure 2-5**.
- The slope distribution for the ‘intergranular-fractured’ aquifer type shows a similar pattern, but with an increase in slope; viz. less than 20° in more than 75% of the area. The distribution in the West Coast, Atlantis and Voëlvlei-Tulbagh IWRM domains shows distinctly lower slopes than the other IWRM domains. The histograms mainly resemble the Group 5 and Group 6 character, as shown in **Figure 2-5**.
- The slope distribution for the Nardouw Aquifer shows a similar pattern in all IWRM domains with less than 30° slope in 80% of the area, except the Brandvlei, IWRM domain where more areas of steeper slope exist. The histograms mainly resemble the Group 3 and Group 4 character, as shown in **Figure 2-5**.

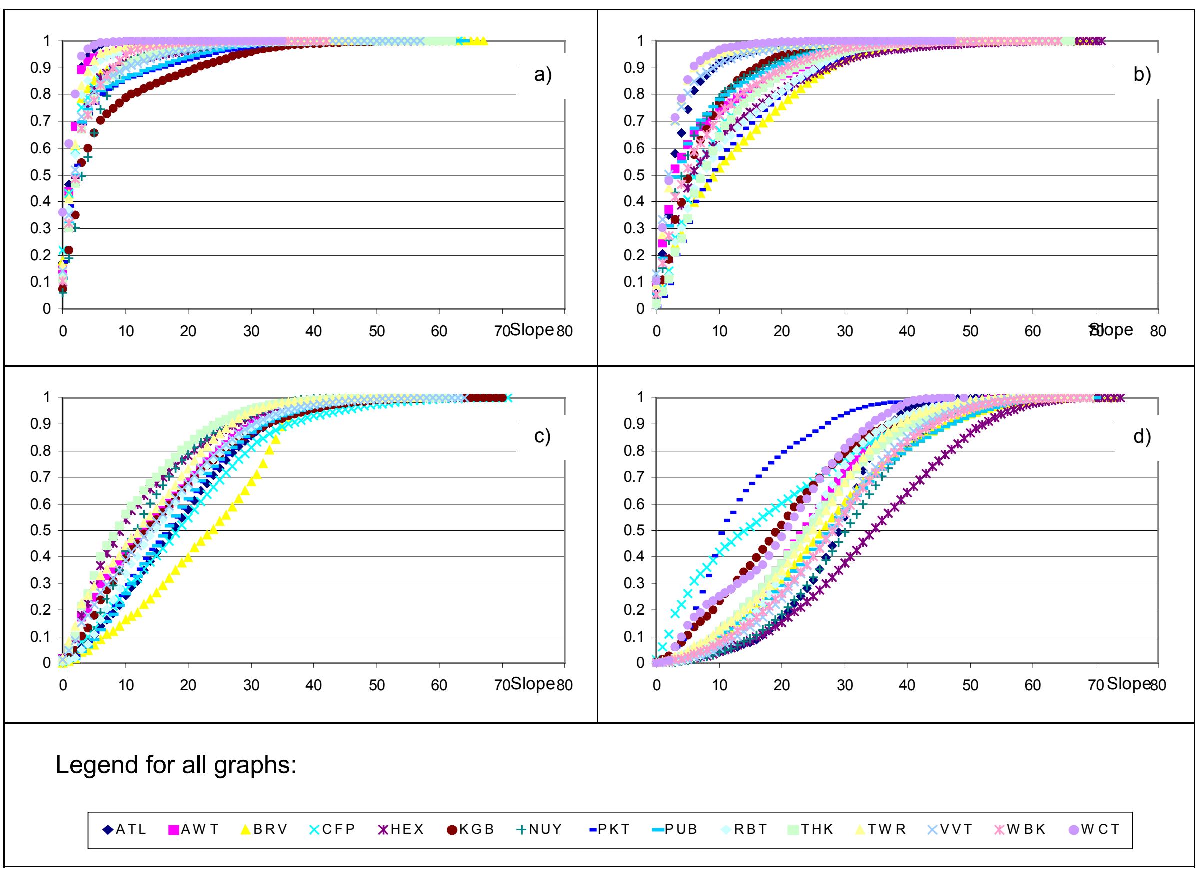


Figure 2-16 Slope Distribution per aquifer type;
a) Intergranular, b) Weathered fractured, c) Nardouw, d) Peninsula

- The Peninsula Aquifer shows a different pattern in the slope distribution. In most IWRM domains, the histogram shows an S-curve type with very few flat areas and more than 20% with slopes above 30° or 40°, resembling the Group 1 and Group 2 character. However, there are three distinct outliers to this pattern:
  - About 40% of the area in the Hex River IWRM domain has a slope above 40°;
  - 80% of the area in the Piketberg IWRM domain has a slope of less than 20°;
  - The distribution for the Cape Flats-Peninsula IWRM domain shows a bimodal character, with one third of the area being relatively flat, i.e. less than 5°.

A comparison of the slope distribution for the different aquifer types within an IWRM domain (**Figure 2-17**) further illustrates the fact that the intergranular formations predominantly form the flatter areas. The 'intergranular-fractured' aquifer type generally shows a slope distribution that tends slightly to higher slopes than for the intergranular aquifers, as the outcrops of the Malmesbury Shale and Granites mostly form the hills that are surrounded by intergranular deposits. The histograms for both aquifer types are equal in the Voëlvlei-Tulbagh IWRM domain due to the fact that the Malmesbury outcrops are as flat as the surrounding alluvium.

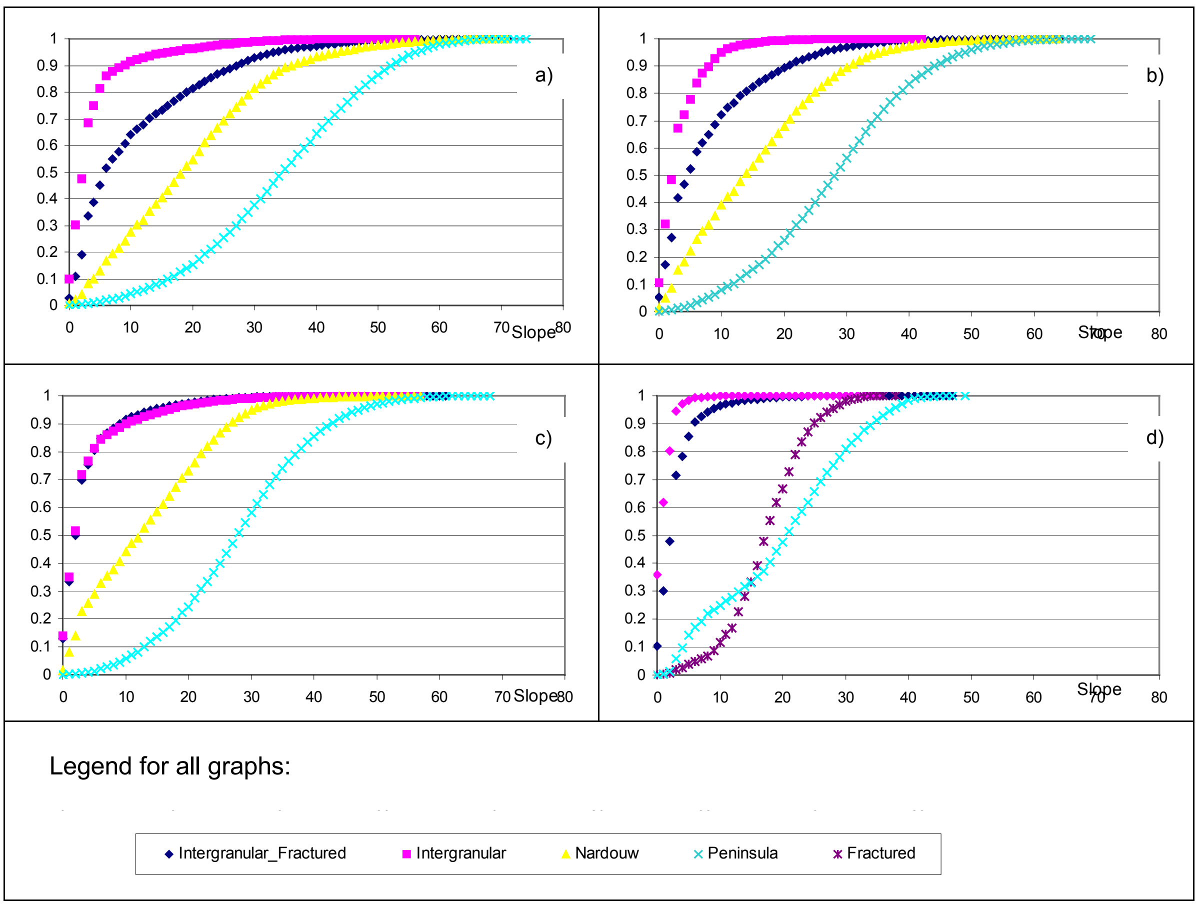


Figure 2-17 Slope Distribution per aquifer type within IWRM domains; a) Group A – HEX; b) Group B – WBK; c) Group C – VVT; d) Group D – WCT

The Peninsula Formation mainly forms the high lying, steep terrains. However, a fair percentage of flat areas also exist within the outcrop areas of the Peninsula Formation, especially in the high lying areas where endorheic drainage patterns persist which reflect the pseudo-karstic character of the upper layers (see Cape Flats-Peninsula IWRM domain [CFP] in **Figure 2-16d**). The histogram for the Peninsula Aquifer in the West Coast IWRM domain is distinctly different to the other examples, as only a very small part of the Peninsula outcrop of the Piketberg falls within the West Coast IWRM domain, which does not cover the whole slope profile.

As the slope angle θ is an important factor determining the run-off potential and therefore the infiltration and recharge potential, a uniform rainfall – recharge relationship across the study domain is not sufficient. The aquifer specific differences in slope frequency need to be taken into account in the recharge estimation (see Section 5.2.4).

The aquifer types summarise the underlying geology and rock formations and reflect to a certain degree the soil type. Since the soil conditions further determines the infiltration capacity and soil moisture retention, the correlation between aquifer type and soil type can be used in the run-off and recharge model (see Section 5.2.4).

However, the aquifer types ‘intergranular’ and ‘intergranular-fractured’ are a simplification in that they summarise different formations into the same type. Hence, it is not expected that the aquifer type and soil type correspond over the whole study domain. But it can be reasonably assumed that a consistent correlation exists within each IWRM domain. This will be addressed in more detail in the run-off and recharge model (Section 5.2.4).

3. APPROACH FOR WATER BALANCE MODEL

3.1 INTRODUCTION

It is imperative in this study to establish a groundwater balance that can be reasonably linked to the surface water balance. The main elements of the groundwater balance are recharge, storage, natural discharge and abstraction, while the surface water balance comprises rainfall, run-off, evaporation and abstraction. The approach adopted in this study ensures that the input parameters for the estimation of the different components are the same as for the surface water modelling. The interrelationship of the main processes and components are shown in a simplified manner in **Figure 3-1**. Each of these components can be broken down into smaller units that interact which each other and with units of other processes.

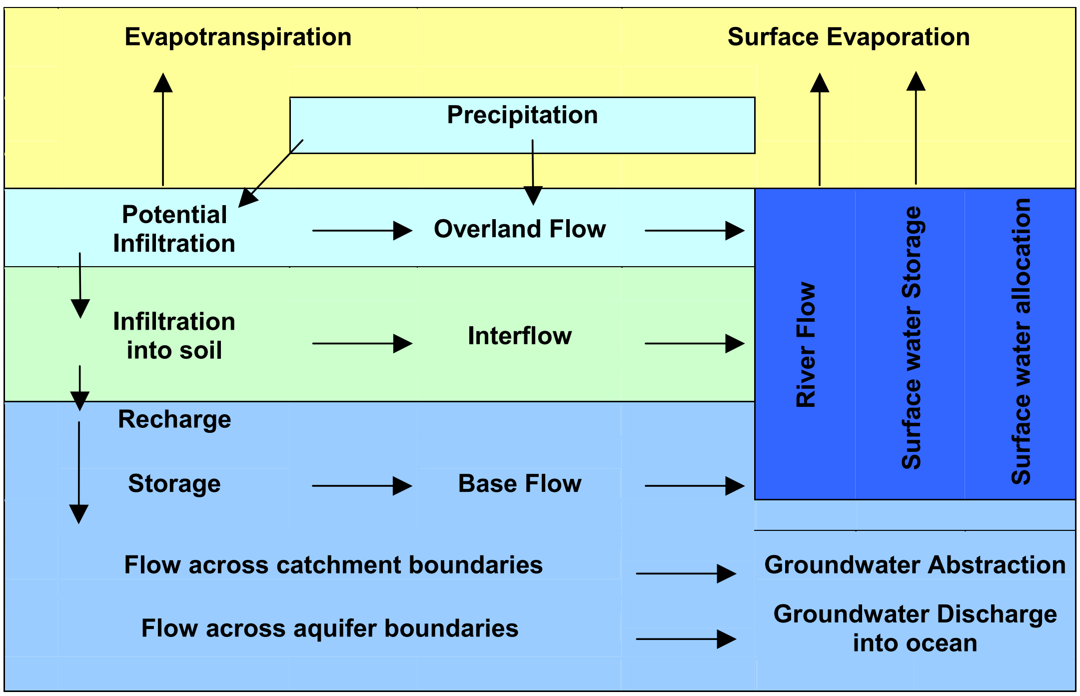


Figure 3-1 Main hydrological processes for Water Balance Model

In order to establish the catchment mass balance as well as the groundwater mass balance it is useful to establish the "Total Yield" available in the catchment. This is the volume of rain falling less that lost to evaporation, which must be accounted for before dividing the rain between surface water and groundwater. Transpiration is lost from either the surface water yield or the groundwater yield, depending upon the characteristics of the unsaturated zone, the patterns of interflow and type of vegetation.

The approach adopted in this study divides the rainfall into that part that directly runs off the surface, called overland flow, and that part that potentially infiltrates into the soil and unsaturated zone, called potential infiltration. Evaporation is then assigned to the overland flow only, while the potential infiltration is further reduced due to evapotranspiration. The remaining infiltration is then subdivided into the interflow and the recharge components. Depending upon the aquifer system, a part of the recharge discharges into rivers, contributing to base flow, while another part flows across catchment boundaries and discharges either in different catchments as springs or a component of baseflow or into the ocean.

3.2 STORAGE

The storage capacity, viz. the total available storage of the TMG aquifers, is calculated with an in-house developed GIS model based on aquifer geometry calculated using first principles of structural geology and assumed values for effective porosity. Based on these calculations and assuming conservative values for the storage coefficient of the confined portions of the TMG aquifers, the potential yield is estimated.

The detailed methodology and results are described in Section 4 below.

3.3 RECHARGE

Aquifer specific recharge is estimated using a GIS based Water Balance Model that takes rainfall, run-off and evapotranspiration as well as the delineation of recharge and discharge zones into account. The results are compared with other GIS models. In addition, other recharge estimation methods, such as the Chloride Mass Balance method and the Saturated Volume Fluctuation method, are applied in localised areas to compare with the regional estimation.

The detailed methodology and results are described in Section 5 below.

3.4 DISCHARGE

Discharge from the aquifer systems is mainly two-fold; i.e. natural discharge via springs or baseflow, and groundwater abstraction. For both parameters the currently available regional estimates are disaggregated into aquifer specific values, using assumptions and knowledge about distribution of discharge sites and boreholes.

There are no estimates available for other forms of groundwater discharge, such as lateral recharge via hydraulic connections between aquifers and discharge to the ocean.

The detailed methodology and results are described in Section 6 below.

3.5 YIELD

The potential aquifer yield depends mainly on two factors, viz. the long-term replenishment and the impact of abstraction on the hydraulic head in the aquifer. Both parameters are taken into account in the yield estimation, which is given per aquifer in each IWRM domain.

The long-term potential yield is calculated as recharge minus groundwater contribution to baseflow. These are compared to estimates for the TMG aquifers, applying the specific storage for the confined portion and different assumed acceptable drawdowns.

Based on the model results for the different processes and the combined yield model, the relevant input parameters for the WRYM and the groundwater modules of the WRSM2000 are given. However, it must be noted that the achievable yield of the aquifer depends on factors such as borehole siting, wellfield and aquifer management, and accepted impacts.

The detailed methodology and results are described in Section 7 below.

4. STORAGE MODEL

4.1 PRINCIPLES

4.1.1 Aim of storage model

The Groundwater Resource Assessment Phase II (GRA II) project proposed a general methodology for groundwater resource evaluation in order to provide an estimate of groundwater potential on a national scale (DWAF, 2006b). For reasons mentioned earlier, the approach is not applicable to this project and the results are not used.

Within the Berg WMA region, the GRA II handling of the storage coefficients and saturated thickness values for the main aquifer types is also highly problematic. For example, in the GRA II scheme (DWAF, 2006b), the (undivided) TMG aquifer is assigned a much lower storage coefficient (0.0008) than that applied to the low-yielding aquifers and aquitards of the Malmesbury Group (0.004). This is inconsistent with hydrogeological field observation and test-pumping results and no distinction is drawn between unconfined and confined modes of groundwater storage in the TMG. Over its exposed outcrop area, the GRA II model also treats the TMG as having a saturated thickness of only 75 m, compared to 40 m for the adjacent Malmesbury and Cape Granite regolith aquifers. This treatment is inconsistent with the large difference in rock strength between the pre-Cape rock types and the TMG quartzites, and the extent to which high-strength, TMG-type materials are able to support open fracture systems at great depths.

As a result, the GRA II project recognises the evident anomaly that "… Eastern Karoo aquifer systems appear to have a greater maximum volume of groundwater stored per unit area than the Table Mountain Sandstone aquifer systems" (DWAF, 2006b, p. 31). There is an implicit suggestion that the result is not realistic and this intuitive understanding is supported by the preponderance of high-yielding thermal springs in the TMG terrain and the obvious importance of TMG derived baseflow to perennial stream systems in the Cape Fold Belt.

The storage model aims to:

- develop an accurate 3D surface of the base and top of the Peninsula Aquifer.
- obtain the rock volume of the Peninsula Aquifer
- model the amount of water in storage in the Peninsula Aquifer
- model the amount of water available for sustainable abstraction from the Peninsula Aquifer.

4.1.2 Confined aquifer principles

A "confined' (or "artesian") aquifer is "immediately overlain by a low-permeability unit (confining layer) … (and) does not have a water table" (Sharp, 1999) but usually has a water table in the unconfined area of recharge. The term "unconfined" refers to "an aquifer, which has a water table and implies direct contact from the water table to the atmosphere" (op. cit., p. 2).

The quality of water that can be released from the aquifer per unit area for a unit decline of head is termed storativity (S). In a confined aquifer, S is essentially the specific storage S_s multiplied by the aquifer thickness; in an unconfined aquifer, S is essentially equal to the specific yield S_y or the effective porosity" (op. cit., p. 30).

Box 1 – Specific storage in confined aquifers

The theoretical specific storage S_s (m^{-1}) of a confined aquifer, under the simplifying assumption of solely vertical strain in the aquifer can be calculated by the classic Jacob relation

$S_s = \rho w\ g\ (\beta_p\ + n\ \beta_w)$

(Domenico and Schwartz, 1990, Equation 4.34, p. 113), where

ρ_w is the mass density of water (kg m^{3}),

g is the gravitational acceleration (m s^{-2}),

β_p is the "skeletal compressibility" of the fracture-porous aquifer matrix ($m^2\ N^{-1}$ or Pa^{-1}),

β_w is the compressibility of water, and

n is the effective porosity, expressed as a dimensionless ratio.

In this formulation, the term involving skeletal compressibility ($\rho_w g \beta_p$) represents the volumetric contraction of the pore space as the porosity is reduced. Counter-intuitively to some, it does not itself involve the porosity factor (*n*), because its correct derivation involves mass conservation in a system in which both the fluids and the solids are in motion, and where the material derivative follows the motion of the solid phase (op. cit., p 113-114).

The term involving water compressibility ($\rho_w g n \beta_w$) represents the volumetric expansion of the water as the pressure is lowered, and therefore contains the porosity factor. The compressibility of water, β_w is 4.8×10^{-10} Pa^{-1} at 25°C.

The above key definitions establish that, for the quantitative estimation of storage, data are required on the aquifer

- area,
- thickness,
- volume,
- effective porosity, and
- the particular hydrogeological setting (unconfined versus confined).

Since ρ_w and β_w can be assumed as physical constants for water, the measurement of the effective porosity *n* and skeletal compressibility are required for specification of S_s. For most confined aquifer systems, the water contribution from pore-space contraction by far exceeds the contribution from fluid expansion, because of order-of-magnitude differences between rock compressibility β_p and water compressibility β_w.

4.2 STORAGE MODELING

4.2.1 Methodology

Storage modelling was undertaken for the Peninsula and the Skurweberg Aquifer in the study area using a combination of spreadsheet models developed by Dr. Chris Hartnady and GIS models developed by Ms Andiswa Mlisa following the procedure used in the Clanwilliam Dam Raising Study (DWAF, 2006a). The spreadsheet models require 3-D input (X, Y and Z coordinates) of geological contacts, derived from accurately georeferenced satellite imagery and digital elevation models (DEM).

The X-Y-Z data is first used to calculate orientations of particular geological contacts at specified intervals along the surface trace in a first spreadsheet model. After GIS inspection and consistency checks against existing map data, a second spreadsheet model is used to calculate depths to and elevations of the top and base boundaries of the aquifer units at all points along the mapped contacts, using true thickness information preferably derived from GIS measurements between the base and top boundaries along short section lines of well-known strike and dip value.

The X-Y-Z data for aquifer base and top, augmented by additional, in-fill elevation data derived from structural cross-sections, fault geometry, and boreholes is imported into a GIS and fitted to a referenced surface, from which a raster grid model at the same grid interval as the DEM is prepared for the top and bottom boundaries of the aquifer. The subsurface volume of the aquifer is then calculated accurately by sequential subtraction of the aquifer base from surface topography and then the aquifer top from surface topography to obtain the solid volumes above each, and finally subtraction of the top value from the base value (see **Figure 4-3** for the Peninsula Aquifer).

The unconfined and confined portions of the aquifer are distinguished and delineated according to the surface expression of the overlying units. The total area, average apparent thickness and total rock volume are obtained for both the confined and unconfined portions of the aquifer and summed to obtain the totals. These parameters are then applied to hydrogeological principles to calculate the total pore volume and the impact of head decline as a result of abstraction.

The use of the above-described digital model has certain advantages over a pen-and-paper approach:

1. The model is physically correct in terms of obtaining the Rock Volume
2. It is possible to obtain a visually descriptive spatial overview of the aquifer geometry.
3. The apparent thickness of the aquifer can be more accurately determined than in earlier estimations where only broad / representative geology data could be applied.

The model does however have certain limitations

4. The model is only as accurate as the scale of the input data. 20m DEM and 1:50 000 geological map were used, implying that the results are reliable for the scale of the whole study area, the IWRM domains and with some revisions, for quaternary catchment scale.
5. Exact depth of contacts cannot be accurately determined at fault zones but can be reasonably estimated. Further detailed information can only be obtained from drilling for example.

The model is based on an assumption that in the Berg WAAS area, the aquifer units have undergone flexural slip (or bedding parallel) folding implying that the orthogonal thickness of the units remains constant about the fold hinges and across the limbs of the folds. In light of this, particular attention was paid to the apparent thickness variations of the aquifer around major fold structures.

4.2.2 Model Input

The area where the aquifer outcrops or exists below surface is considered in the storage model. The lithostratigraphic / hydrostratigraphic contacts that were used during the modelling process include the base of the Peninsula Aquifer, the top of the Peninsula Aquifer, the base of the Skurweberg Aquifer, the top of the Skurweberg Aquifer, as well as the Rietvlei-Gydo contacts, which served as controls during the modelling process.

The aquifer boundaries were delineated according to the bounding lithological contacts of the Peninsula Aquifer, namely the Graafwater – Peninsula, Peninsula – Pakhuis and Peninsula – Cedarberg contacts, as present on the 1: 50 000 field sheets used in preparation of the 1:250 000 3318 Cape Town, 3319 Worcester and 3218 Clanwilliam Geological Maps. These boundaries enclose a total area for the Peninsula Formation storage basin of 6 863 km^2.

Similarly the boundaries of the Skurweberg Aquifer were delineated according to the bounding lithological contacts, namely the Goudini – Skurweberg and Skurweberg – Rietvlei contacts, from the 1: 50 000 field sheets. These boundaries enclose a total area for the Skurweberg Aquifer storage basin of 3 645 km^2.

4.2.3 Model scenario selection

Results of the spreadsheet-based numerical modelling tool using Microsoft Excel are used to illustrate various possible scenarios in the relationships between aquifer area and apparent thickness, on the one hand, and assumed porosity-compressibility properties, on the other. In the absence of any measured data from the present study area, an extremely conservative range of porosity values is assumed, namely, 0.005 (or 0.5%) to 0.05 (or 5%) based on upper-crustal porosity values cited in a geophysical context (Talwani & Acree, 1985). The apparent thickness of the aquifers was obtained during modelling, having applied a true thickness for the Peninsula Aquifer of 1150 m and 300 m for the Skurweberg Aquifer under the assumption of constant thickness throughout the study area.

Porosity estimates for a 325-800 m-deep section of the Peninsula Aquifer in the Blikhuis Experimental Deep Drilling (BEDD) Project borehole BH2, between Citrusdal and Clanwilliam, have been based on downhole resistivity and density logging (Hartnady, in prep.). Using the resistivity data combined with Archie’s Law, and assuming normal TMG groundwater quality, the derived porosity values range from 0.060 (6%), for the “matrix” or relatively unfractured borehole sections, to 0.28 (28%) for highly fractured zones. Using the density logs and a reference value of 2 650 kg/m^3 for solid pure quartz, the matrix porosity is calculated at 0.048 (nearly 5%) and the fracture zone porosity at 0.163 (~16%).

These geophysically derived porosity values for the fractured zones are higher than those published in literature (e.g. Freeze and Cherry, 1979) for fractured crystalline (0 – 10%) or metamorphic rock (2 – 5%).. However, the values for relatively unfractured sections are in the same order as the published data. Although they still require future experimental confirmation from the present study area, they encourage the further expectation that, at the large scale of a borehole or wellfield, the *in-situ* compressibility values for the deep Peninsula Aquifer are also much higher than the values normally assumed for, or measured on small-scale laboratory samples of intact quartzite. A conservative approach is taken in this study and having taken into account the previously mentioned calculated porosity values, the storage modeling in this study applies a porosity of 0.05 (5%).

The range of pore-space compressibility (β_p) values used to calculate S_s according to the Jacob equation is between 3.3×10^{-10} Pa^{-1} and 6.9×10^{-10} Pa^{-1} (see **Table 4-1**), i.e., typical of "fissured" rock (Domenico and Schwartz, 1990, p. 111), which is close to the water compressibility cited earlier.

Table 4-1 Model Input Parameters for the Peninsula and Skurweberg Storage Models

Model Input Parameters	Source	Detail
Contacts for aquifer base	1:250 000 and 1:50 000	Dwyka – Ecca Bidouw - Weltevrede Rietvlei - Gydo Skurweberg - Rietvlei Goudini - Skurweberg Cedarberg - Goudini Pakhuis - Cedarberg Peninsula - Cedarberg Peninsula - selected others
Controls	1:250 000	Faults
	Previous	Cross-sections
Rock Compressibility (used to calculate S_s)	Domenico & Schwartz (1990)	$3.3x10^{-10}Pa^{-1}$ to $6.9x10^{-10}Pa^{-1}$
Porosity	Talwani & Acree (1985) & Blikhuis Borehole Data	0.005 - 0.163
Specific Storage (S_s; used for Storage Yield Model)	Calculated from Rock Compressibility and Porosity	3.0E-06 to 7.0E-06
True Thickness	Literature	Formation Specific

4.3 STORAGE MODEL RESULTS

4.3.1 Peninsula Aquifer

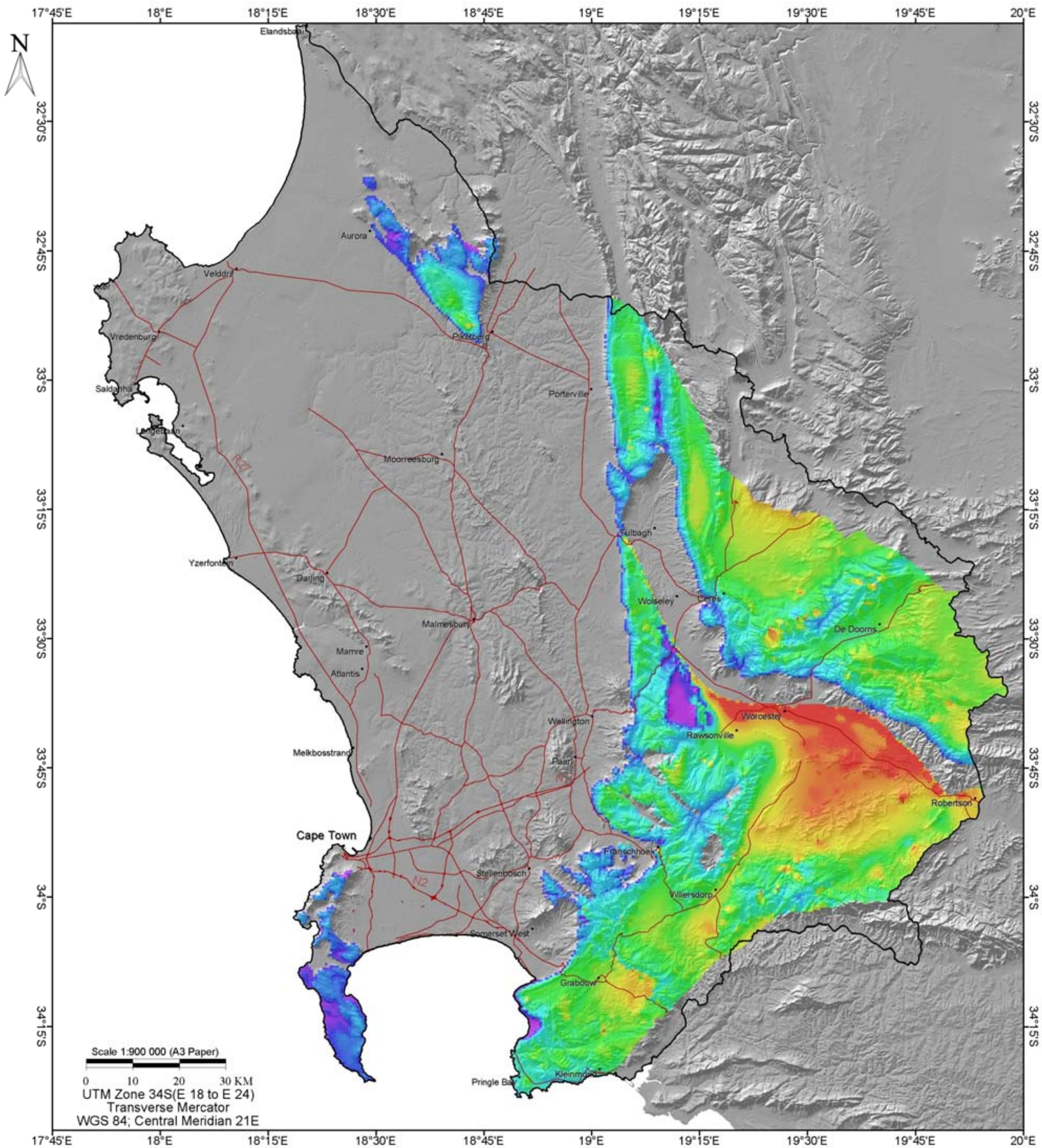
Figure 4-3 illustrates the storage modelling of the Peninsula Aquifer. The coloured sections of the study area cover the area where the Peninsula Aquifer exists either on or below surface. This is the area considered in the storage model. The colour palette illustrates the range in the aquifer rock volume per pixel over the storage area. i.e. for each pixel, the colour represents the vertical rock volume from surface to the aquifer in cubic meters. Blues and purples thus indicate where the aquifers are at their deepest while reds indicate that they outcrop at surface.

The total solid material volume (rock volume) of the Peninsula Aquifer is 7.35 x 10^{12} m^3. The total confined rock volume is 5.92 x 10^{12} m^3. The total (and confined) modelled rock volume and the calculated pore volume, given an accepted porosity of 0.05, is summarized in **Table 4-2**. The total confined pore volume of the Peninsula Aquifer is approximately 296 x 10^9 m^3.

Table 4-2 Rock Volume vs Pore Volume for Peninsula Aquifer, given a porosity of 0.05 (5%)

Peninsula Aquifer	Area (km^2)	Rock Volume (Mm^3)	Pore Volume (Mm^3)
Unconfined portion	1 750.27	1 414 520	70 726
Confined portion	5 112.44	5 919 580	295 979
Whole Peninsula Aquifer	**6 862.71**	**7 334 100**	**366 705**

The model of the aquifer storage intentionally makes use of low, geologically reasonable values for porosity and aquifer compressibility, so as to provide *minimum estimates of the amount of water in storage and subsequently the potential yield*. However, as new data accumulate from the TMG aquifers in the study area, these initial porosity and compressibility assumptions will probably be revised upwards.



LEGEND

- Towns
- Roads
- Study Area

Aquifer Bottom (m)

- -679 - -147
- -146 - 195
- 195 - 365
- 365 - 705
- 705 - 1045
- 1045 - 1215
- 1215 - 1380
- 1890 - 2400
- 2400 - 2910
- 2910 - 3420
- 3420 - 4100
- 4100 - 4610
- 4610 - 9708

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

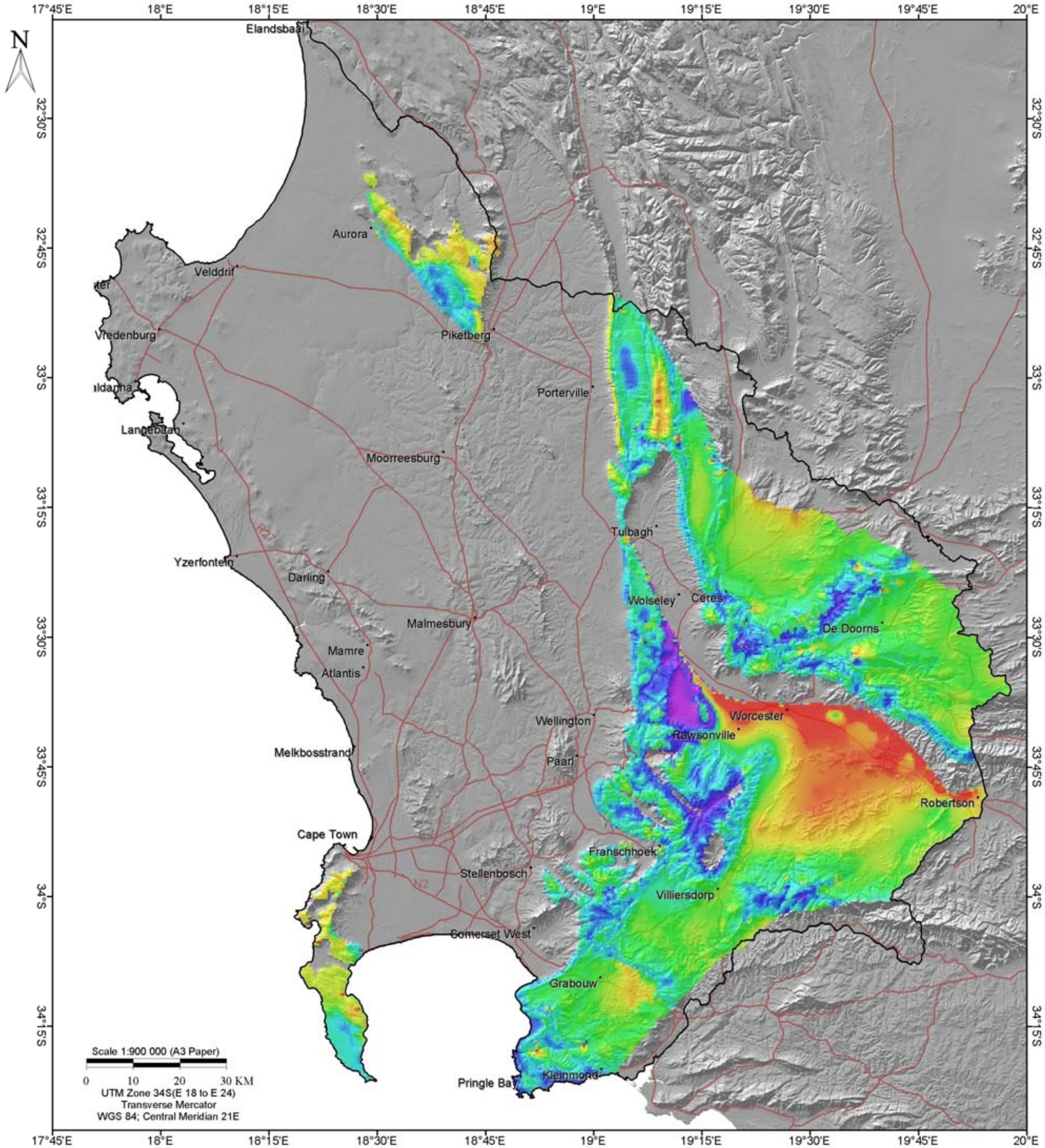
CONSULTANT

UMVOTO

TITLE

AQUIFER BOTTOM FOR PENINSULA AQUIFER

FIGURE 4.1



LEGEND

Towns
Roads
Study Area

Aquifer Top (m)

-1345 - -1185
-1182 - -860
-860 - -215
-215 - -55
-55 - 110
110 - 270
270 - 750
752 - 912
750 - 1400
1400 - 1720
1880 - 2040
2040 - 2525
2525 - 3500
3500 - 8486

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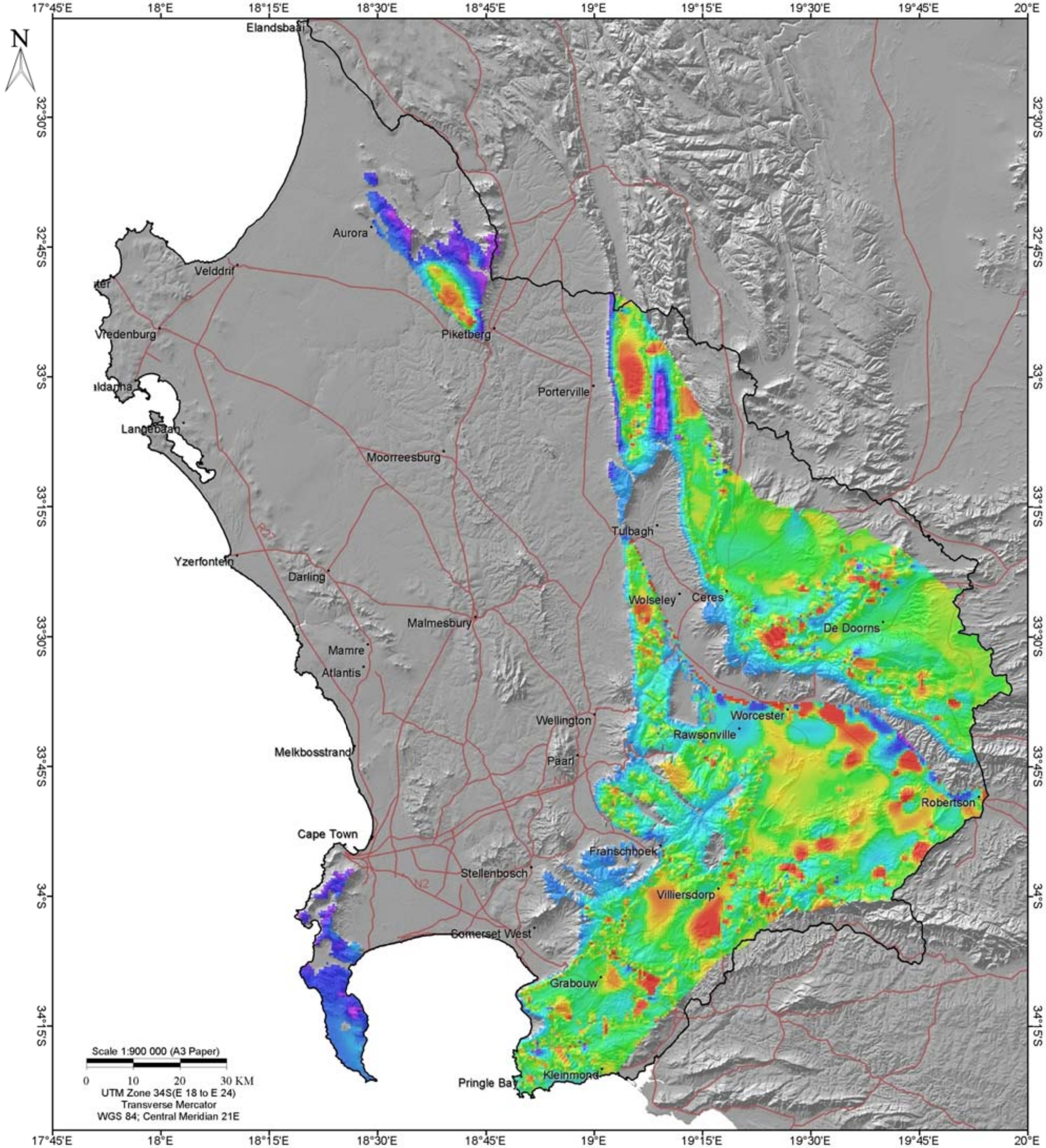
AQUIFER TOP FOR PENINSULA AQUIFER

FIGURE 4.2



LEGEND

- Towns
- Roads
- Study Area

Aquifer Thickness (m)

9708

1079

0

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ROCK VOLUME AND STORAGE MODEL OF PENINSULA AQUIFER

FIGURE 4.3

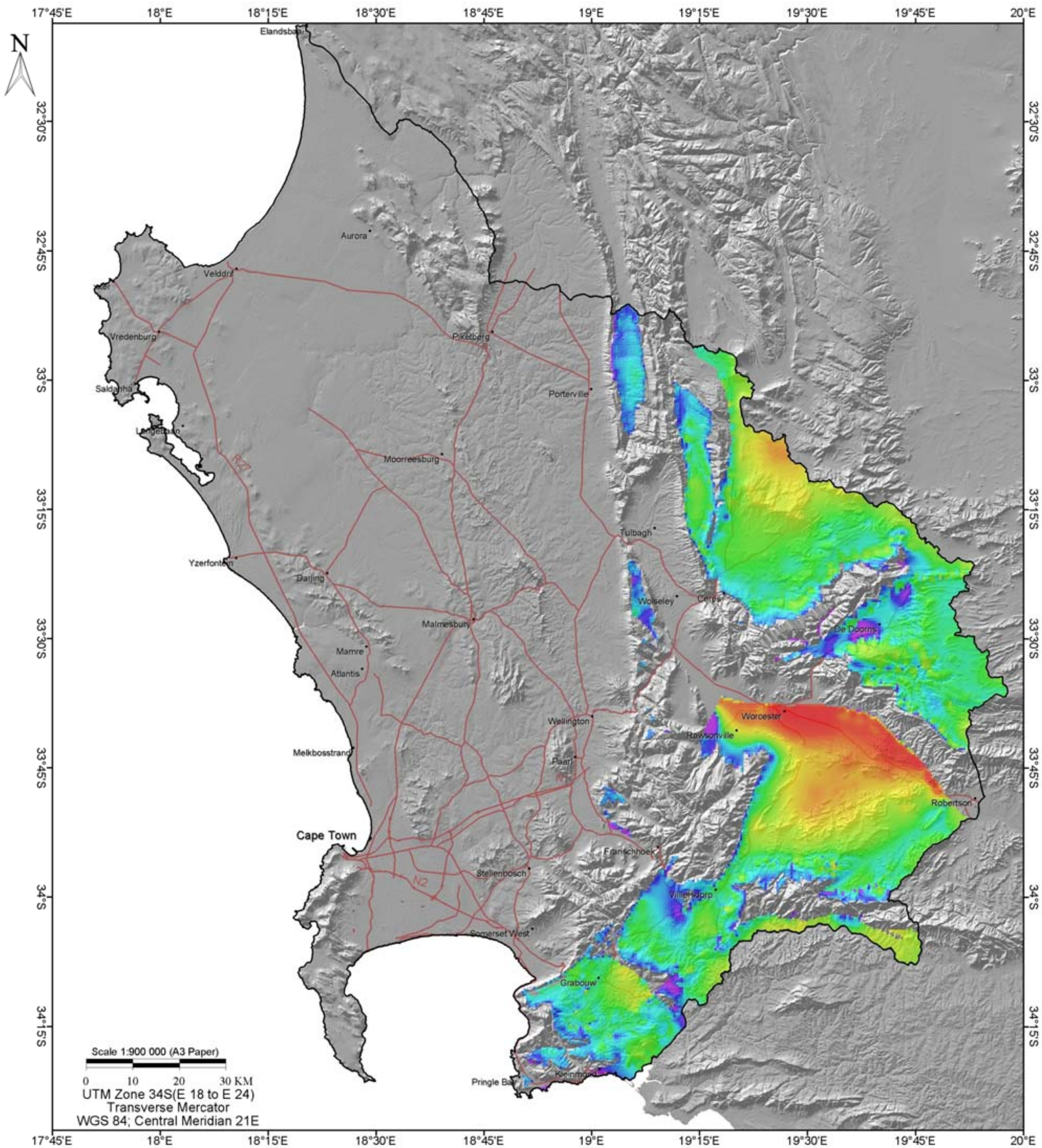
4.3.2 Skurweberg Aquifer

The storage model was set up for the Skurweberg Aquifer in the main mountain chain of the Cape Fold Belt. No storage modelling was undertaken for the Piketberg area, as the geological maps (both the 1:250 000 Clanwilliam sheet and the 1:50 000 field sheets) don't distinguish between the different formations within the Nardouw Group.

Figure 4-6 illustrates the storage modelling of the Skurweberg Aquifer. The total solid material volume (rock volume) of the Skurweberg Aquifer is 1.53 x 10^{12} m^3. The total confined rock volume is 1.26 x 10^{12} m^3. The total (and confined) modelled rock volume and the calculated pore volume, given an accepted porosity of 0.05, is summarized in **Table 4-3**. The total confined pore volume of the Skurweberg Aquifer is approximately 62.8 x 10^9 m^3.

Table 4-3 Rock Volume vs Pore Volume for the Skurweberg Aquifer, given a porosity of 0.05 (5%)

Skurweberg Aquifer	Area (km^2)	Rock Volume (Mm^3)	Pore Volume (Mm^3)
Unconfined portion	1 120.13	271 255	13 563
Confined portion	3 644.94	1 256 882	62 844
Whole Skurweberg Aquifer	**4 765.06**	**1 528 137**	**76 407**



LEGEND

- Towns
- Roads
- Study Area

Aquifer Bottom (m)

- -1754 - -375
- -375 - -220
- -220 - -70
- -70 - 85
- 85 - 235
- 235 - 390
- 390 - 1000
- 1000 - 1600
- 1600 - 1900
- 1900 - 3000
- 3000 - 3600
- 3600 - 4300
- 4300 - 8056

PROJECT NAME

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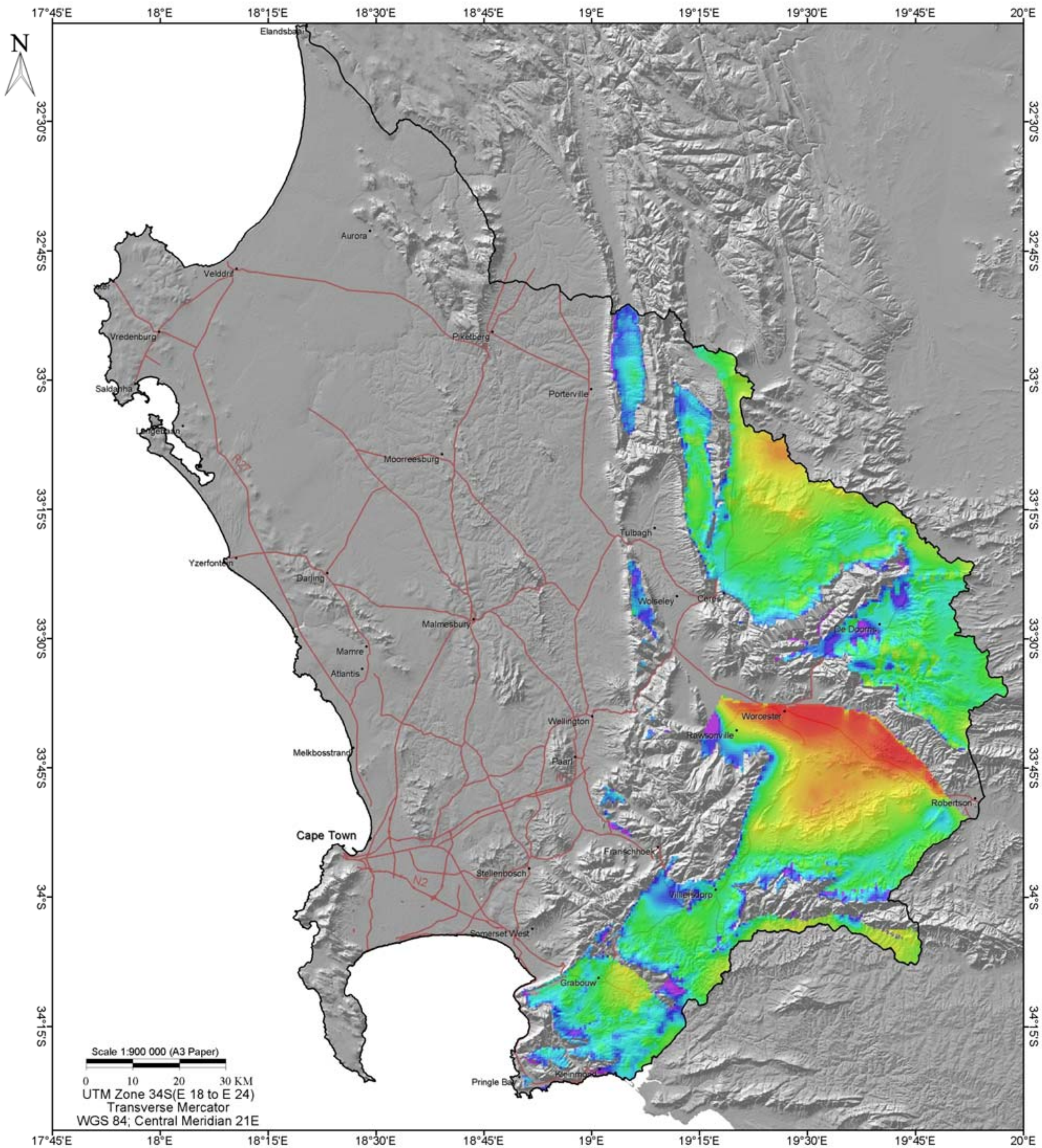
TITLE

AQUIFER BOTTOM FOR SKURWEBERG AQUIFER

FIGURE 4.4



LEGEND

- Towns
- Roads
- Study Area

Aquifer Top (m)

- -2045 - -650
- -650 - -500
- -500 - -300
- -300 - -200
- -200 - -100
- -100 - -15
- -15 - 20
- 20 - 130
- 130 - 980
- 980 - 1350
- 1350 - 1900
- 1900 - 2700
- 2700 - 2900
- 2900 - 3500
- 3500 - 4000
- 4000 - 7365

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

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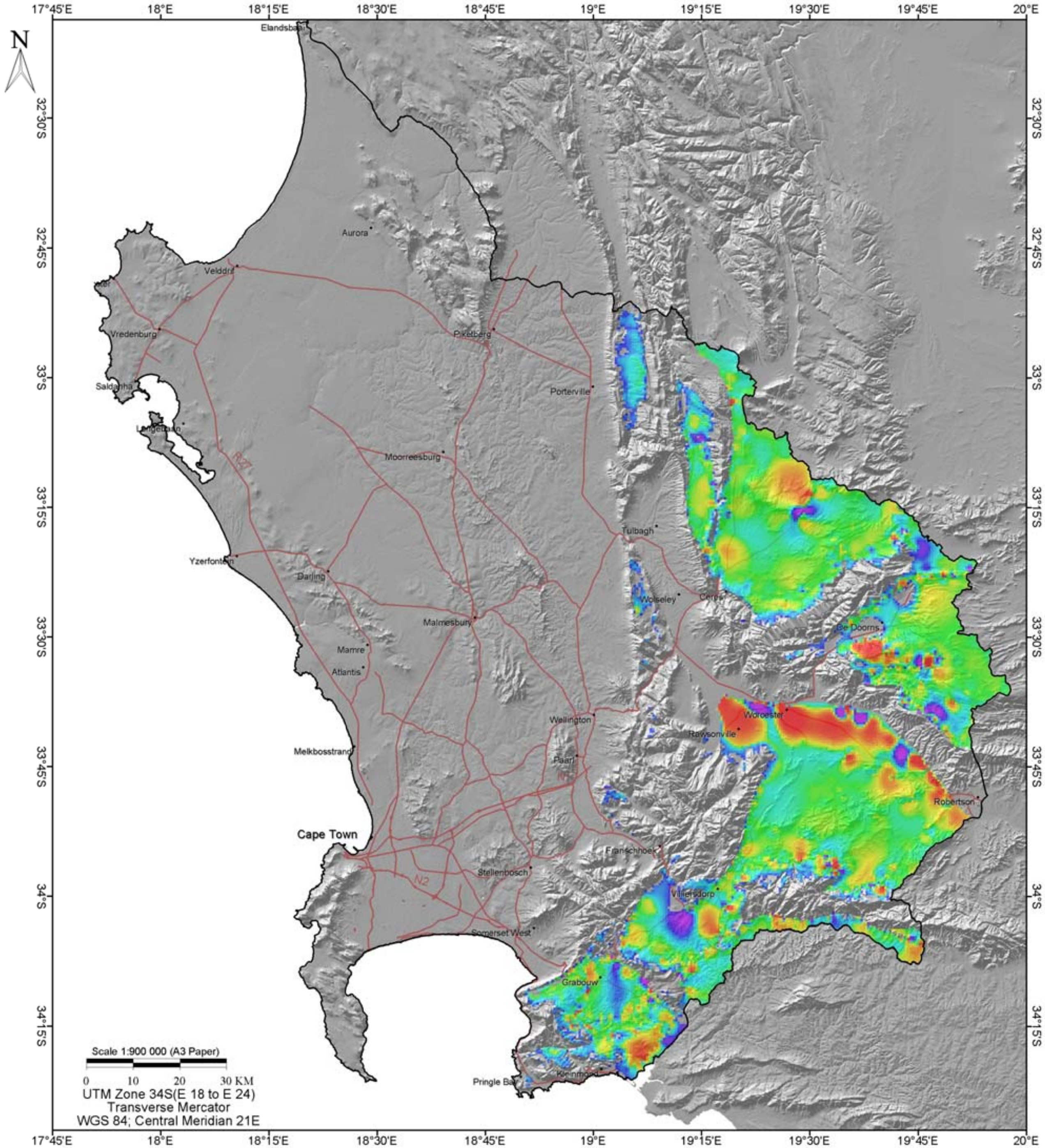
CONSULTANT

UMVOTO

TITLE

AQUIFER TOP FOR SKURWEBERG AQUIFER

FIGURE 4.5



LEGEND

- Towns
- Roads
- Study Area

Aquifer Thickness (m)

- -2930 - -270
- 200 - -170
- -170 - 2
- 2 - 50
- 50 - 150
- 150 - 250
- 250 - 280
- 280 - 330
- 330 - 430
- 430 - 630
- 630 -800
- 800 - 3462

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

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TITLE

ROCK VOLUME & STORAGE MODEL OF THE SKURWEBERG AQUIFER

FIGURE 4.6

5. RECHARGE

5.1 PREVIOUS STUDIES

In semi-arid regions such as the western part of South Africa, aquifers usually have to be exploited either for a long continuous period or at abstraction rates higher than the initial abstraction for a substantial length of time, before their economic use on a sustainable basis is assured. Reliable estimates of average annual recharge and its interannual variability can only be obtained after several years of monitoring and reassessment. Bredenkamp *et. al*. (1995) therefore advocate the "estimation of a preliminary value of recharge by means of a simple rainfall/ recharge relationship".

The quantification of recharge to the aquifers is critical to the development and improvement of the current water-balance analysis. Groundwater recharge to most South African aquifers is generally taken to be less than 10% of MAP, with Cenozoic sand aquifers being regarded as exceptional with recharge in the range of 15 – 20% MAP.

However, in several previous studies in the TMG terrain, recharge to the Peninsula Aquifer was estimated with different methods to vary spatially between 7% and 43% of MAP, depending upon the method used, the annual rainfall and the geographic location of the study area. In the CAGE study (DWAF, 2000b) the spatially weighted average is 23% of MAP, where MAP varies from 200 mm – 2000 mm. If MAP is less than 200 mm per annum it was considered that there was no recharge.

Applying the above-mentioned ranges of infiltration, estimated for other areas of the TMG, the recharge for both the Peninsula and the Nardouw aquifers can be calculated. The infiltration rates for the aquifers based on conditions in the Gouritz basin were conservatively assumed as (Kotze, 2002):

Peninsula Aquifer	14% of Mean Annual Precipitation
Skurweberg Aquifer	7% of Mean Annual Precipitation

With these assumptions and using MAP values for each sub-catchment as calculated in Task 4, the mean annual recharge in the study area is calculated as 404 million m^3 for the Peninsula Aquifer in the study area and 140 million m^3 for the Nardouw Aquifers in the study area, respectively (see **Table 5-1**). The results per quaternary catchment are documented in **Appendix B**.

Relatively recent estimates of groundwater recharge in the study domain from the Groundwater Resource Assessment Phase II (GRA II) project (DWAF, 2006d) indicate a mean annual recharge of 1 264 million m^3/a equalling 57 mm/a. The GRDM software (DWAF, 2006f) contains recharge values per quaternary catchment, which are used as default values for the Reserve Determination on a quaternary catchment scale. Using the GRDM default values, the recharge in the study area is calculated as 916 million m^3/a, which equals 41 mm/a (see **Appendix B**)

Table 5-1 Recharge estimation, using fixed percentage of recharge per aquifer type

Tertiary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Total Recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
E10	17.74	18.17	0.02	1.97	0.31	38.2	74
E21/E22	2.11	3.08	0.88	7.27	0.75	14.1	30
G10	109.98	12.34	2.01	49.69	55.9	229.94	54
G21	0.56	0	0.02	14.75	18.26	33.59	15
G22	39.77	0.08	0.04	9.55	31.84	81.29	56
G30	4.74	0	1.98	0.98	12.42	20.11	18
G40	24.44	32.46	0	7.04	2.36	66.3	69
H10	109.08	22.39	0.04	11.37	13.65	156.52	82
H20	27.55	12.3	0	2.95	2.53	45.33	57
H40	18.57	21.18	1.89	12.17	6.07	59.88	28
H60	49.21	14.95	0	5.08	2.68	71.93	87
J12	0.49	3.24	0	0.42	0.61	4.75	24
Total	**404**	**140**	**7**	**123**	**147**	**822**	**37**

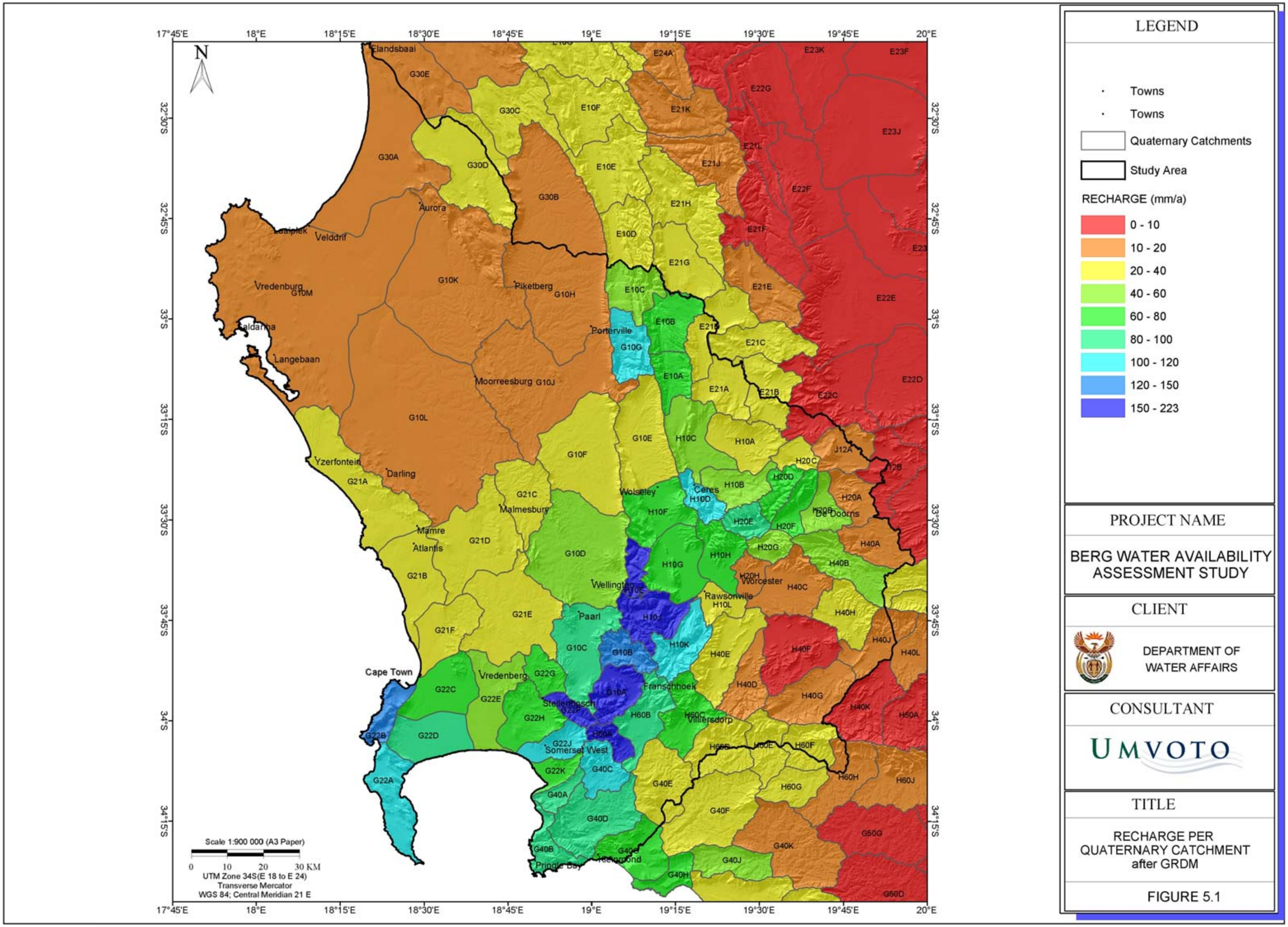
Recharge estimations for parts of the study area are given in previous studies (see **Table 5-2**). However, the estimates other than those in the TMGA project (CCT, 2004) are mostly neither aquifer specific nor spatially weighted. Because of the extreme topographic variation in an orographic rainfall area and the spatial distribution of the different aquifers with respect to altitude, temperature and rainfall character, most of the results are not suitable for the purpose of this study.

The results in **Table 5-2** vary significantly due to the difference in approaches and underlying assumptions as well as varying data input. It was therefore decided to undertake a recharge estimation with a variety of GIS-based methods to establish the sensitivity in results to different approaches and input variables.

Table 5-2 Recharge estimations in selected areas of the study domain from previous studies (all values in million m^3/a)

Area	Quaternary Catchment	GRA II (2005) [1)]	GRDM (2006) [1)]	Local studies	
Cape Flats	G22C	15.3	15.3	61.5	Gerber (1980) [2)]
				25 – 58	Vandoolaeghe (1989) [3)]
	G22D	23.8	24.0	30 – 71	
	G22E	12.7	13.5	23 – 53	
	G22H	16.1	14.7	N/a	
	Subtotal	**67.9**	**67.5**	**78 – 182**	
West Coast	G10K	15.3	17.0	16.9	SRK (2004) [4)]
	G10L	28.1	31.6	23.6	
	G10M	30.1	32.4	21.2	
	G21A	15.2	10.4	8.7	
	Subtotal	**88.7**	**91.7**	**70.4**	
TMG Aquifer (Peninsula)	G10A	57.4	26.9	19.0	CCT (2004) [5)]
	G10B	30.7	15.8	9.8	
	G10G	25.6	21.9	4.7	
	G40B	19.6	12.1	6.2	
	H10E	22.6	15.3	5.9	
	H10J	63.5	35.3	40.3	
	Subtotal	**219.4**	**127.3**	**85.9** [5)]	

1) Values given for whole catchment (not aquifer specific)
2) Value given for primary aquifer in Gerber's study area, which equals the catchment size
3) Values calculated from the recharge percentages, given by Vandoolaeghe (1989)
4) Values given for whole catchment (not aquifer specific)
5) Values given for Peninsula Aquifer outcrop within catchment


LEGEND
Towns
Towns
Quaternary Catchments
Study Area
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
CONSULTANT
UMVOTO
TITLE
RECHARGE PER QUATERNARY CATCHMENT after GRDM
FIGURE 5.1
Scale 1:900 000 (A3 Paper)
0 10 20 30 KM
UTM Zone 34S(E 18 to E 24)
Transverse Mercator
WGS 84; Central Meridian 21 E
17°45'E 18°E 18°15'E 18°30'E 18°45'E 19°E 19°15'E 19°30'E 19°45'E 20°E
32°30'S 32°45'S 33°S 33°15'S 33°30'S 33°45'S 34°S 34°15'S
Elandsbaai
Aurora
Velddrif
Vredenburg
Saldanha
Langebaan
Piketberg
Porterville
Moorreesburg
Yzerfontein
Darling
Malmesbury
Mamre
Atlantis
Wolseley
Ceres
De Doorns
Wellington
Worcester
Rawsonville
Paarl
Cape Town
Franschhoek
Stellenbosch
Villiersdorp
Somerset West
Pringle Bay

5.2 GIS-BASED MODELS

5.2.1 Groundwater Resource Assessment Phase II (GRA II Method)

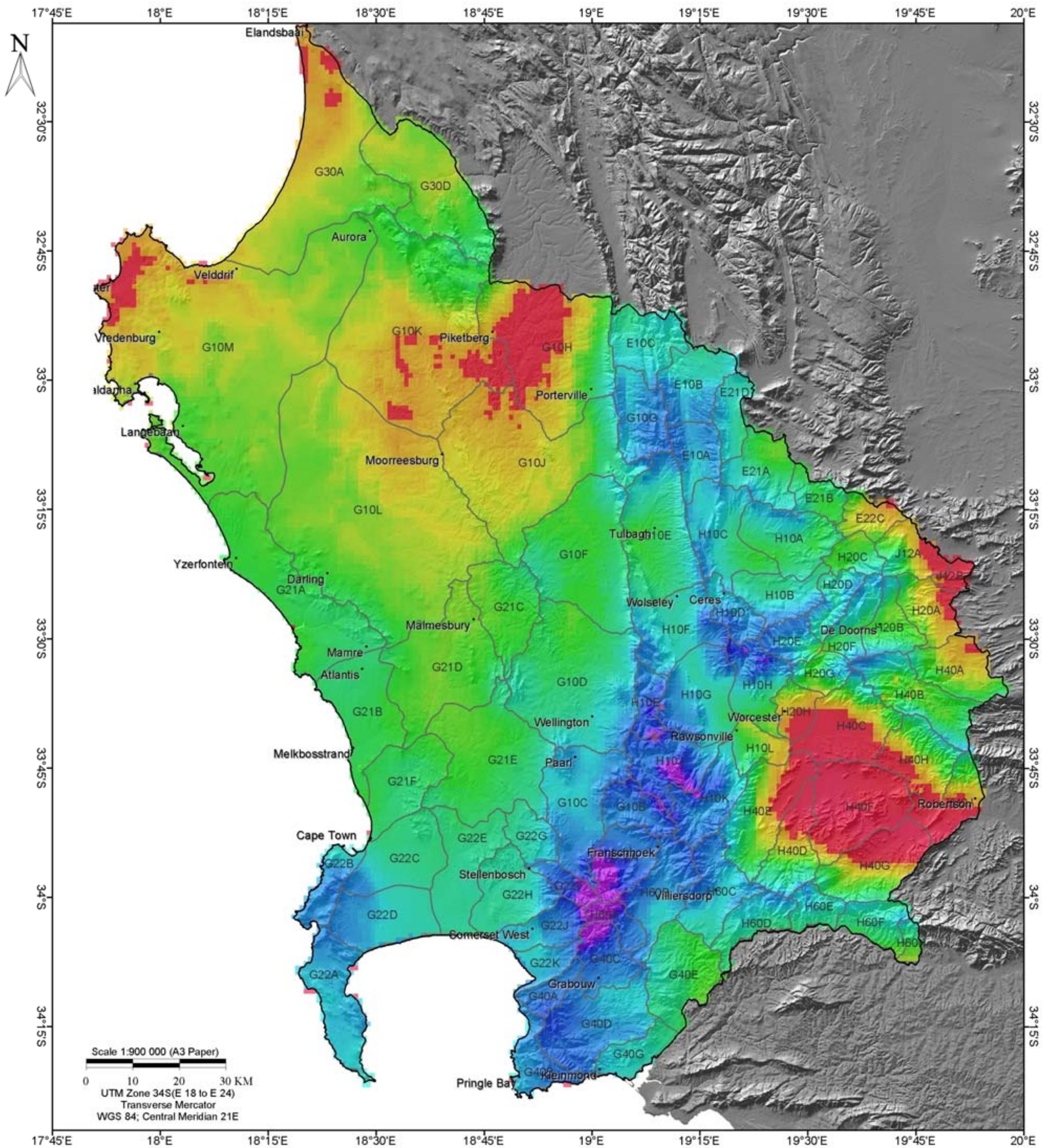
The Groundwater Resource Assessment Phase II (GRA II) project comprised five different tasks to develop a general methodology for groundwater resource evaluation and provide an estimate of groundwater potential on a national scale. The recharge estimation on a national scale was part of Task 3a (DWAF, 2006d).

The results are given as recharge percentage on a 1 km x 1 km grid and are based on the Chloride Mass Balance method, which requires that data on the chloride concentration in the rain and the groundwater are available. The input data sets were not available to check the distribution of input values.

Aquifer specific recharge is not directly available from the data set. However, recharge per grid was calculated applying the recharge percentage after GRA II and the revised MAP (DWAF, 2007c), and then overlain with the spatial distribution of the aquifer types to calculate recharge per aquifer type (**Table 5-3**). It appears from the distribution that there is a close correlation between recharge percentage and rainfall (**Figure 5-2**).

Table 5-3 Aquifer specific recharge estimation per IWRM domain, using the recharge percentage from the GRA II, after DWAF (2006d)

IWRM Domain	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Total aquifer specific recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
ATL	0.28	0.00	0.02	27.73	28.89	56.94	27
AWT	15.20	33.95	0.03	12.04	1.06	62.28	125
BRV	110.40	10.93	0.04	21.58	39.54	182.73	116
CFP	48.88	0.21	0.11	44.20	97.55	191.53	114
HEX	24.02	17.73	0.00	6.32	4.05	52.19	57
KGB	26.73	61.82	0.00	22.16	7.29	119.66	156
NUY	4.22	8.00	0.00	4.62	0.33	17.20	33
PKT	7.83	1.02	2.52	2.66	14.04	28.06	22
PUB	82.35	7.51	0.08	46.48	47.46	185.01	136
RBT	4.97	8.49	0.41	7.67	2.65	24.32	18
THK	61.35	40.30	0.00	28.33	9.86	145.89	128
TWR	21.89	18.09	1.39	19.12	5.49	65.98	36
VVT	11.18	2.70	0.23	19.88	13.68	48.18	52
WBK	13.50	29.93	1.20	41.55	6.84	93.02	84
WCT	0.04	0.00	0.02	18.90	46.66	65.63	13
Total	**433**	**241**	**6**	**323**	**325**	**1 339**	**60**



LEGEND

Towns

Quaternary Catchments

Study Area

Recharge (mm)

Red	0.0 - 8.1
Yellow	8.1 - 16.2
Yellow-green	16.2 - 24.3
Green	24.3 - 40.5
Sea green	40.5 - 64.8
Cyan	64.8 - 97.3
Light blue	97.3 - 210.7
Blue	210.7 - 421.5
Violet	421.5 - 461.9
Magenta	461.9 - 810.5

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RECHARGE DISTRIBUTION Using GRA II Method

FIGURE 5.2

5.2.2 Rainfall – Recharge relationship

In the Breede River Basin Study (DWAF, 2002) DWAF introduced a method for preliminary recharge estimation, which takes MAP per quaternary catchment into account (hereafter referred to as BRBS method). The rainfall - recharge ratios used are given in **Table 5-4.** Since rock types differ in their capacity to absorb infiltration, this method is combined with an aquifer specific factor, varying between 0.5 for low permeability aquifers and 1.5 for primary aquifers (see **Table 5-5**).

Table 5-4 Rainfall dependent Recharge Factors (DWAF, 2002)

MAP Range [mm]		Recharge
Min	Max	% of MAP
0	300	3
300	600	6
600	900	9
900	1200	12
1200	1500	15
1500	1800	18
1800	2100	21

Applying these values, the total infiltration for the study area is conservatively estimated to be 1,135 million m^3/a (equal to 51 mm/a), which is less than the estimates given in the GRA II (DWAF, 2006d) of 1,264 million m^3/a (equal to 57 mm/a).

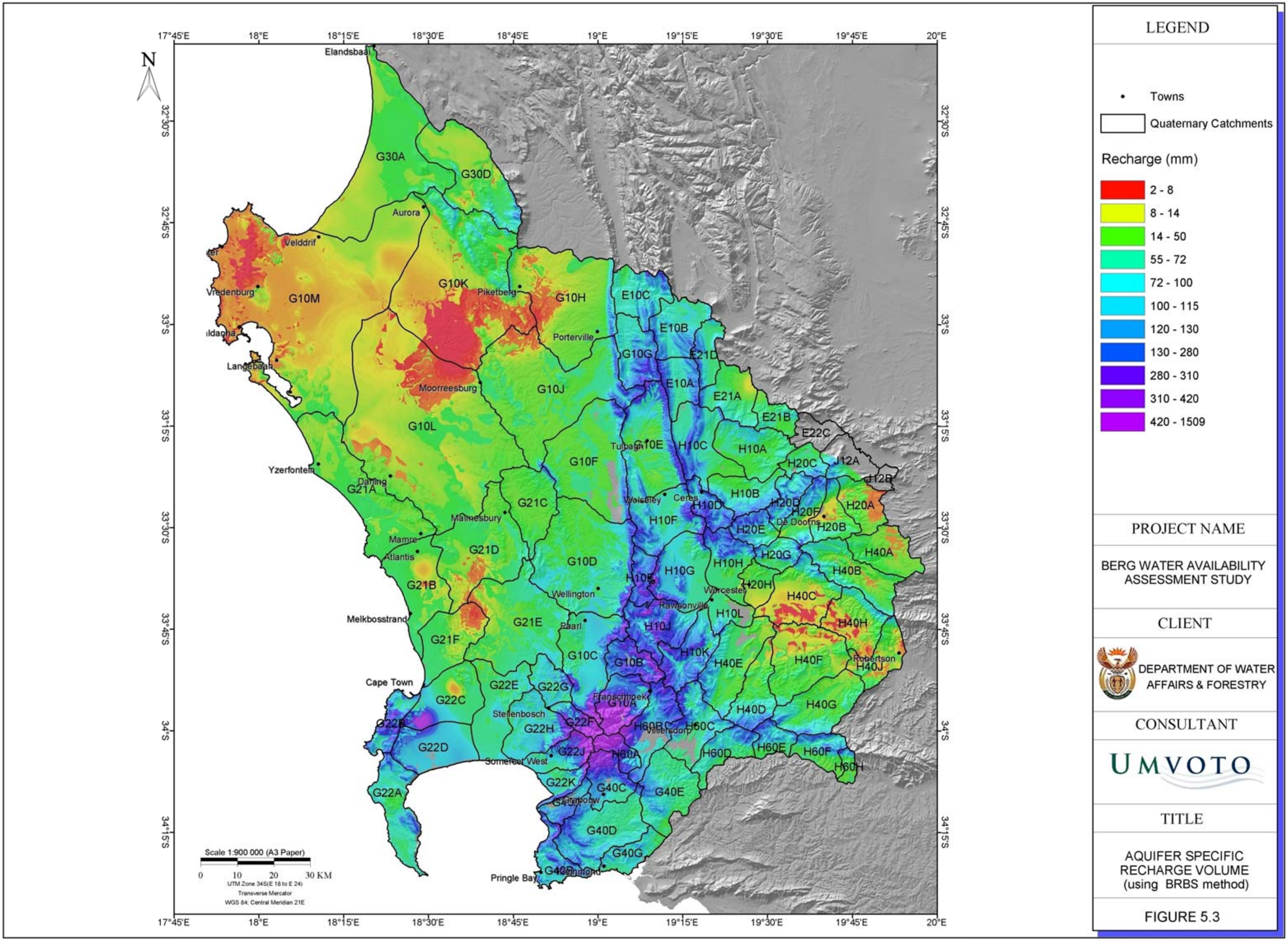
Table 5-5 Aquifer-specific Recharge factors (DWAF, 2002)

Aquifer Type		Recharge factor
(DWAF, 2002)	As per Table 5-3	
Primary Aquifer	Intergranular	1.5
Fractured Rock Aquifer	Fractured	0.8
Peninsula Aquifer	Peninsula	1.0
Skurweberg Aquifer	Nardouw	1.0
Witteberg Aquifer	Fractured	0.8
Weathered Fractured	Intergranular fractured	0.7

Applying the recharge factors and outcrop area for the Peninsula and Nardouw Aquifers, the recharge is estimated to be 388 million m^3/a for the Peninsula Aquifer, and 207 million m^3/a for the Nardouw Aquifer, respectively. The primary aquifers along the coast and in the river valleys receive recharge of 362 million m^3/a. The results per quaternary catchment are documented in **Appendix B**.

Table 5-6 Aquifer specific recharge estimation per IWRM domain, using the variable rainfall % and aquifer specific recharge factors (DWAF, 2002)

IWRM Domain	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Total aquifer specific recharge**	
	Mm^3	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*mm*
ATL	0.48	0.00	0.02	19.62	36.48	56.62	27
AWT	13.18	28.77	0.03	7.34	1.16	50.48	102
BRV	90.34	9.75	0.04	12.33	38.65	151.61	96
CFP	42.26	0.21	0.10	28.33	113.04	184.52	110
HEX	23.31	20.72	0.00	6.24	4.37	54.74	59
KGB	19.22	41.06	0.00	10.71	7.41	79.41	104
NUY	6.30	8.95	0.00	3.51	0.50	19.27	37
PKT	10.83	1.49	3.09	2.81	19.38	37.60	29
PUB	79.75	5.34	0.04	27.33	52.58	165.99	122
RBT	7.31	17.62	1.37	11.94	8.31	46.90	34
THK	59.94	38.77	0.00	20.24	10.00	133.38	117
TWR	23.46	12.90	1.77	19.79	11.54	69.46	38
VVT	17.24	3.86	0.19	12.11	19.35	53.29	57
WBK	12.12	25.35	0.77	26.62	7.83	72.69	66
WCT	0.12	0.00	0.05	14.41	45.32	59.90	12
Total	**406**	**215**	**7**	**223**	**376**	**1 236**	**56**


LEGEND
Towns
Quaternary Catchments
Recharge (mm)
2 - 8
8 - 14
14 - 50
55 - 72
72 - 100
100 - 115
120 - 130
130 - 280
280 - 310
310 - 420
420 - 1509
PROJECT NAME
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UMVOTO
TITLE
AQUIFER SPECIFIC RECHARGE VOLUME (using BRBS method)
FIGURE 5.3
N
Scale 1:900 000 (A3 Paper)
0 10 20 30 KM
UTM Zone 34S(E 18 to E 24)
Transverse Mercator
WGS 84; Central Meridian 21E
17°45'E
18°E
18°15'E
18°30'E
18°45'E
19°E
19°15'E
19°30'E
19°45'E
20°E
32°30'S
32°45'S
33°S
33°15'S
33°30'S
33°45'S
34°S
34°15'S
Elandsbaai
Velddrif
Aurora
Vredenburg
Langebaan
Piketberg
Porterville
Moorreesburg
Yzerfontein
Darling
Malmesbury
Mamre
Atlantis
Melkbosstrand
Cape Town
Stellenbosch
Somerset West
Wellington
Paarl
Franschhoek
Villiersdorp
Tulbagh
Wolseley
Ceres
De Doorns
Worcester
Rawsonville
Robertson
Pringle Bay
G30A
G30D
G10M
G10K
G10H
G10J
G10L
G10G
G10E
G10F
G10D
G10C
G10B
G10A
G21A
G21B
G21C
G21D
G21E
G21F
G22A
G22B
G22C
G22D
G22E
G22F
G22G
G22H
G22J
G22K
G40C
G40D
G40E
G40G
E10A
E10B
E10C
E21A
E21B
E21D
E22C
J12A
J12B
H10A
H10B
H10C
H10D
H10F
H10G
H10H
H10J
H10K
H10L
H20A
H20B
H20C
H20D
H20E
H20F
H20G
H20H
H40A
H40B
H40C
H40D
H40E
H40F
H40G
H40H
H40J
H60A
H60C
H60D
H60E
H60F
H60H

5.2.3 Aquifer specific Water Balance Model (ISP Method)

DWAF refined the regional recharge estimations during the ISP process in the Olifants/Doorn WMA (DWAF, 2005d), using a GIS based model, developed by Riemann et al. (2004), to calculate aquifer-specific recharge and groundwater potential at the scale of a quaternary catchment (hereafter referred to as ISP method). The model is based on existing maps of rainfall and temperature distribution, aquifer yield, lithology and catchment boundaries. However, this information is captured at different scales.

For each quaternary catchment MAP and MAR are obtained from existing data sets (DWAF, 2007c; WR2005). EVT is then calculated using a modification of the approach of Turc (1954), which was originally developed in the context of Mediterranean climatic areas, depending on MAP and mean annual temperature (see Section 5.2.4). Recharge is then calculated as:

Recharge = MAP – MAR – EVT **(1)**

To distinguish the recharge per aquifer unit, the exposed outcrop areas of the different formations were calculated from a common GIS overlay of the digital geological map and digital map of quaternary sub-catchments, with area polygons of different aquifer units differentiated for each sub-catchment.

Through a vector merging process and analysis of remote sensing data, values of the relevant parameters were assigned to small entities of aquifer outcrop per catchment (see **Figure 5-4**). The assigned values are transferred to an external database, in which the actual calculations are conducted.

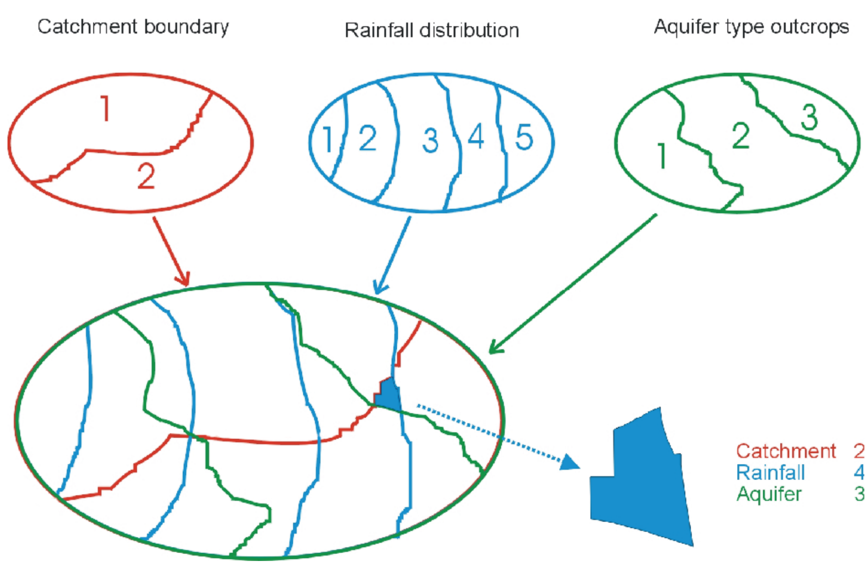


Figure 5-4 Model process, merging rainfall distribution, aquifer types and catchment boundaries creating small entities with assigned parameters

Since MAR values are only available as average per catchment (from WR2005), a spatial distribution of MAR is simulated, assuming that the run-off efficiency is uniform across the catchment. The spatial distribution of MAP is only available from the Berg WAAS (DWAF, 2007c). It is therefore assumed that the run-off efficiency will be equal for WR2005 and the Berg WAAS.

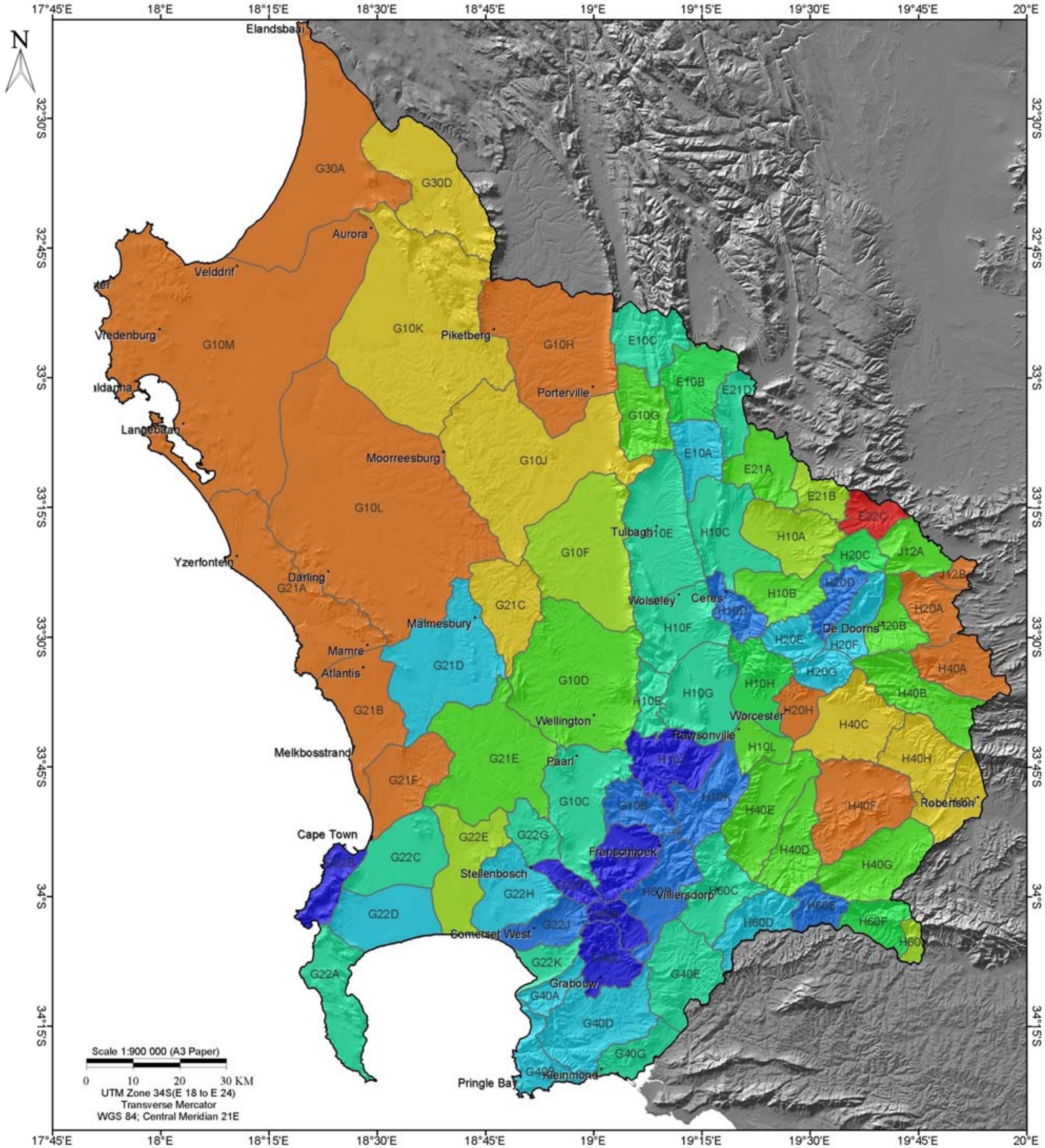
The relevant MAR for the aquifer outcrop areas is then calculated as

MAR aquifer = MAP aquifer (Berg WAAS) * MAR (WR2005) / MAP (WR2005)

Applying the GIS-based model above with respect to the MAP distribution within the quaternary catchment and therefore related to aquifer outcrop areas, recharge in the study area is calculated as 511 million m^3/a for the Peninsula Aquifer and 275 million m^3/a for the Nardouw Aquifer, respectively. The primary aquifers along the coast and in the river valleys receive recharge of 363 million m^3/a. The results per quaternary catchment are documented in **Appendix B**.

Table 5-7 Aquifer-specific recharge estimation per IWRM domain from Water Balance Model (ISP Method)

IWRM Domain	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Total aquifer specific recharge**	
	Mm^3	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*mm*
ATL	0.94	0.00	0.06	51.69	74.83	127.52	61
AWT	16.80	31.67	0.03	4.78	0.80	54.09	242
BRV	97.10	12.25	0.04	8.96	32.31	150.66	95
CFP	62.69	0.24	0.13	23.57	100.85	187.47	111
HEX	36.07	31.63	0.00	4.86	3.15	75.71	82
KGB	22.24	50.01	0.00	7.33	6.29	85.87	112
NUY	9.67	15.26	0.00	1.89	0.42	27.24	53
PKT	15.05	2.23	2.93	1.68	12.04	33.94	26
PUB	90.82	5.06	0.07	27.95	40.85	164.74	121
RBT	15.42	27.55	2.18	8.05	4.94	58.13	42
THK	64.23	44.20	0.00	15.23	6.76	130.42	115
TWR	36.23	15.23	2.22	12.52	11.35	77.53	42
VVT	33.61	4.97	0.46	13.99	18.79	71.82	77
WBK	9.66	34.85	1.43	27.89	6.73	80.56	58
WCT	0.13	0.00	0.05	11.61	43.20	54.99	11
Total	**511**	**275**	**10**	**222**	**363**	**1 381**	**62**



LEGEND

- Towns
- Quaternary Catchments
- Study Area

Recharge (mm)

- 0 - 10
- 10 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- 120 - 150
- 150 - 200
- 200 - 263

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

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RECHARGE PER QUATERNARY CATCHMENT (using ISP method)

FIGURE 5.5

5.2.4 Map-centric Simulation of Recharge

In the CAGE study (DWAF, 2000b), recharge to the Peninsula Aquifer was estimated using a digital elevation model and GIS-based approach that considered only the monthly winter rainfall and the EVT based on winter-temperature data, both modelled over the altitude and area of exposed, high-lying TMG.

The CAGE map-centric simulation method was adapted for the Berg WAAS with the emphasis on altitude and slope, these being the controlling variables on MAP, temperature and runoff as well as defining characteristics of aquifer type. The model takes the following into account:

- The MAP distribution was provided by the surface water team on a 100 m x 100 m grid;
- Mean monthly rainfall data from the Agrohydrology Atlas (Schulze et al., 1997) are re-calculated to be consistent with the revised MAP distribution
- Model Overland Flow (MOF) calculated for each slope element in the terrain model (**Figure 2-2**) to account directly for a component of surface run-off that is not available for infiltration;
- Actual evapotranspiration estimated for each pixel element in the digital elevation model, based on effective infiltration (MAP-MOF) and monthly temperature distribution, obtained from the Agrohydrology Atlas (Schulze et al., 1997);
- Rainfall, overland flow and evapotranspiration are calculated per month.

Precipitation

In order to account for seasonal influences on recharge, average monthly precipitation will be required as input to the recharge model. Spatial distribution of mean monthly rainfall was obtained from the Agrohydrology Atlas (Schulze et al., 1997).

The monthly rainfall data were re-calculated so that the total of 12 months is equal to the revised MAP distribution, adjusting the cell values proportionally.

$$\mathbf{MMP_{Berg} = MMP_{CCWR} * MAP_{Berg} / MAP_{CCWR}} \quad \textbf{(2)}$$

Overland flow

The determination of pixel level Model Overland Flow (MOF) is based on an analysis of a Newtonian fluid in laminar flow down an inclined plane surface (Welty et al., 1976, p. 115-117), wherein it is shown that the maximum velocity v_{max} at the parabolic profile is

$$v_{\max} = \frac{\rho g L^2 \sin(\theta)}{2\mu} \quad \textbf{(3)}$$

where ρ is the fluid density, g is the gravitational acceleration, L is the flow depth, μ is the fluid viscosity, and θ is the slope angle (op. cit., eqn 8-13). As ρ and μ are fluid constants, we assume that the MOF for each slope element is proportional to sin θ and a climate-terrain factor F, which incorporates and scales with the flow-depth (L^2):

$$\mathbf{MOF = MAP * \sin(\theta) * F} \quad \textbf{(4)}$$

As a first approximation of the factor F at a quaternary catchment scale, the MAP * sin (θ) component of MOF is normalised to the quaternary MAR value given in the WR90 summary compilation (Midgley at al., 1994a). This is undertaken to ensure that the modelled overland flow is not exceeding the observed run-off per catchment. However, this does not take into account the groundwater contribution to baseflow and interflow.

The factor F varies between 3.11 and 0.09, indicating a wide range of rainfall – run-off relationship that apparently depends on several factors, slope being only one. Furthermore, the factors vary significantly between neighbouring catchments, resulting in distinct changes of overland flow at catchment boundaries. If using the MAR values from the WR2005 study, the range of the factor F increases, but the overall distribution remains similar.

The spatial distribution of these catchment specific factors shows two distinct areas, where the factor F is far less than 1, indicating a calculated overland flow that is significantly higher than the reported MAR, while in most of the study domain the calculated overland flow is less than the reported MAR. These areas can be linked to specific IWRM domains:

- Piketberg and adjacent low-lying catchments (PKT);
- Hex River Mountains and Hex River Valley (HEX);
- Nuy Valley and northern tributaries (NUY);
- Middle Breede and southern tributaries (RBT).

The catchment with the lowest factor, namely 0.09, is the Nuy valley (H40B) with a reported MAR of 15 mm and a calculated overland flow of 160 mm. H40B together with the adjacent Hex River valley catchments H20B, H20C, H20F and H20G fall in zone B1 for the Pitman model calibration, using a set of calibration parameter values that are unusually different (see **Table 5-8**) compared to the adjacent B24 zone. It comprises the highest values of ST, ZMIN and ZMAX as well as the lowest values of FT for a perennial system, which together results in significantly decreasing the simulated river flow (see Table 5.11 in Midgley et al., 1994b). Further analysis of the physiography and hydrology of these areas indicates significant differences to the adjacent IWRM domains and catchments, viz.

- bimodal distribution of the slope frequency, indicating a mix of flat areas and steep mountain ranges (PKT, RBT, partly in HEX and NUY);
- dominance of Peninsula and Nardouw outcrops in high mountain range (PKT, HEX, NUY);
- dominant soil type of moderate to deep, undulating sandy loam (HEX, NUY);
- very low rainfall – runoff response, distinctly different from adjacent catchments, resulting in very low MAR (HEX, NUY);
- mostly ephemeral system (PKT, RBT, upper parts of NUY), or
- distinct discharge area, fed by deep groundwater flow from different catchments (HEX).

Table 5-8 Pitman model parameters for selected zones (Midgley et al., 1994a)

Parameter Zone	Catchments	POW	SL	ST	FT	ZMIN	ZMAX
A1	H20A, H40A	0	0	250	0	30	250
A4	G10K – M, G21A, B, G30A, B	0	0	200	0	15	450
A7	H10L, H20H, H40C – J	0	0	200	0	15	220
B1	H20B, C, F, G, H40B	2	0	450	4	50	900
B8	G10J, H, G21C – F, G22A – E, G, H	2	0	270	10	30	500
B14	G10C – G	2	0	250	40	20	500
B19	H60A – C	2	0	270	60	0	450
B20	H10E, J, K	2	0	340	70	0	600
B23	G22J, K, G40A – D	2	0	270	75	0	450
B24	H10A – D, F – H, H20D, E	2	0	180	75	0	450
B26	G10A, B, G22F	2	0	270	100	0	400

The parameter zones can be mapped against the slope distribution grouping, as developed in Section 2.1.2. **Table 5-9** shows that the coastal ephemeral catchments (Parameter zone A4) mainly fall within the slope distribution groups 7 and 9, while the mountain catchments in parameter zones B20 and B26 comprises the slope groups 2 and 3, respectively. The parameter zone B1 comprises catchments that show different slope distribution (Group 1, 3 and 4), but all fall within the IWRM Group A.

Table 5-9 Pitman model parameter zones vs. slope distribution grouping

Parameter Zone	Catchments	Slope Distribution Groups	
		Quaternary	IWRM
A1	H20A, H40A	5	HEX (A), NUY (A)
A4	G10K – M, G21A, B, G30A, B	7, 9	PKT (C), WCT (D)
A7	H10L, H20H, H40C – J	4, 5, 7, 9	RBT (B), BRV (A)
B1	H20B, C, F, G, H40B	1, 3, 4	HEX (A), NUY (A)
B8	G10J, H, G21C – F, G22A – E, G, H	7, 8	CFP (C), ATL (D), TWR (C)
B14	G10C – G	7, 5	PUB (B), VVT (C)
B19	H60A – C	5	THK (A)
B20	H10E, J, K	2	BRV (A)
B23	G22J, K, G40A – D	5, (3, 4)	KGB (B), CFP (C)
B24	H10A – D, F – H, H20D, E	1, 5, 6, 0	BRV (A), WBK (B)
B26	G10A, B, G22F	3	PUB (B), CFP (C)

As discussed in Section 2.3.3, there is a close relationship between slope frequency distribution, geology and aquifer type. It was therefore decided to apply aquifer-specific correction factors in each IWRM domain for calculating the modelled overland flow (see **Table 5-10**). The factors were determined based on the premises that

- the modelled overland flow should not be exceeding the reported MAR for a specific quaternary catchment;
- the aquifer-specific factors are in a similar range across the study domain;
- differences between coastal, flat IWRM domains and mountainous IWRM domains are expected and acceptable.

Although the above criteria are not always met, the range of factors applied is justified due to the difference in hydrological response to rainfall in the catchments and IWRM domains.

The disadvantage of this approach is that it is not fully independent of the catchment run-off (MAR), which is measured as river flow and includes other components such as interflow and baseflow.

Since the recharge estimation will be undertaken in monthly time steps, the modelled overland flow is also calculated per month, as

$$\mathbf{MOF_i = MMP_i * \sin(\theta) * F} \qquad \mathbf{(5)}$$

Table 5-10 Aquifer-specific correction factors per IWRM domain for map-centric recharge estimation

IWRM Domain	Peninsula	Nardouw	Other Fractured	Intergranular fractured	Intergranular
ATL	1.0		1.0	1.2	2.0
AWT	0.8	0.8	1.0	0.8	0.8
BRV	0.8	0.8	1.0	0.7	0.8
CFP	0.6	0.8	0.9	0.9	0.8
HEX	0.5	0.3		0.6	0.6
KGB	0.8	0.6		2.0	0.9
NUY	0.6	0.5		0.6	0.6
PKT	0.5	0.4	0.6	0.6	0.8
PUB	0.8	0.7	0.9	2.0	0.8
RBT	0.5	0.7	0.9	0.8	0.8
THK	0.8	0.8		0.8	0.9
TWR	0.8	0.8	0.9	1.0	0.9
VVT	0.8	0.7	0.9	1.3	0.8
WBK	0.6	0.8	0.9	1.3	1.0
WCT	1.0		1.0	1.5	1.5

Temperature

As for the precipitation, spatial distribution of mean monthly values of maximum temperature was obtained from the Agrohydrology Atlas (Schulze et al., 1997). This will be input to the evapotranspiration calculation.

Evapotranspiration

Evapotranspiration from soil and plants can only be applied to the effective rainfall, as the overland flow is not available for soil infiltration and plant uptake. The modified equation from Turc (1954) then reads:

$$EVT = \frac{(MAP - MOF)}{\sqrt{0.9 + (MAP - MOF)^2 / L^2}} \qquad \textbf{(6)}$$

with

$$L = 586 - 10T + 0.05T^3 \qquad \textbf{(7)}$$

where T is mean maximum temperature.

Since the estimation is conducted using monthly time steps, the equation for each month i reads:

$$EVT_i = \frac{(MMP_i - MOF_i)}{\sqrt{0.9 + (MMP_i - MOF_i)^2 / L^2}} \qquad \textbf{(8)}$$

The application of the equation from Turc (1954) for the estimation of actual evapotranspiration is supported by the Food and Agricultural Organisation (FAO), which ranked the Turc equation second after the Penman-Monteith method (FAO, 2001).

Recharge

The above equations are then applied to monthly values and summed over one annual cycle to calculate recharge as:

$$\mathrm{Re} = \sum_{i=1}^{12} (MMP_i - MOF_i - EVT_i) \quad \textbf{(9)}$$

Alternatively, the equations are summed over the winter rainfall period (i.e. May to October) to account for the seasonal pattern in the Western Cape.

$$\mathrm{Re} = \sum_{i=5}^{10} (MMP_i - MOF_i - EVT_i) \quad \textbf{(10)}$$

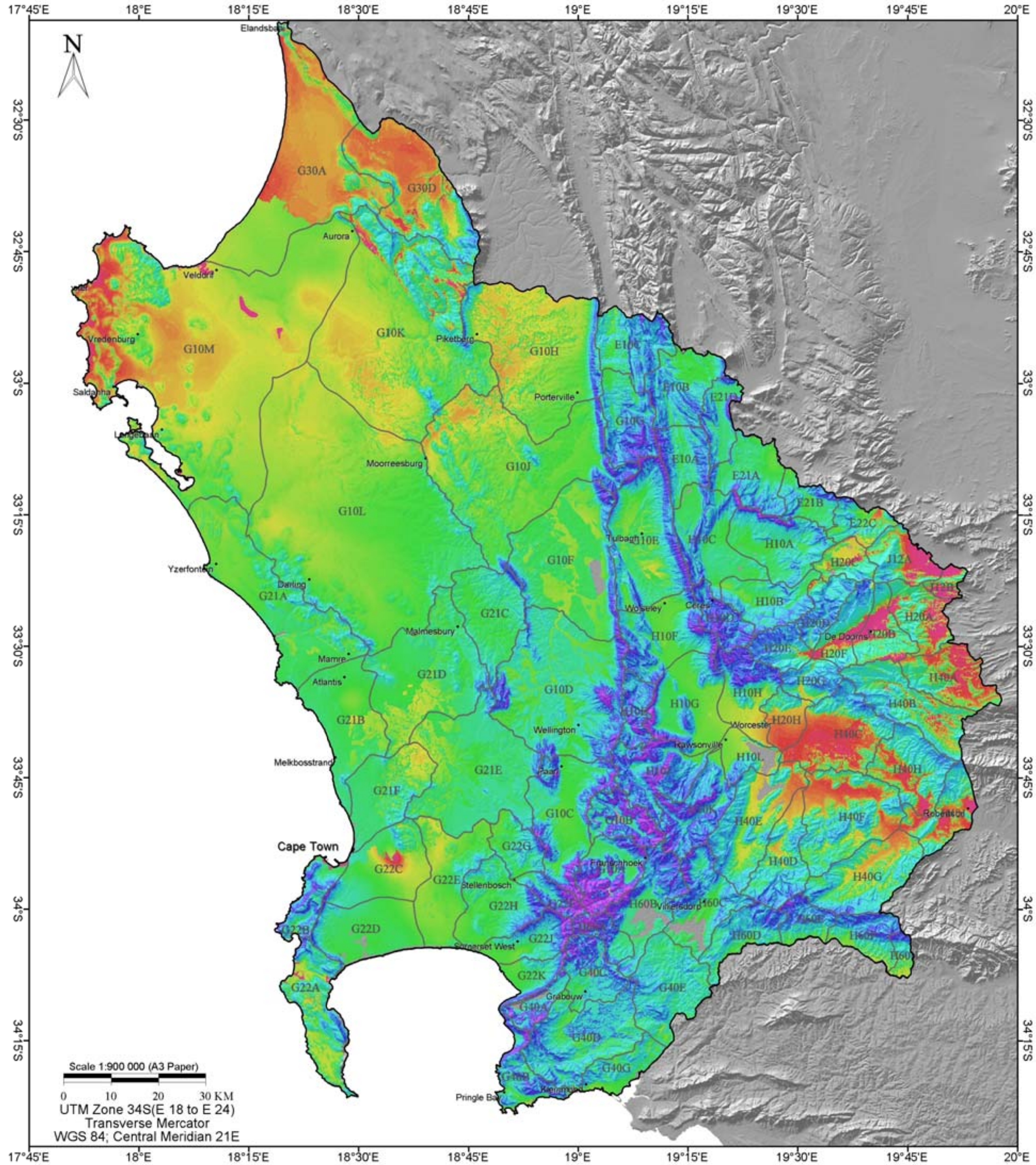
Irrespective of the calculation above, the recharge is generally set to zero in the areas that are delineated as discharge areas (i.e. relative relief <-40).

The equation (9) is very similar to equation (1) as used in the ISP Method. The main differences in the two approaches are that:

- the map-centric approach uses a modelled overland flow that is dependent upon the slope, while the ISP method uses the MAR values per catchment;
- the map-centric approach is calculated in a 100 m grid size, while the ISP method averages the input parameters over a much larger area, normally several km^2: and
- discharge areas are assigned zero recharge in the map-centric simulation.

Table 5-11 Aquifer-specific recharge estimation per IWRM domain from map-centric Method

IWRM Domain	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Total aquifer specific recharge**	
	Mm^3	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*mm*
ATL	0.14		0.02	34.99	29.47	64.63	31
AWT	6.31	19.25	0.01	7.69	0.67	33.93	68
BRV	48.09	6.97	0.13	20.37	39.85	115.41	74
CFP	16.20	0.05	0.03	21.88	57.07	95.23	57
HEX	20.88	33.01		16.51	8.82	79.22	86
KGB	9.40	30.14		11.18	4.59	55.32	73
NUY	8.50	17.83		14.87	1.00	42.20	82
PKT	13.22	2.21	4.14	4.30	28.06	51.93	40
PUB	32.00	3.72	0.04	24.86	31.39	92.01	68
RBT	6.62	25.97	4.16	44.39	19.11	100.25	73
THK	32.81	30.96		28.55	8.49	100.81	93
TWR	9.14	6.97	0.78	30.78	6.66	54.34	30
VVT	5.71	1.80	0.14	13.36	10.05	31.07	34
WBK	5.09	16.66	1.24	34.61	5.51	63.11	57
WCT	0.10		0.04	39.69	99.49	139.32	27
Total	**214.22**	**195.54**	**10.75**	**348.02**	**350.26**	**1 118.79**	**51**



LEGEND

- Towns
- Quatenary Catchments
- Study Area

Overlandflow Distribution

2392
532
266
0

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

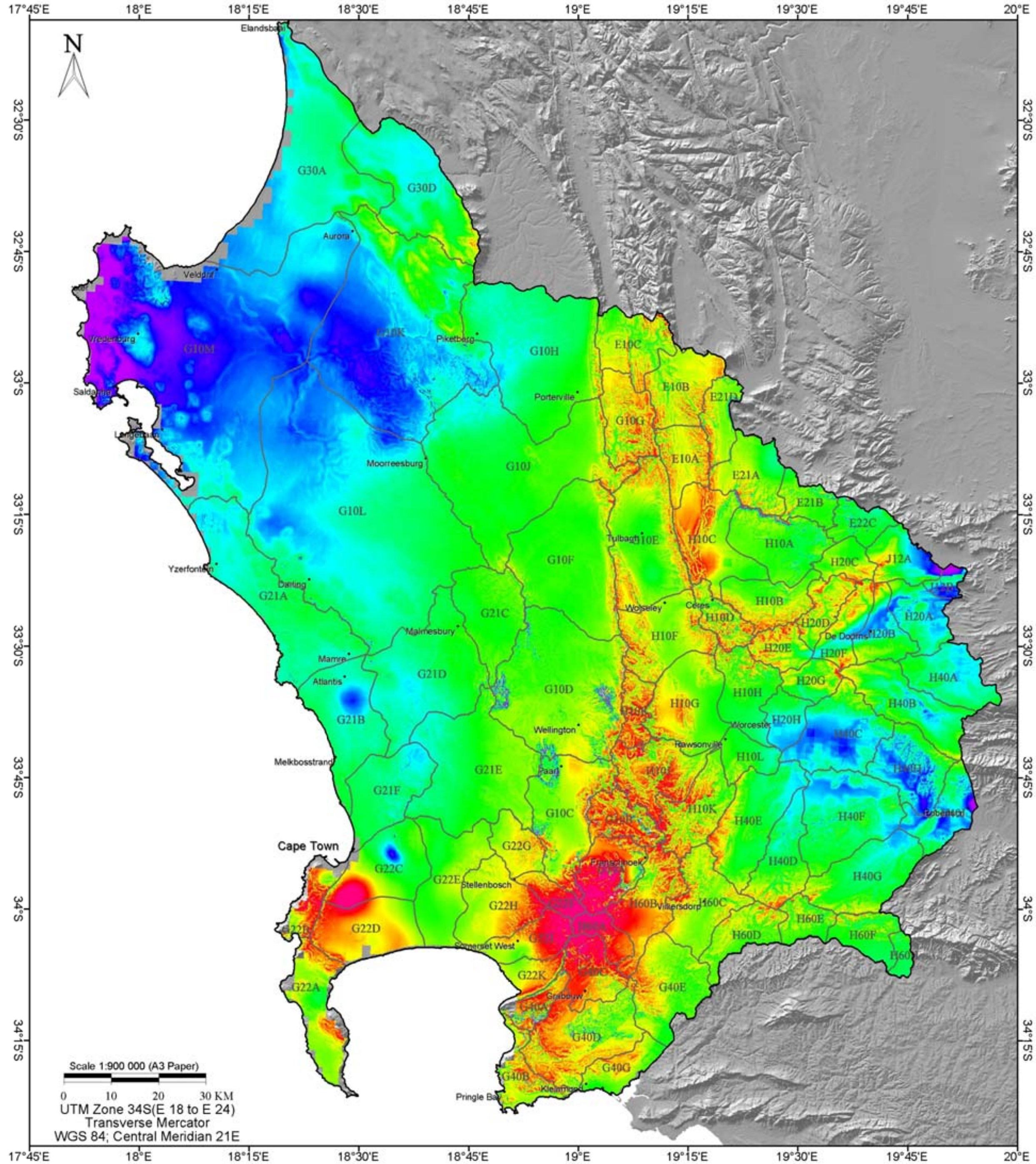
CONSULTANT

UMVOTO

TITLE

MODELLED OVERLANDFLOW DISTRIBUTION

FIGURE 5.6



LEGEND

- Towns
- Quatenary Catchments
- Study Area

Evapotranspiration Distribution

2350
841
673
505
337
170
2

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

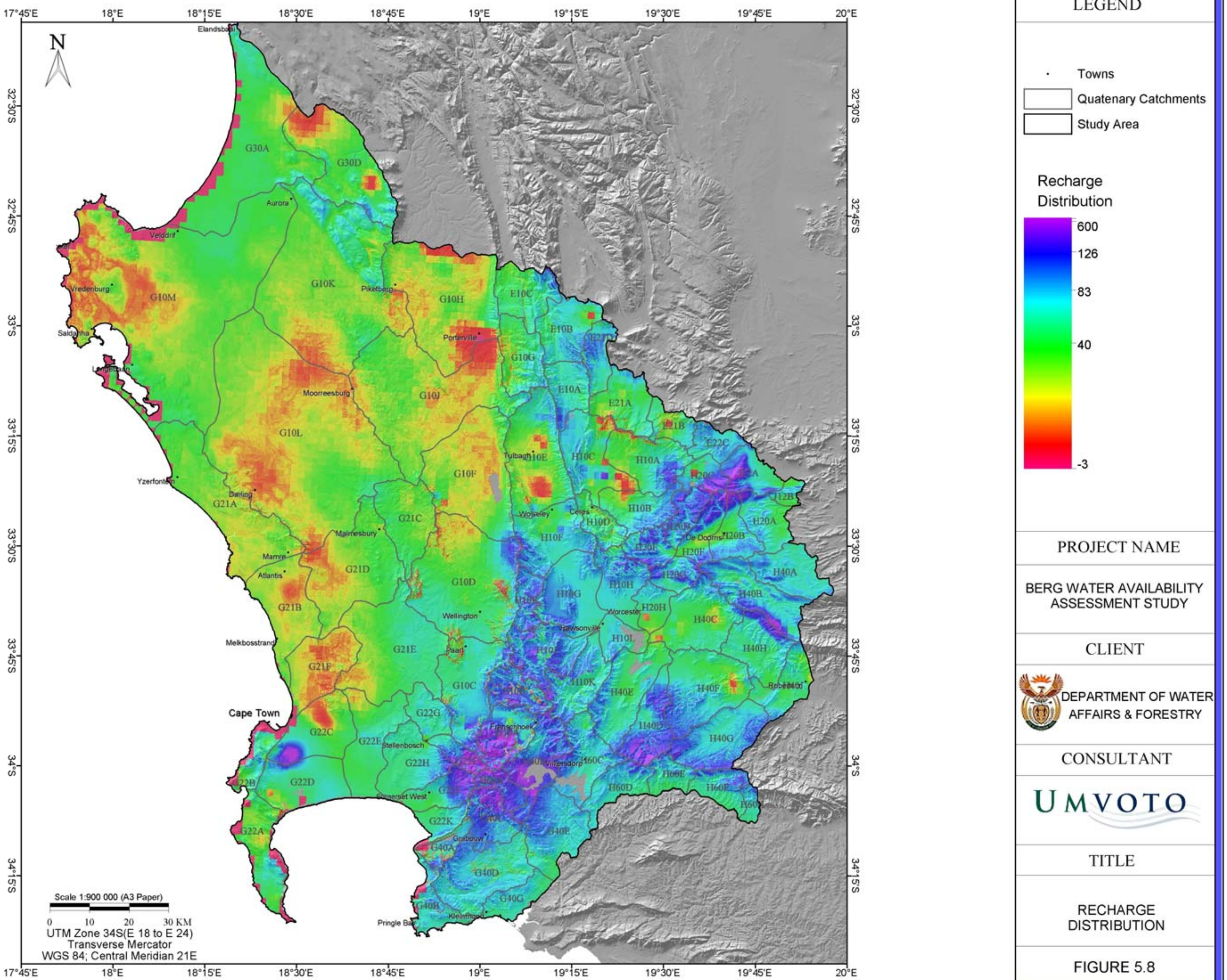
CONSULTANT

UMVOTO

TITLE

EVAPOTRANSPIRATION DISTRIBUTION

FIGURE 5.7



PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

RECHARGE DISTRIBUTION

FIGURE 5.8

5.2.5 Monthly Water Balance Model of Recharge

Recharge was estimated for three catchments (G10E, G21C and G22H) in monthly time steps as a comparison and sensitivity analysis of the water balance model. The following three scenarios were considered:

Scenario 1

This scenario attempts to replicate the approach that was followed in the Water Balance Model i.e. runoff is not adjusted to account for groundwater contributions to baseflow. In addition, the potential evapotranspiration is used as opposed to the actual evapotranspiration.

MAP = updated Berg WAAS MAP

MAR = naturalised WR2005 runoff volumes

EVT = S-pan values adjusted with relevant pan factors to represent potential catchment evapotranspiration

Scenario 2

In an attempt to ensure that the runoff volumes that are used in the water balance equation are more representative of only the surface water component of runoff, i.e. excluding groundwater contribution to baseflow, the WR2005 monthly runoff volumes for each hydrological year were adjusted (reduced) by the average value of the January, February and March runoff volumes in the subsequent hydrological year. This assumes that all of the streamflow during these low flow months may be ascribed to groundwater discharge.

The estimates of groundwater contribution to baseflow based on this approach are comparable to the GRDM estimates (see Section 6.2) i.e. 9.2 mm vs 13.6 mm (G10E), 2.3 mm vs 8.0 mm (G21C) and 9.2 mm vs 9.2 mm (G22H). The second value in each instance represents the GRDM estimate.

MAP = updated Berg WAAS MAP

MAR = adjusted (reduced) WR2005 runoff volumes to account for groundwater contribution to baseflow

EVT = S-pan values adjusted with relevant pan factors to represent potential catchment evapotranspiration

Scenario 3

In order to ensure that the evapotranspiration that is used in the water balance equation is representative of actual evapotranspiration, monthly estimates of actual evapotranspiration were calculated based on Acocks crop factors and monthly A-pan values.

MAP = updated Berg WAAS MAP

MAR = adjusted (reduced) WR2005 monthly runoff volumes to account for groundwater contribution to baseflow

EVT = actual evapotranspiration based on A pan evaporation * Acocks crop factor

The monthly estimates of EVT, based on Acocks crop factors multiplied by monthly A-pan values, represent the EVT demand / potential field EVT. During the dry season, this EVT demand is often not met, which implies that the actual EVT is less than the potential EVT on an annual basis.

In all three scenarios recharge is calculated in monthly time steps. In months where EVT and or run-off exceed precipitation, recharge is set to zero.

Figure 5-9 shows the time series of annual precipitation and run-off, as well as the calculated actual evapotranspiration and estimated recharge for the G10E catchment. Actual evapotranspiration was calculated in monthly time steps by assuming that rainfall in that month either contributes to run-off or to recharge or evaporates. In months, where recharge is set to zero, the actual EVT is less than the EVT demand. As can be seen in **Figure 5-9** the actual EVT is always significantly less than the EVT demand according to Acocks. The calculated actual EVT is in the same order of magnitude than the EVT calculated with Turc (1954).

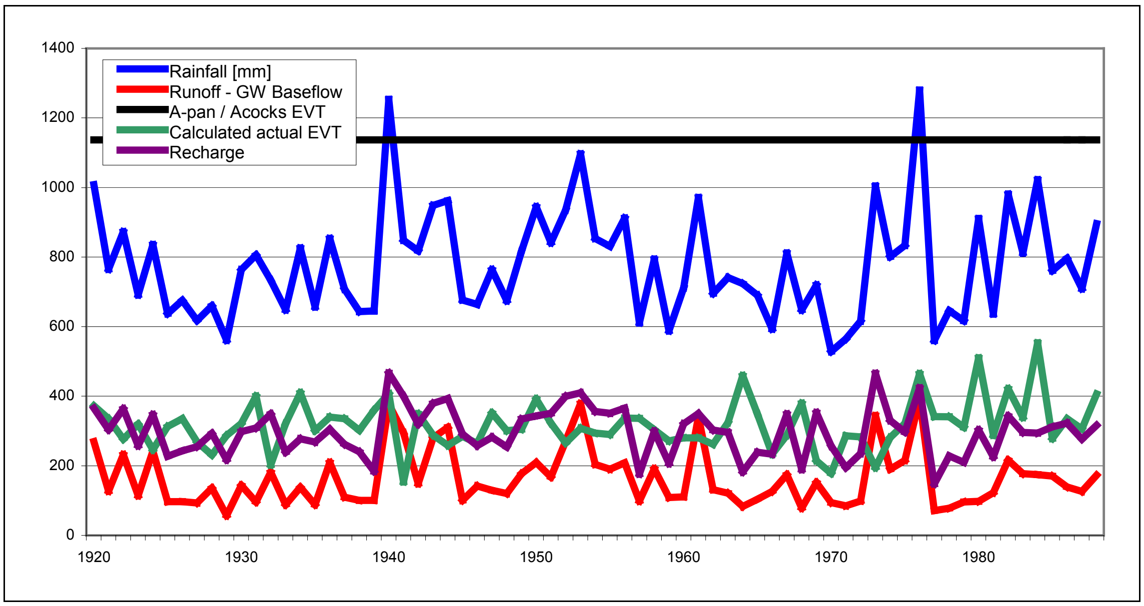


Figure 5-9 Time series of rainfall, run-off, calculated EVT and estimated recharge for catchment G10E [in mm/a]

The results of the sensitivity analyses are presented in **Table 5-12** and indicate that:

- in the case of Scenario 1, which neglects groundwater contributions to baseflow and assumes evapotranspiration equal to potential evapotranspiration, annual recharge varies between 21% and 27% of MAP
- the adjustment (reduction) to runoff to take into account the effect of groundwater contribution to baseflow has a negligible effect on recharge volume (Scenario 2)
- the use of actual evapotranspiration instead of potential evapotranspiration has a significant impact on recharge volumes and increases annual recharge by between 49% and 59% (Scenario 3).

Table 5-12 Results of water balance sensitivity analyses

Quaternary Catchment	ISP	Map-centric	Scenario	MAP	MAR	EVT	Recharge	
	(mm)	(mm)		(mm)	(mm)	(mm/a)	(mm/a)	(% MAP)
G10E	105	41	1	769	201	1568	160	21
			2	769	192	1568	162	21
			3	769	192	1137	255	33
G21C	27	36	1	547	58	1496	147	27
			2	547	56	1496	147	27
			3	547	56	1113	226	41
G22H	122	62	1	814	191	1353	202	24
			2	814	182	1353	205	24
			3	814	182	993	301	36

Although the above analyses were primarily aimed at investigating the relative sensitivity of recharge to various assumptions and interpretations of the terms in the proposed water balance equation, it is interesting to note that the recharge volumes as calculated with this review are an order of magnitude larger than the recharge estimates obtained from the ISP and map-centric methods (see **Table 5-12**). This apparent discrepancy in terms of the absolute recharge volumes may be ascribed to several factors, e.g.

- scale effects (in this model, the water balance equation was applied on a quaternary catchment scale as opposed to finer, sub-quaternary scales in the ISP and map-centric methods),
- the application of different methodologies for the estimation of evapotranspiration.

5.3 ENVIRONMENTAL TRACERS

5.3.1 Chloride method

The CAGE recharge model was calibrated and the results confirmed using the chloride method as part of the Clanwilliam Dam Raising Feasibility Study (DWAF, 2006a).

The chloride mass balance method is based on the fact that chloride is a conservative environmental tracer, i.e. it is subject to neither adsorption nor desorption during transport. Chloride enters the soil from infiltrating rainfall and is subsequently concentrated by evaporation and transpiration. Recharge can then be estimated as (Bredenkamp et al., 1995)

$$\textbf{Recharge (mm/a)} = (\textbf{MAP} \times \textbf{Cl}_{\textbf{rain}} + \textbf{D}) / \textbf{Cl}_{\textbf{gw}} \qquad \textbf{(11)}$$

Where

- MAP is annual precipitation (mm),
- Cl_{rain} is average Chloride concentration in rain water,
- D is dry chloride deposition ($mg/m^2/a$), and
- Cl_{gw} is harmonic mean Chloride concentration in boreholes.

The Chloride Mass Balance method was used in the Clanwilliam Study (DWAF, 2006a) to calibrate the GIS-based recharge estimation from the CAGE project (DWAF, 2000b). The rainfall chloride concentration was established by sampling of rain with rainfall collectors installed at different elevations throughout the Peninsula outcrop area. The same method was applied in Hermanus to estimate the recharge to the Peninsula Aquifer (Umvoto, 2007). It is important to have rainfall samples from strategically placed positions across the study domain for a reliable application of the chloride method.

The recharge estimation on a national scale from the GRA II project (DWAF, 2006d) is based on the Chloride method. Currently the distribution of rainfall sampling points is not sufficient to generate a reliable distribution of rainfall chloride concentration. Since the spatial distribution and actual values of the rainfall chloride concentration are not available for evaluation, the results of the GRA II project are not considered reliable.

5.3.2 Isotopes

The Deuterium (^2H) ratio and Oxygen (^{18}O) ratio of samples from the Peninsula, taken during the CAGE projects have an average of –19.96 and –4.31, respectively; samples taken from the Boschkloof wellfield near Citrusdal show ratios of –26.44 and –5.32, respectively (DWAF, 2006a). Samples from springs and high-lying streams, taken during a hydrocensus in the TMG domain early 2004, show average ratios of –20.02 and –4.28, respectively (City of Cape Town, 2005).

These values are very close to the Global Meteoric Water Line (GWML), indicating a high recharge percentage. However, the data set is not sufficient for quantification of recharge.

5.4 WATER LEVEL FLUCTUATION METHODS

The seasonal groundwater level fluctuations can be used to calculate the recharge to the aquifer. However, the standard methods (i.e. Saturated Volume Fluctuation, SVF, and Cumulative Rainfall Departure, CRD) only apply to unconfined aquifers and require an estimate of the groundwater outflow or discharge.

An alternative method was developed for the confined Peninsula Aquifer, which is based on fluctuations in hydraulic head, measured in boreholes that are not influenced by pumping, and the storage coefficient, as derived in Section 6. The underlying assumptions are illustrated in **Figure 5-10** and listed below:

- Recharge enters the unconfined portion of the aquifer across the whole outcrop area;
- Recharge results in water level rise in the unconfined portion at least up to the same amount than measured in the confined portion;
- Discharge from the confined portion of the aquifer continues during the recharge period;
- Storage coefficient is uniform over the confined portion of the aquifer;
- Specific yield is uniform over the unconfined portion of the aquifer.

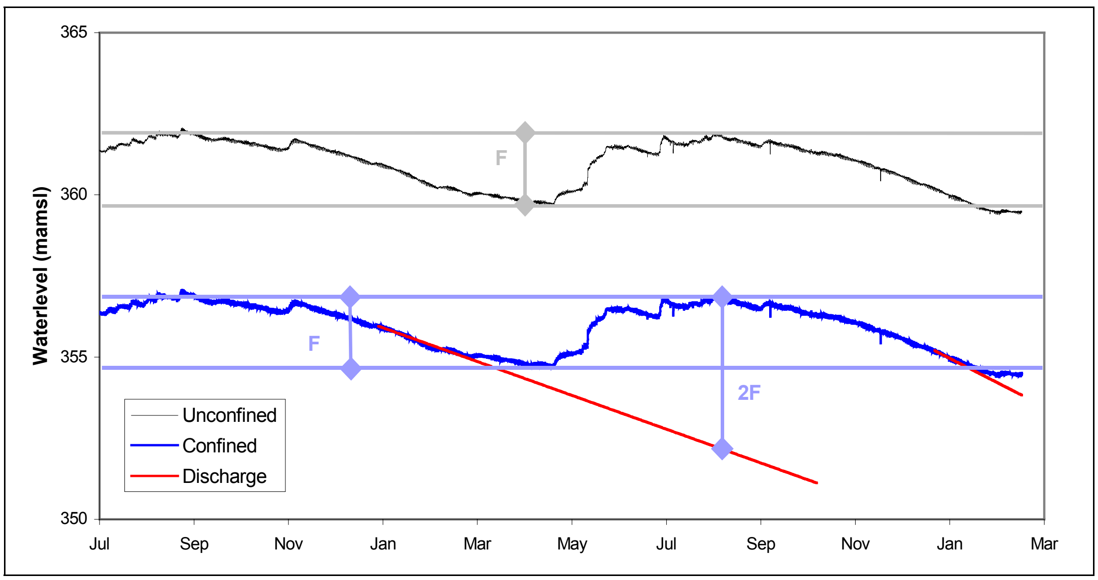


Figure 5-10 Principles of Water Level Fluctuation method for confined aquifer

The average recharge for the aquifer [in mm/a] is then calculated as:

$$Re = (A_{conf} * S + A_{unconf} * S_y) * 2F / A_{unconf} \qquad (12)$$

with

A_{conf}	Effective area of confined portion of aquifer
A_{unconf}	Outcrop area (i.e. unconfined portion) of aquifer
S	Storativity of confined portion of aquifer
S_y	Specific Yield of unconfined portion of aquifer
F	Annual fluctuation of hydraulic head (difference winter – summer)

Time series data of water level measurements in the confined Peninsula Aquifer are available from different sites within the model domain as well as from sites in close proximity. An analysis of these data indicated a range of seasonal water level fluctuations, depending upon physiographic setting and length of flow path from recharge area (see **Table 5-13**).

Table 5-13 Seasonal water level fluctuations in Peninsula Aquifer from different areas

Area	Source	Seasonal fluctuation	Physiographic setting
Hermanus	Umvoto (2007)	0.5m	Coastal area, short flow path
Kogelberg	WRC (in prep.)	1.5m	Faulted system, medium flow path
Purgatory	WRC (in prep.)	2.2m	Faulted system, short flow path
Blikhuis	Hartnady (in prep.)	1.5m	Within basin, long flow path

Based on these field data, average annual water level fluctuations were assigned to each IWRM domain and equation 12 applied to calculate the average recharge to the Peninsula Aquifer (see **Table 5-14**).

Table 5-14 Recharge estimation for the Peninsula Aquifer, based on water level fluctuations

IWRM	Area [km^2]		Pore Volume	Seasonal Fluctuation	Recharge	Recharge Volume
Domain	Confined	Unconfined	[Mm^3]	[m]	[mm/a]	[Mm^3/a]
ATL	Not considered, as aquifer is too small					
AWT	229.05	45.21	15 044	1.2	204	9.21
BRV	540.98	518.13	52 063	2	229	118.83
CFP	3.27	45.46	617	1	101	4.60
HEX	564.59	182.59	41 418	1.5	212	38.75
KGB	568.36	91.92	36 102	1.5	274	25.22
NUY	428.21	77.86	26 961	1.5	263	20.47
PKT	55.00	55.76	38 128	1	116	6.45
PUB	49.98	210.72	9 244	1.5	155	32.61
RBT	1 193.47	59.27	73 173	0.5	192	11.36
THK	627.63	220.76	49 716	2	282	62.30
TWR	189.37	101.21	15 492	1.5	193	19.58
VVT	47.47	80.87	4 916	1.5	162	13.11
WBK	615.07	60.53	36 514	1.5	353	21.36
WCT	Not considered, as aquifer is too small					
TOTAL	**5 112.44**	**1 750.27**	**399 390**		**219**	**383.84**

5.5 SUMMARY AND COMPARISON

The results of the GIS-based aquifer-specific recharge calculations are compared to other approaches and results from other studies (see **Table 5-15**).

A comparison of the different methods indicates significant differences in several quaternary catchments. While a fixed recharge percentage assumes a linear relationship between recharge and total MAP and does not consider topographically controlled differences in MAP, the BRBS model from the Breede River Basin Study does not take into account different topographic settings as reflected in the rainfall – run-off responses. Neither methods take into account the winter recharge pattern in the study domain, i.e. the systems are recharged when EVT is at the lowest.

On the other hand the ISP method yields higher values of recharge to the Peninsula Aquifer than the other GIS-based methods. This is possibly due to the recharge in the high-lying areas that receive the highest precipitation and have little evapotranspiration. Possible reasons for this discrepancy are the different approach and the different data sources as well as the different scales of the data sets.

The GRA II 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 the dry deposit of chloride is most relevant in close 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.

Table 5-15 Comparison of recharge estimations

	Recharge [million m^3/a]					
Aquifer type	Fixed %	BRBS	ISP	GRA II	Map-centric	SVF conf
Peninsula	404	406	511	433	214	384
Nardouw	140	215	275	241	196	N/a
Fractured	7	7	10	6	11	N/a
Intergranular-fractured	123	223	222	323	348	N/a
Intergranular	147	375	363	326	350	N/a
Total aquifer specific	**822**	**1 227**	**1 381**	**1 328**	**1 119**	**N/a**

The map-centric simulation considers the different rainfall – run-off responses, the potential overland flow, as well as the actual evapotranspiration, which is dependent upon the effective rainfall and maximum temperature. Furthermore, the delineation of recharge and discharge zones and the seasonal pattern of winter rainfall are taken into account. However, the results for the TMG aquifers are considerably lower than with the other methods (see **Table 5-15**), probably due to the emphasis on the slope-dependent overland flow that is not available for infiltration and the delineation of discharge and recharge zones, i.e where the aquifer is discharging it is assumed that it cannot be recharged. The results are considered conservative and require verification with other methods like Chloride Mass Balance or Saturated Volume Fluctuation, using spatially distributed field data.

On the other hand, the results for the ‘intergranular-fractured’ aquifer type are significantly higher than compared to the other methods. This would require verification on a local scale prior to allocating the water for use.

Based on the comparison of the different approaches the average of the different methods will be used as average recharge, while the recharge estimations from the ISP Method and from the map-centric simulation are used as best case and worst case, respectively, in the discharge estimation and the water balance yield analysis (see Section 6.1 and 7.2).

6. DISCHARGE

Discharge from the groundwater system occurs either naturally as discharge in springs and seepzones, into rivers or into the sea, or artificially as abstraction from boreholes.

6.1 NATURAL DISCHARGE

The most common way to estimate the natural discharge from aquifers into river reaches is the baseflow separation method. Historically, hydrologists separated river flow into floods and baseflow components based on flow characteristics, while geohydrologists tried to consider that component derived from groundwater, i.e. process hydrology. Depending upon the applied hydrograph separation method baseflow comprises flow from different sources; i.e. interflow, delayed run-off and groundwater discharge. Groundwater contribution dominates only in prolonged dry periods.

In applying this method, it is therefore important to distinguish between the total baseflow and the groundwater contribution to baseflow. The published estimates for baseflow and groundwater contribution to baseflow in the different quaternary catchments are listed in **Appendix A**.

The differences in baseflow estimation indicate the inaccuracy and subjectivity of this method. It is beyond the scope of the regional water balance task to verify the baseflow estimation figures. It is recommended to use the GRDM data (DWAF, 2006f) as input for the water balance model and resource evaluation in section 7, as these are the most recent data and were prepared for groundwater reserve determination and resource evaluation. Alternatively, groundwater contribution to baseflow can be assumed to be equal to the averaged flow in the three driest months per year, viz. January, February and March. This method would allow producing annual time series of baseflow, showing the impact of climate variation.

However, the disadvantage of both methods is that they cannot account for different aquifers, i.e. the result is not aquifer specific. To calculate the baseflow contribution from the Peninsula Aquifer in the study area, two approaches are considered;

- spatial disaggregation of data proportionally to outcrop area, and
- spatial disaggregation of data proportionally to recharge.

The results of both approaches are documented per quaternary catchment in **Appendix D.1** and **D.2**. The spatial disaggregation based on recharge is summarised per IWRM domain in **Table 6-1** and **Table 6-2.**

The spatial disaggregation of data based on outcrop area lacks physical meaning because it assumes that all aquifers present in the catchment have continuous contact with the river along the river reaches, and neglects the three dimensional (3D) relationship between different aquifers and springs. It also neglects the fact that the contribution of different aquifers towards the total baseflow in the river varies significantly. In that regard, the second approach, viz. using recharge as indicator, is considered more appropriate and realistic.

However, this method does not take into account the possible subsurface transfer of water between catchments or even between IWRM domains, nor groundwater discharge to the ocean as it only uses the aquifer-specific recharge within each catchment compared to the total groundwater contribution to baseflow within the same catchment. This simplification is required in the analytical and GIS modelling, as no other data and information is currently available to quantify subsurface transfer between catchments. Thus the method most likely overestimates the groundwater contribution to baseflow in certain catchments. This will be addressed in the detailed model reports (Volume 5 to 9), where applicable.

The Conceptual Model Report (DWAF, 2007b) identified the Sand River in the Hex River IWRM domain as a major discharge area, which is fed by recharge in the Agter-Witzenberg IWRM domain. Similar subsurface transfers between catchments and between IWRM domains can be expected in other areas. This transfer can only be addressed and quantified using a groundwater flow or other numerical models.

It also raises the question as to the scale at which the WRYM can be reliably used for water regulation decisions if groundwater storage and discharge to the ocean is not included in it. Given that the critical limitation in the current integration of groundwater into the Pitman model, which is input to the WRYM, is that all groundwater recharge is discharged into the same quaternary aquifer, mapping and quantifying the scale of surface water groundwater interaction process becomes critical to establishing reliable fluxes. This aspect is addressed further in Section 7.4.

Table 6-1 and **Table 6-2** below show the variations in the baseflow contribution for the aquifer types in different IWRM domains, based on proportional recharge. A significant baseflow contribution is calculated from the Peninsula Aquifer (almost 40% of total groundwater contribution to baseflow in the study area). This increases to more than 70% in the TMG dominated IWRM domains (e.g. Brandvlei, Hex River and Paarl-Upper Berg IWRM domains).

Table 6-1 Aquifer-specific discharge estimation per IWRM domain, groundwater contribution to baseflow disaggregated according to recharge (based on map-centric recharge estimation)

IWRM Domain	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Total GW contribution to baseflow**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
ATL	0.03	0.00	0.00	7.44	5.10	12.57	6
AWT	2.43	7.75	0.00	2.69	0.28	13.15	59
BRV	17.98	2.08	0.01	3.87	8.50	32.44	21
CFP	5.58	0.01	0.01	4.24	10.90	20.74	12
HEX	3.76	2.74	0.00	0.60	0.52	7.62	8
KGB	5.59	13.76	0.00	8.19	2.17	29.71	39
NUY	0.10	0.56	0.00	0.41	0.03	1.10	2
PKT	0.00	0.00	0.00	0.00	0.00	0.00	0
PUB	9.97	1.41	0.01	4.17	6.13	21.69	16
RBT	0.07	0.24	0.01	0.31	0.17	0.79	1
THK	6.06	6.31	0.00	5.07	1.70	19.13	17
TWR	2.92	2.88	0.19	6.68	1.44	14.11	8
VVT	1.81	0.59	0.07	4.11	3.14	9.72	10
WBK	1.64	4.87	0.30	6.29	0.94	14.04	10
WCT	0.00	0.00	0.00	0.04	0.13	0.16	0
Total	**58**	**43**	**1**	**54**	**41**	**197**	**9**

Table 6-2 Aquifer-specific discharge estimation per IWRM domain, groundwater contribution to baseflow disaggregated according to recharge (based on ISP Method recharge estimation)

IWRM Domain	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Total GW contribution to baseflow**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
ATL	0.27	0.00	0.01	5.65	6.63	12.56	6
AWT	4.01	8.02	0.00	1.18	0.27	13.48	60
BRV	23.22	2.24	0.00	1.54	5.21	32.22	20
CFP	6.69	0.02	0.01	2.59	11.42	20.74	12
HEX	4.56	2.59	0.00	0.32	0.22	7.69	8
KGB	7.27	17.95	0.00	2.63	1.62	29.47	38
NUY	0.23	0.85	0.00	0.08	0.02	1.18	2
PKT	0.00	0.00	0.00	0.00	0.00	0.00	0
PUB	13.32	0.96	0.01	3.14	4.37	21.80	16
RBT	0.15	0.37	0.01	0.10	0.08	0.71	1
THK	9.31	6.72	0.00	2.23	1.15	19.41	17
TWR	6.24	2.42	0.50	2.84	1.99	13.99	8
VVT	4.54	0.65	0.07	1.92	2.55	9.72	10
WBK	1.83	6.46	0.32	4.26	0.93	13.80	10
WCT	0.00	0.00	0.00	0.03	0.14	0.17	0
Total	**82**	**49**	**1**	**29**	**37**	**197**	**9**

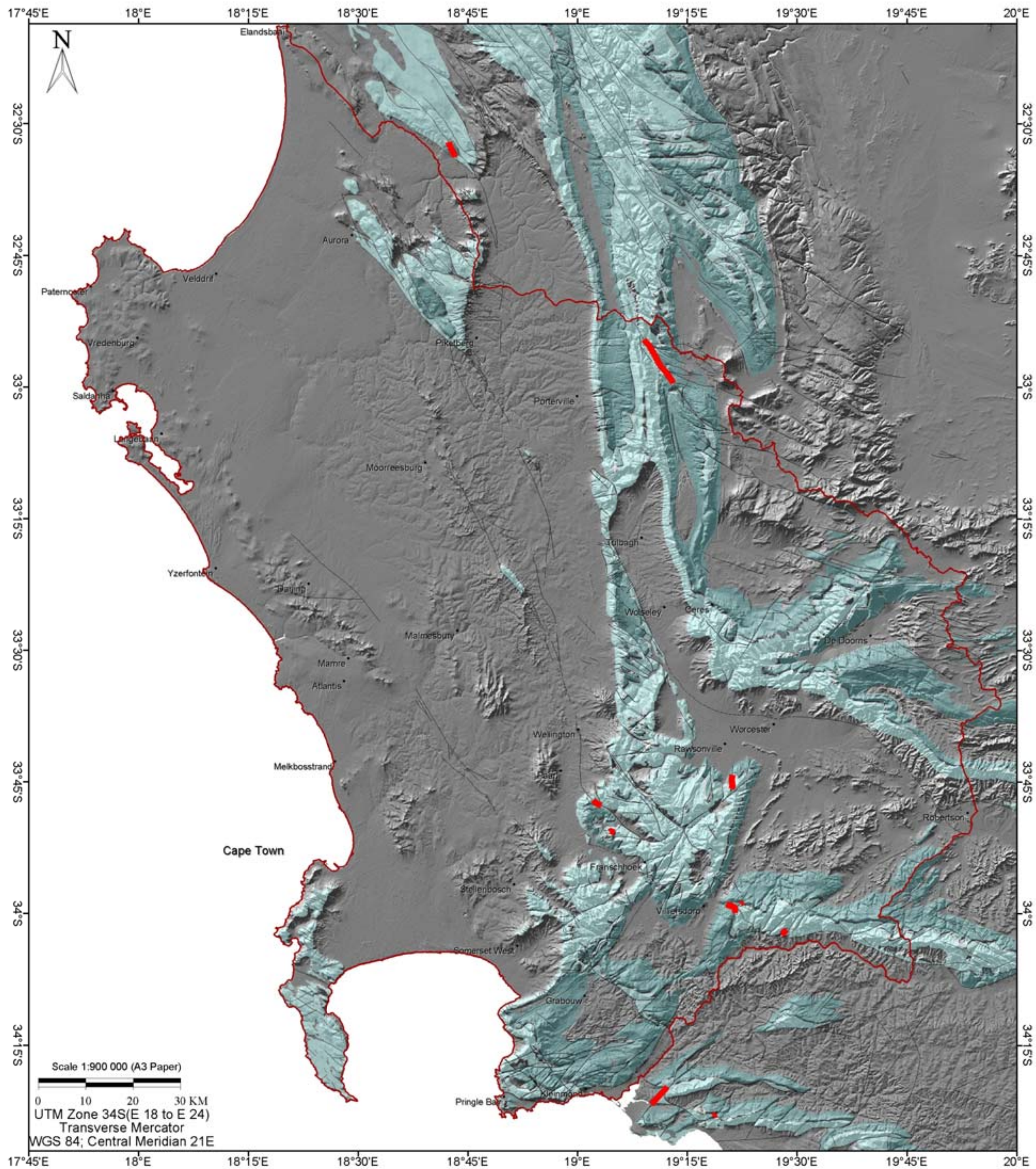
Table 6-3 Aquifer-specific discharge estimation per IWRM domain, groundwater contribution to baseflow disaggregated according to average recharge

IWRM Domain	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Total GW contribution to baseflow**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
ATL	0.15	0.00	0.01	6.10	6.31	12.56	6
AWT	3.33	7.82	0.00	1.84	0.32	13.31	60
BRV	20.61	2.12	0.00	2.50	7.10	32.34	20
CFP	5.84	0.02	0.01	3.18	11.69	20.73	12
HEX	4.20	2.60	0.00	0.45	0.40	7.65	8
KGB	6.46	16.17	0.00	4.91	2.04	29.58	39
NUY	0.17	0.71	0.00	0.23	0.03	1.14	2
PKT	0.00	0.00	0.00	0.00	0.00	0.00	0
PUB	11.57	1.10	0.01	3.62	5.43	21.74	16
RBT	0.11	0.30	0.01	0.20	0.13	0.75	1
THK	7.88	6.45	0.00	3.43	1.52	19.28	17
TWR	4.50	2.60	0.31	4.73	1.89	14.04	8
VVT	3.17	0.61	0.06	2.82	3.05	9.72	10
WBK	1.74	5.69	0.28	5.18	1.05	13.94	10
WCT	0.00	0.00	0.00	0.03	0.14	0.17	0
Total	**70**	**46**	**1**	**39**	**41**	**197**	**9**

6.2 LATERAL DISCHARGE – RECHARGE

The potential hydraulic connection between the Peninsula and the Skurweberg Aquifers was investigated by mapping where these two lithologies are contiguous due to faulting. Twenty-four (24) such sites were identified. They are associated with normal down faulting. It is important to establish in the future whether these faults that separate the aquifers, are or are not, annealed. This is important for the appropriate design of a monitoring network for surface and groundwater, ecology and climate. Preliminary indications based on hydrocensus and piezometric levels as well as spring elevations suggest that the two aquifers behave as separate systems. This does not presume that under different head conditions resulting from large-scale abstraction this circumstance would not change. It does, however, indicate that the natural recharge and discharge process together with whatever abstraction is current (which implicitly take into account aquifer storage and hydraulic characteristics) have different time responses in both aquifers.

The Conceptual Model Report (DWAF, 2007b) showed distinctly different piezometric maps for the Nardouw and the Peninsula Aquifer, indicating that it can be reasonably assumed that the two aquifers respond independently. Therefore no account of lateral exchange between the two aquifers is made in the regional water balance results. This approach can be refined at IWRM model domain scale.



LEGEND

Towns

Faults

Hydraulic Connectivity

Study Area

AQUIFERS

Nardouw Subgroup

Peninsula Formation

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

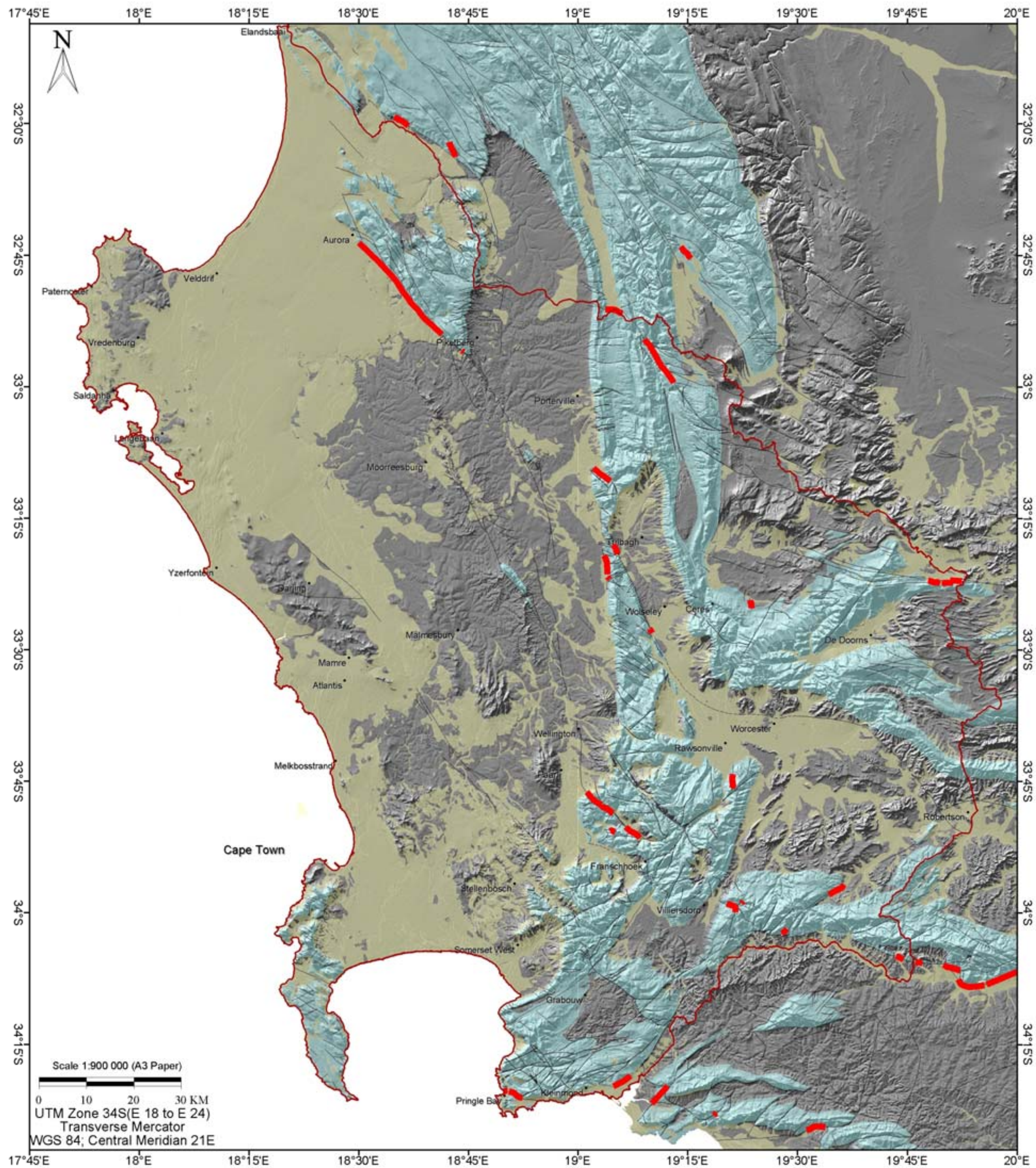
CONSULTANT

UMVOTO

TITLE

HYDRAULIC CONNECTIVITY BETWEEN THE NARDOUW AND PENINSULA AQUIFERS

FIGURE 6.1



LEGEND

- Towns
- Faults
- Hydraulic Connectivity
- Study Area

AQUIFERS

- Primary Aquifers
- Table Mountain Group

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

HYDRAULIC CONNECTIVITY BETWEEN THE TMG AND PRIMARY AQUIFERS

FIGURE 6.2

6.3 GROUNDWATER ABSTRACTION

Relatively recent estimates of the groundwater use in the study domain from the Groundwater Resource Assessment Phase II (GRA II) project (DWAF, 2004) indicate an annual abstraction of 150.8 million m^3/a (see **Appendix A**). The highest demand is estimated for irrigation with 107.5 million m^3/a, mainly in the G10E and H10C catchments (above 10 million m^3/a each, and in the E21A, E21D, G10K, H10F and H10G catchments (above 5 million m^3/a each).

According to the GRA II calculations urban domestic use accounts for 19 million m^3/a and is apparently concentrated in the G21B catchment (Atlantis, 8.5 million m^3/a) and the G22D catchment (Cape Flats, 5.9 million m^3/a). Relevant abstraction for domestic use is also assigned to the G22B (Cape Town) and H10C (Tulbagh / Ceres) catchments.

Unfortunately, the information, on which the GRA II results are based, were not available from the DWAF to recalculate the results and to assign the groundwater abstraction to the different aquifers. Therefore the required detail of the spatial component of the information is lost.

Since these estimations are not aquifer specific, it was decided to recalculate the groundwater use per aquifer per catchment, using two different approaches:

- disaggregating the GRA II values with respect to the outcrop area of the different aquifers, assuming an equal and *pro rata* spatial distribution of boreholes and abstraction points over the catchments;
- assigning the registered groundwater abstraction in the WARMS database to aquifers by linking WARMS registered use with boreholes in the NGDB and assigning volumes *pro rata* to the number of boreholes in different aquifers.

Table 6-4 Estimated groundwater use per aquifer per IWRM domain, after GRA II

IWRM Domain	Peninsula Aquifer *Mm³/a*	Nardouw Aquifer *Mm³/a*	Other Fractured Aquifers *Mm³/a*	Intergranular fractured Aquifers *Mm³/a*	Intergranular Aquifers *Mm³/a*	**Total Groundwater use** *Mm³/a*
ATL	0.00	0.00	0.00	5.13	15.06	20.18
AWT	1.18	7.00	0.00	3.38	0.22	11.77
BRV	5.96	1.75	0.05	5.03	13.21	26.00
CFP	0.82	0.00	0.01	1.56	10.22	12.61
HEX	0.95	3.54	0.00	1.41	1.84	7.74
KGB	0.01	0.04	0.00	0.02	0.01	0.08
NUY	0.66	0.47	0.00	0.38	0.03	1.53
PKT	0.69	0.10	0.38	0.44	3.69	5.30
PUB	0.28	0.02	0.00	1.41	0.79	2.49
RBT	0.39	1.02	0.30	2.22	1.26	5.18
THK	0.28	0.30	0.00	0.43	0.11	1.11
TWR	0.53	0.16	0.08	5.75	1.89	8.41
VVT	1.76	1.05	0.08	4.79	3.61	11.29
WBK	1.07	8.38	0.59	18.00	2.78	30.81
WCT	0.01	0.00	0.00	1.47	3.77	5.25
Total	**14.57**	**23.83**	**1.48**	**51.40**	**58.48**	**149.76**

The disaggregating of the GRA II data (see **Appendix D-3** and **Table 6-4**) is purely based on the outcrop area of the different aquifers and therefore not physically correct. It is also not necessarily realistic since certain aquifers are very much more developed than others. It can be expected that the groundwater use from the primary aquifers as well as the 'intergranular-fractured' aquifers in certain areas is underestimated with this approach, as aspects such as accessibility and yield are not taken into account.

The methodology applied in the GRA II project utilises different sources of information for the different sectors of water use; viz.

- Agriculture – Livestock Department of Agriculture, Water Situation Assessment Model (WSAM)
- Agriculture – Irrigation Department of Agriculture, WSAM, National Land Cover (NLC)
- Domestic – Rural Community Water Supply and Sanitation (CWSS)
- Domestic – Urban DWAF
- Mining DWAF, WARMS database
- Industry DWAF, WARMS database

Some of the estimates and allocations to different water use sectors in the GRA II database seem to mismatch with the registered use in WARMS. This is especially true for the municipal use in the Cape Flats, where according to WARMS and local knowledge the majority of the groundwater abstraction is used for agricultural use / irrigation. Similarly, it is not known where in the G22B catchment groundwater abstraction for municipal use occurs. It is assumed that the abstraction from the Newlands Aquifer is meant here, which actually is situated in the G22C catchment.

It was therefore decided to use the WARMS database and link the entries with borehole information from the NGDB to increase the confidence in groundwater use per aquifer. The cadastral data on farm and properties, as received from Department for Land Affairs, CD: Survey and Mapping (CDSM), was used to link the registered groundwater use on the WARMS database to a farm or property. Unfortunately, this was not possible in the Cape Metropolitan, as the cadastral file does not contain any property detail for this area.

The boreholes registered on the NGDB were also linked to the properties from the cadastral database and to the aquifers, based on the surface geology as described in Volume 2 of this report. Since on most farms a number of boreholes exist, often in different aquifers, the registered use from the WARMS was assigned proportionally to the aquifers with the most boreholes. In cases where more than 90% of the boreholes were situated in a particular aquifer, the use volume was assigned to this aquifer only. The results of this calculation are documented in **Appendix D-4** and summarised in **Table 6-5.**

Table 6-5 shows an unrealistically high groundwater abstraction from the Peninsula Aquifer in the Piketberg (PKT) and Breede River valley (BRV), while the groundwater abstraction from the Nardouw Aquifers seems to be too low. The farmers in the Piketberg area abstract water mainly from the Nardouw, while the physiography of the Peninsula outcrops along the Breede River valley does not allow for a reasonable amount of boreholes to be drilled. These discrepancies could be due to

- the uncertainty of the borehole positions, as recorded in the NGDB,
- the uncertainty of whether the borehole is actually in use,
- the difference in borehole yield and

- the inclusion of dry boreholes in the calculation.

It is therefore suggested to verify the groundwater use in these areas through detailed data analysis and field verification.

Table 6-5 Estimated groundwater use per aquifer per IWRM domain, based on WARMS and NGDB

IWRM Domain	Peninsula Aquifer Mm^3/a	Nardouw Aquifer Mm^3/a	Other Fractured Aquifers Mm^3/a	Intergranular fractured Aquifers Mm^3/a	Intergranular Aquifers Mm^3/a	**Total Groundwater use** Mm^3/a
ATL	0.00	0.00	0.00	8.86	14.95	23.80
AWT	0.05	1.20	0.00	4.17	0.01	5.43
BRV	2.28	2.87	0.00	6.47	25.41	37.03
CFP	0.22	0.00	0.00	2.44	9.25	11.91
HEX	0.96	8.13	0.00	1.70	12.13	22.92
KGB	0.00	0.22	0.02	1.03	0.95	2.21
NUY	0.44	0.41	0.00	2.97	0.82	4.63
PKT	3.68	0.00	0.32	0.26	0.51	4.78
PUB	0.33	0.33	0.03	2.96	6.93	10.58
RBT	0.00	1.07	0.09	2.82	2.70	6.68
THK	0.04	0.43	0.00	1.84	0.67	2.97
TWR	0.25	0.25	0.08	2.64	0.48	3.71
VVT	0.13	0.00	0.04	2.32	2.41	4.90
WBK	0.15	5.70	0.00	14.91	3.16	23.92
WCT	0.05	0.00	0.02	3.07	12.26	15.40
Total	**8.58**	**20.60**	**0.60**	**58.44**	**92.63**	**180.86**

Table 6-4 and **Table 6-5** indicate major disparities for the estimations of groundwater use per aquifer in the different IWRM domains. Interestingly, the total registered groundwater use (WARMS database) in the study area is about 30 million m^3/a higher than the estimation from the GRA II. This relates mainly to the BRV, HEX, KGB, NUY, PUB and WCT domains. However, the GRA II estimation for the AWT, TWR, VVT and WBK IWRM domains is much higher than the registered use. These discrepancies cannot be resolved satisfactory, as the input data for the GRA II estimation is not available for re-evaluating.

As expected, the groundwater use from the intergranular aquifers appears to be clearly underestimated in the GRA II calculation, while the groundwater use from the Peninsula Aquifer seems overestimated.

A detailed analysis of the data further revealed that there is also a discrepancy between sectors in the two databases (see **Table 6-6**). The major differences occur in the municipal water supply and the agricultural water use sector. It appears that more agricultural use is registered on the WARMS than actually required by the farming sector on a regular basis. On the other hand, groundwater abstraction for municipal supply is apparently not always registered on the WARMS; e.g. only 260 000 m^3/a are registered for municipal domestic supply from the Atlantis wellfield, while more than 7 million m^3/a are registered for urban industrial use.

Table 6-6 Comparison of GRA II and WARMS database per water use sector

Method	Rural	Municipal	Irrigation	Livestock	Mining	Industry	Aqua	Total
GRA II	0.35	18.98	107.54	2.43	0.04	21.02	0.40	150.77
WARMS	0.42	2.76	154.02	3.36	0.04	16.49	0.74	178.35
Difference	-0.07	16.22	-46.48	-0.93	0.00	4.53	-0.34	-27.58

Despite these discrepancies the results from the combination of WARMS and NGDB databases are used for further calculations on a regional scale, as they are more conservative and considered more realistic in terms of the aquifer-specific allocation.

However, the results can be refined for the detailed model domains, using the NGDB database, where it is updated with recent hydrocensus data. This will be confirmed with DWAF.

7. YIELD MODEL

Resource evaluation is a transient rather than a steady state problem as it depends not only on standard mass balance of recharge and discharge, as discussed and documented in previous sections, but also on a more dynamic perspective of how recharge estimates and discharge rates are likely to change depending upon the time lag between recharge, discharge and abstraction, the available volume of water in storage and the aquifer development and management strategy.

Groundwater resource evaluation also requires knowledge of how much groundwater can be stored and what is the aquifer water table or piezometric level response to abstraction. A preliminary model based on physically measurable data (e.g. water table) and interpretation of aquifer geometry is needed to establish the likely drawdown, given different aquifer geometry, to different volumes of abstraction. Numerical modeling is not within the scope of the regional water balance model but will be undertaken in the detailed model domains to establish longer-term evaluation of the sustainable use.

A frustration of, and currently the most limiting factor in groundwater resource development is the perception that if the confined portions of the Peninsula and Skurweberg aquifers are pumped that springs and seep zones will be significantly impacted upon. A second perception is that the only water that can viably and sustainably be abstracted from an aquifer is that portion which would otherwise be lost to the ocean and or evaporated prior to being absorbed by plants. If this approach is used the concept of acceptable impact is discarded and would therefore apply also to any future decisions to impound water. It does not consider the concept of management of the time lag between surface and groundwater, nor the sustainable use of storage, factoring in residence or through-flow time.

Any development of a resource will result in changes in natural patterns. It is necessary to place these changes in the context of the society, the economy, the advantages of optimising the time lag between surface water and groundwater as well as longer-term changes such as climate change and sensible adaptation to this, through demand management and optimising the use of natural storage. Local and regional natural resource development and planning must play a part and is catered for in the National Water Act (Government of South Africa, 1998). It is also possible, based on desk top evaluation and preliminary field reconnaissance, to determine most likely zones of impact, to initially use a conservative evaluation of acceptable impact and to recommend where and how monitoring should take place in order to adapt the aquifer management strategy as confidence increases. It will also be necessary in the planning of a drilling programme to put in place monitoring infrastructure to support ongoing refinement of resource evaluation and management.

The concept of "groundwater resource potential" Vegter, (1995) embraces the following and these factors must be considered *(inter alia)* when evaluating a potential scheme:

- Accessibility - aquifer depth and drilling risk;
- Exploitability - yield and pumping depth;
- Availability - resource (i.e. storage) and recharge;
- Suitability - chemistry and risk of pollution; and
- Conservation - size and hydrodynamic situation.

Key to integrated water resource evaluation, exploration, development and management is the concept of storage, one that is common to both surface and groundwater resource evaluation. Vegter (1995) considered storage in his conceptual approach to groundwater resource potential but neither in quantitative terms nor in the context of IWRM. His concept of availability (see below) referred primarily to recharge and his evaluation of storage, accessibility, yield and exploitability was limited by data in a set that was dominated by boreholes drilled to less than 120 m and in a time when groundwater exploration was not or very seldom conducted below 150 m.

In this study the definitions and approach to evaluating "accessibility" has been taken to mean where a drill rig can realize boreholes between 500 and 1500 m, provided the evaluation of cost benefit warrants the risk.

The ultimate limit to a perennial supply is replenishment, also termed recharge. Traditionally, the average annual recharge has been used to evaluate the groundwater resource, using a static mass balance equation calculated over a one-year cycle. This approach is warranted if the natural recharge and discharge cycle of the aquifer is 1-2 calendar years, which also implies that the aquifer storage is limited. In this study a hydrodynamic mass balance approach is used, since the residence time of the groundwater exceeds two years and the volume of water in storage significantly exceeds the annual recharge volumes.

This section addresses the yield analysis on the IWRM domain level. At the level of this investigation (situation assessment) it would not be realistic to provide yield estimates per scheme or wellfield. To achieve this level of detail and confidence, a feasibility study would be required; comprising detailed geological fieldwork, exploration drilling, extensive testing, sample collection, analysis and modelling.

The approach taken for the yield estimation at the regional scale comprises two aspects:

- Sustainable yield estimation based on acceptable average drawdown
- Sustainable yield estimation based on long-term water balance (i.e. recharge – discharge)

Both methods will be discussed separately in the following sections below and the results combined and compared in the summary section 7.3.

7.1 GROUNDWATER POTENTIAL

Aquifer specific recharge estimations are discussed in Section 5 for each quaternary catchment, as well as for the different IWRM domains. Natural discharge and groundwater abstraction are discussed in Section 6 for each quaternary catchment and IWRM domain. Using the relationship between recharge areas and potential discharge areas, as discussed in Volume 3 of this report, the available groundwater for abstraction per IWRM domain are estimated.

The unexploited potential is then estimated as recharge minus baseflow minus current use. This is considered conservative and realistic, as:

- the recharge estimation is aquifer specific and is calibrated with different methods;
- the possibility that some recharge does not reach the confined portion of the aquifer, but is discharged in other directions and or in floods, is taken into account;
- a significant part of the recharge to the TMG aquifers is discharging into the sea;

- part of the recharge to the intergranular and intergranular-fractured aquifers will discharge locally as rejected recharge, if the aquifers are not utilised;
- it is assumed that the baseflow volume is in a linear relationship to the recharge.

However, the method does not take into account the desired ecological status of the aquifer in terms of the Reserve determination and RQOs, and does not consider the water quality.

In applying this method the groundwater potential for the Peninsula Aquifer and the Nardouw Aquifer was estimated to 148 million m^3/a and 132 million m^3/a, respectively, applying the very conservative map-centric recharge estimation (see **Table 7-1** and **Table 7-2** below). Applying the ISP method, the groundwater potential for the Peninsula Aquifer and the Nardouw Aquifer amounts to 420 million m^3/a and 205 million m^3/a respectively (see **Table 7-3** and **Table 7-4**). The available groundwater potential in the TMG dominated IWRM domains is above 50% of recharge and mostly very close to recharge minus baseflow, indicating that the TMG aquifers are not exploited and currently under-utilised.

Although the intergranular aquifers are used more, the available potential appears to still be more than for the TMG aquifers with a total groundwater potential estimated to be 216 million m^3/a, applying the map-centric recharge estimation (see **Table 7-5**). The total groundwater potential for the intergranular aquifers is very similar, applying the ISP recharge method (see **Table 7-6**). However, the two methods show significant differences in most IWRM domains, with more catchments already indicating overallocation with the ISP method (in HEX and NUY IWRM domains).

Table 7-1 Unexploited groundwater potential for Peninsula Aquifer in IWRM domains based on map-centric recharge and baseflow estimation (all values in Mm^3/a)

IWRM Domain	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
ATL	0.14	0.03	0.11	0.00	0.11
AWT	6.31	2.43	3.88	0.05	3.83
BRV	48.09	17.98	30.12	2.28	27.84
CFP	16.20	5.58	10.62	0.22	10.40
HEX	20.88	3.76	17.12	0.96	16.16
KGB	9.40	5.59	3.82	0.00	3.82
NUY	8.50	0.10	8.40	0.44	7.96
PKT	13.22	0.00	13.22	3.68	9.54
PUB	32.00	9.97	22.03	0.33	21.70
RBT	6.62	0.07	6.55	0.00	6.55
THK	32.81	6.06	26.75	0.04	26.71
TWR	9.14	2.92	6.22	0.25	5.97
VVT	5.71	1.81	3.90	0.13	3.77
WBK	5.09	1.64	3.44	0.15	3.29
WCT	0.10	0.00	0.10	0.05	0.05
Total	**214**	**57.9**	**156**	**8.6**	**148**

Table 7-2 Unexploited groundwater potential for Nardouw Aquifer in IWRM domains based on map-centric recharge and baseflow estimation (all values in Mm^3/a)

IWRM Domain	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
ATL	0.00	0.00	0.00	0.00	0.00
AWT	19.25	7.75	11.50	1.20	10.30
BRV	6.97	2.08	4.89	2.87	2.02
CFP	0.05	0.01	0.04	0.00	0.04
HEX	33.01	2.74	30.27	8.13	22.14
KGB	30.14	13.76	16.39	0.22	16.17
NUY	17.83	0.56	17.27	0.41	16.86
PKT	2.21	0.00	2.21	0.00	2.21
PUB	3.72	1.41	2.31	0.33	1.98
RBT	25.97	0.24	25.73	1.07	24.66
THK	30.96	6.31	24.65	0.43	24.22
TWR	6.97	2.88	4.10	0.25	3.85
VVT	1.80	0.59	1.21	0.00	1.21
WBK	16.66	4.87	11.79	5.70	6.09
WCT	0.00	0.00	0.00	0.00	0.00
Total	**196**	**43.2**	**152**	**20.6**	**132**

Table 7-3 Unexploited groundwater potential for Peninsula Aquifer in IWRM domains based on ISP method recharge and baseflow estimation (all values in Mm^3/a)

IWRM Domain	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
ATL	0.94	0.27	0.67	0.00	0.67
AWT	16.80	4.01	12.79	0.05	12.74
BRV	97.10	23.22	73.87	2.28	71.59
CFP	62.69	6.69	56.00	0.22	55.78
HEX	36.07	4.56	31.51	0.96	30.55
KGB	22.24	7.27	14.97	0.00	14.97
NUY	9.67	0.23	9.44	0.44	9.00
PKT	15.05	0.00	15.05	3.68	11.37
PUB	90.82	13.32	77.50	0.33	77.17
RBT	15.42	0.15	15.27	0.00	15.27
THK	64.23	9.31	54.92	0.04	54.88
TWR	36.23	6.24	29.99	0.25	29.74
VVT	33.61	4.54	29.08	0.13	28.95
WBK	9.66	1.83	7.83	0.15	7.68
WCT	0.13	0.00	0.13	0.05	0.08
Total	**511**	**81.6**	**429**	**8.6**	**420**

Table 7-4 Unexploited groundwater potential for Nardouw Aquifer in IWRM domains based on ISP method recharge and baseflow estimation (all values in Mm³/a)

IWRM Domain	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
ATL	0.00	0.00	0.00	0.00	0.00
AWT	31.67	8.02	23.65	1.20	22.45
BRV	12.25	2.24	10.01	2.87	7.14
CFP	0.24	0.02	0.21	0.00	0.21
HEX	31.63	2.59	29.04	8.13	20.91
KGB	50.01	17.95	32.06	0.22	31.84
NUY	15.26	0.85	14.40	0.41	13.99
PKT	2.23	0.00	2.23	0.00	2.23
PUB	5.06	0.96	4.10	0.33	3.77
RBT	27.55	0.37	27.18	1.07	26.11
THK	44.20	6.72	37.48	0.43	37.05
TWR	15.23	2.42	12.80	0.25	12.55
VVT	4.97	0.65	4.32	0.00	4.32
WBK	34.85	6.46	28.38	5.70	22.68
WCT	0.00	0.00	0.00	0.00	0.00
Total	**275**	**49.3**	**226**	**20.6**	**205**

Table 7-5 Unexploited groundwater potential for Intergranular Aquifer in IWRM domains based on map-centric recharge and baseflow estimation (all values in Mm³/a)

IWRM Domain	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
ATL	29.47	5.10	24.37	14.95	9.42
AWT	0.67	0.28	0.38	0.01	0.37
BRV	39.85	8.50	31.34	25.41	5.93
CFP	57.07	10.90	46.17	9.25	36.92
HEX	8.82	0.52	8.30	12.13	**-3.83**
KGB	4.59	2.17	2.42	0.95	1.47
NUY	1.00	0.03	0.97	0.82	0.15
PKT	28.06	0.00	28.06	0.51	27.55
PUB	31.39	6.13	25.26	6.93	18.33
RBT	19.11	0.17	18.95	2.70	16.25
THK	8.49	1.70	6.80	0.67	6.13
TWR	6.66	1.44	5.22	0.48	4.74
VVT	10.05	3.14	6.92	2.41	4.51
WBK	5.51	0.94	4.57	3.16	1.41
WCT	99.49	0.13	99.37	12.26	87.11
Total	**350.26**	**41.15**	**309.11**	**92.64**	**216.47**

Table 7-6 Unexploited groundwater potential for Intergranular Aquifer in IWRM domains based on ISP method recharge and baseflow estimation (all values in Mm^3/a)

IWRM Domain	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
ATL	74.83	6.63	68.20	14.95	53.25
AWT	0.80	0.27	0.53	0.01	0.52
BRV	32.31	5.21	27.11	25.41	1.70
CFP	100.85	11.42	89.42	9.25	80.17
HEX	3.15	0.22	2.92	12.13	**-9.21**
KGB	6.29	1.62	4.67	0.95	3.72
NUY	0.42	0.02	0.40	0.82	**-0.42**
PKT	12.04	0.00	12.04	0.51	11.53
PUB	40.85	4.37	36.49	6.93	29.56
RBT	4.94	0.08	4.86	2.70	2.16
THK	6.76	1.15	5.61	0.67	4.94
TWR	11.35	1.99	9.36	0.48	8.88
VVT	18.79	2.55	16.24	2.41	13.83
WBK	6.73	0.93	5.80	3.16	2.64
WCT	43.20	0.14	43.06	12.26	30.80
Total	**363**	**36.6**	**327**	**92.6**	**234**

Table 7-7 Comparison of groundwater potential between map-centric and ISP method recharge and baseflow estimation (all values in Mm^3/a)

IWRM Domain	Groundwater Potential Peninsula Aquifer		Groundwater Potential Nardouw Aquifer		Groundwater Potential Intergranular Aquifer	
	Map-centric	ISP	Map-centric	ISP	Map-centric	ISP
ATL	0.11	0.67	0.00	0.00	9.42	53.25
AWT	3.83	12.74	10.30	22.45	0.37	0.52
BRV	27.84	71.59	2.02	7.14	5.93	1.70
CFP	10.40	55.78	0.04	0.21	36.92	80.17
HEX	16.16	30.55	22.14	20.91	**-3.83**	**-9.21**
KGB	3.82	14.97	16.17	31.84	1.47	3.72
NUY	7.96	9.00	16.86	13.99	0.15	**-0.42**
PKT	9.54	11.37	2.21	2.23	27.55	11.53
PUB	21.70	77.17	1.98	3.77	18.33	29.56
RBT	6.55	15.27	24.66	26.11	16.25	2.16
THK	26.71	54.88	24.22	37.05	6.13	4.94
TWR	5.97	29.74	3.85	12.55	4.74	8.88
VVT	3.77	28.95	1.21	4.32	4.51	13.83
WBK	3.29	7.68	6.09	22.68	1.41	2.64
WCT	0.05	0.08	0.00	0.00	87.11	30.80
Total	**148**	**420**	**132**	**205**	**216**	**234**

A comparison between the two methods (see **Table 7-7**) shows significant differences in each IWRM domain. The two methods are considered best-case and worst-case scenario in terms of recharge potential and available groundwater.

- It is suggested to use the map-centric recharge estimation for the TMG aquifers as very conservative scenario, until the recharge model is refined and calibrated with other methods.
- For the intergranular-fractured aquifers it is suggested to use the ISP recharge method, as it is more conservative.
- The results of both methods for the intergranular aquifers are not consistent and it is not possible to assign any one method to a best case or worst case scenario. It is therefore suggested to use the most conservative results, unless the recharge estimation is refined and verified with other methods.

Groundwater abstraction from the intergranular aquifer appears to be overallocated at least in the HEX IWRM domain (see **Table 7-5** and **Table 7-6**), while the groundwater use exceeds 50% of recharge minus baseflow in the ATL, BRV, NUY and WBK IWRM domains.

A further breakdown of the groundwater potential into quaternary catchments shows that the overallocation in the HEX IWRM domain is spread throughout the whole Hex River basin (H20B, H20E, H20F, H20G). Additionally, over abstraction of groundwater from the intergranular aquifer occurs in the Breede River valley (H10G, H10L), in the Nuy valley (H40B) and at Atlantis (G21B), as shown in **Table 7-8**.

Table 7-8 Estimated groundwater potential and overallocation of groundwater in selected quaternary catchments, based on map-centric recharge estimation (all values in Mm^3/a)

Quaternary Catchment	Peninsula	Nardouw	Intergranular-fractured	Interganular	Total Groundwater Potential
E21A	0.04	0.20	3.24	**-0.27**	3.21
G21B	0.00	0.00	0.95	**-1.65**	**-0.70**
H10B	0.00	1.00	**-1.31**	0.29	**-0.02**
H10C	0.08	1.77	**-8.29**	**-1.49**	**-7.93**
H10F	4.52	1.52	**-2.39**	2.41	6.06
H10G	2.04	**-0.60**	2.07	**-1.48**	2.02
H10J	9.46	**-0.83**	1.15	1.58	11.36
H10L	0.52	0.47	0.49	**-3.38**	**-1.90**
H20B	0.00	1.51	1.28	**-0.67**	2.12
H20E	4.25	0.67	0.40	**-0.83**	4.48
H20F	2.35	2.22	0.57	**-6.95**	**-1.80**
H20G	3.45	0.94	0.75	**-2.49**	2.65
H40B	1.08	10.02	4.85	**-0.23**	15.71

The details of the estimated groundwater potential and the percentage of groundwater utilisation and overallocation per quaternary catchment are documented in **Appendix E**. It shows that the Peninsula Aquifer and in certain catchments the Nardouw Aquifer are mostly un- or under-utilised, while the intergranular aquifers and the intergranular-fractured aquifers (i.e. Malmesbury, Granites, Bokkeveld) are heavily utilised or over abstracted in a number of catchments.

7.2 STORAGE YIELD MODEL

*"The **sustainable yield** is defined as the discharge rate that will not cause the water level in the borehole to drop below a prescribed limit (the position of a major water strike, for example). It is also important that the total abstraction rates of boreholes situated in an aquifer must not exceed the sustainable yield of the aquifer in total (i.e. the average annual recharge)."* (van Tonder et al., 2002)

A storage yield model was developed to evaluate the potential yield of the aquifers with respect to hydraulic head decline and acceptable environmental impacts. The model uses the results from the storage model (see Section 4) to calculate the potential yield of the Peninsula Aquifer in the Berg WAAS domain. Since large-scale groundwater abstraction is proposed for the confined portion of the aquifer only, the regional hydraulic head decline due to abstraction depends upon the storativity of the aquifer.

The conservative estimate of porosity (i.e. 5%), as used in the storage model (see Section 4.2), coupled with the vertical compressibility of fractured rocks between 3.3×10^{-10} Pa^{-1} and 6.9×10^{-10} Pa^{-1} (Domenico and Schwartz, 1990) delineated a range of Specific Storage values between $3x10^{-6}$ and $7x10^{-6}$ m^{-1} that were used to calculate the Effective Storativity. The Effective Storativity has a range of $3.47x10^{-3}$ to $8.11x10^{-3}$ for the Peninsula Aquifer. The accepted Specific Storage for further calculation for this study is taken as $6x10^{-6}$ m^{-1}, with a corresponding Effective Storativity of $6.95x10^{-3}$.

It is noted that the Specific Storage is more dependent on the rock compressibility value than the porosity. As is shown in **Figure 7-1**, the Specific Storage does not change significantly with varying porosity in the range of rock compressibility relevant to the TMG.

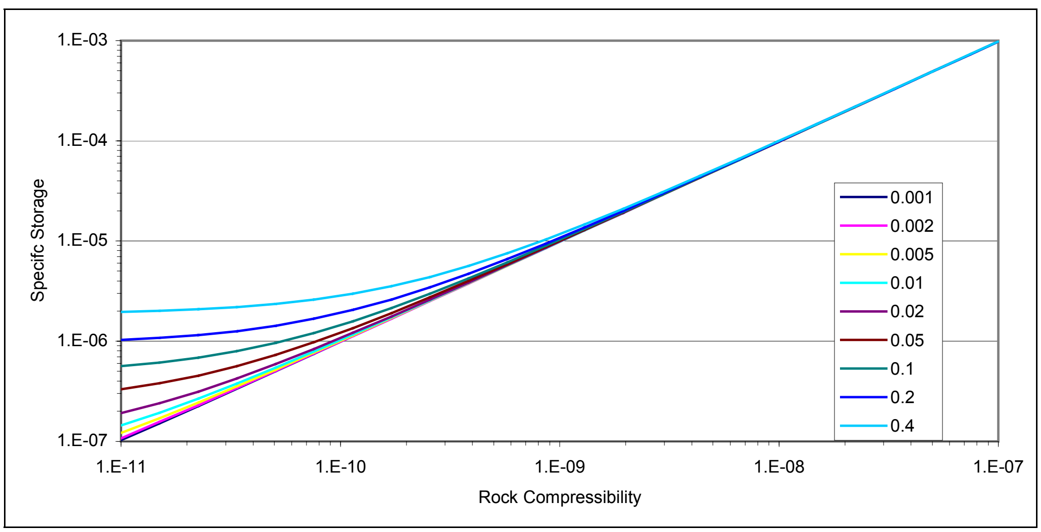


Figure 7-1 Relationship between Specific Storage and Rock Compressibility for different porosities, according to Jacob's Equation

The volumes of water elastically released from confined storage in the Peninsula Aquifer, due to unit (1 m) head or pressure decline causing mainly porosity reduction (aquifer compression), are just a small fraction, less than 0.1% of the total of subsurface water, viz., between 18 and 41 million m^3 only. For the assumption of 5% porosity with a specific storage of $6x10^{-6}$ m^{-1}, the total volume of subsurface water released from a unit head decline in the Peninsula Aquifer is 31 million m^3, 0.01% of the total stored water.

This comparison serves to put into quantitative perspective the common public perception that groundwater abstraction from the deep confined Peninsula aquifer will somehow significantly dewater the system, with (often unspecified) adverse ecological consequences. Even where the regionally averaged decline in hydraulic head approaches 50 m, the volume released by aquifer compression generally remains between 0.3% and 0.7% of the total volume in slow circulation within the deep groundwater flow system. A vastly greater volume of groundwater is essentially *non-extractable* by any practical and/or economical means.

Provided an average drawdown of 20 m, averaged over the whole aerial extent of the suboutcrop, is considered possible and ecologically acceptable, the calculated yield from deep confined storage in the 1 150 m thick Peninsula Aquifer ranges between 355 and 829 million m^3. These results for the model scenario with Specific Storage of $6x10^{-6}$ m^{-1} and porosity of 5% are summarized in **Table 7-9**. The results for the Skurweberg Aquifer are summarised in **Table 7-10**.

This approach is very conservative, as it does not take into account the annual replenishment of the aquifer. It therefore constitutes the yield potential during drought conditions.

The total volume of water stored in the confined portions of the Peninsula Aquifer is tabled below (see **Table 7-9**) together with the yield (water available for abstraction) of these basins given a regional drawdown of the piezometric surface of 1, 20 and 50 m. How much water to actually abstract is an aquifer development design and management issue and would need to take into consideration

- impacts of abstraction
- social factors
- economic advantages
- advantages (environmental and yield) arising from conjunctive use
- water saving arising from conjunctive use.

Comparison of the yield or volume of water abstracted that would result in a 1, 5 or 20 m hydraulic head decline relative to the pore volume is never greater than 0.24% of the total pore volume.

Table 7-10 shows the potential yield from the Skurweberg Aquifer depending upon the acceptable drawdown in the confined portion of the aquifer. IWRM domains that are not listed don’t have confined Skurweberg portions.

Table 7-9 Potential yield of the Peninsula Aquifer for the IWRM domains, based on the storage yield model (Effective Storativity based on Specific Storage)

IWRM Domain	Effective Storativity	Pore Volume Mm^3	Volume per head decline of:					
			1m		5m		20m	
			Mm^3	%	Mm^3	%	Mm^3	%
ATL	No confined Peninsula							
AWT	6.89E-03	13 163	1.58	0.01	7.90	0.06	31.58	0.24
BRV	7.03E-03	31 672	3.80	0.01	19.00	0.06	76.02	0.24
CFP	8.47E-03	230	0.03	0.01	0.14	0.06	0.55	0.24
HEX	6.71E-03	31 568	3.79	0.01	18.94	0.06	75.75	0.24
KGB	6.70E-03	31 749	3.81	0.01	19.05	0.06	76.18	0.24
NUY	6.84E-03	24 406	2.93	0.01	14.64	0.06	58.58	0.24
PKT	7.93E-03	3 632	0.44	0.01	2.18	0.06	8.72	0.24
PUB	6.71E-03	2 796	0.34	0.01	1.68	0.06	6.71	0.24
RBT	7.03E-03	69 925	8.39	0.01	41.96	0.06	167.85	0.24
THK	7.23E-03	37 802	4.54	0.01	22.69	0.06	90.75	0.24
TWR	7.73E-03	12 206	1.46	0.01	7.32	0.06	29.29	0.24
VVT	6.88E-03	2 720	0.33	0.01	1.63	0.06	6.53	0.24
WBK	6.65E-03	34 109	4.09	0.01	20.46	0.06	81.85	0.24
WCT	No confined Peninsula							
Total	**6.19E-03**	**328 664**	**31.63**	**0.01**	**158.15**	**0.05**	**632.59**	**0.19**

Table 7-10 Potential yield of the Skurweberg Aquifer for the IWRM domains, based on the storage yield model (Effective Storativity based on Specific Storage)

IWRM Domain	Effective Storativity	Pore Volume Mm^3	Volume per head decline of:					
			1m		5m		20m	
			Mm^3	%	Mm^3	%	Mm^3	%
AWT	1.80E-03	1 349	0.16	0.01	0.81	0.06	3.24	0.24
BRV	3.82E-03	11 788	1.41	0.01	7.07	0.06	28.29	0.24
HEX	1.70E-03	5 223	0.63	0.01	3.13	0.06	12.53	0.24
KGB	1.66E-03	3 492	0.42	0.01	2.09	0.06	8.38	0.24
NUY	1.77E-03	4 433	0.53	0.01	2.66	0.06	10.64	0.24
RBT	2.01E-03	17 052	2.05	0.01	10.23	0.06	40.93	0.24
THK	1.80E-03	6 677	0.80	0.01	4.01	0.06	16.02	0.24
WBK	1.92E-03	12 831	1.54	0.01	7.70	0.06	30.79	0.24
Total	**2.07E-03**	**62 844**	**7.54**	**0.01**	**37.71**	**0.06**	**150.83**	**0.24**

7.3 WATER BALANCE YIELD MODEL

The long-term averaged annual groundwater potential is calculated in Section 7.1 above, based on the aquifer specific estimations for recharge and discharge, both natural and abstraction. The yield from the confined portions of the Peninsula and the Skurweberg aquifers is calculated in Section 7.2 above, based on scenarios of acceptable averaged drawdown. The water balance yield model combines both the groundwater potential and the storage yield to establish an optimised strategy for short-term and long-term management of different aquifers.

The estimates, given in **Table 7-11** and **Table 7-12**, constitute the potential groundwater yield in the different IWRM domains for the Peninsula Aquifer and the Nardouw Aquifer, respectively. The actual yield than can be achieved depends upon aspects such as access, appropriate drilling technology, optimised borehole siting, economics of drilling, that need to be quantified as part of feasibility studies to refine the yield estimates.

Table 7-11 Groundwater yield for Peninsula Aquifer in IWRM domains based on map-centric recharge and baseflow estimation and storage yield (all values in Mm^3/a)

IWRM Domain	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)	Storage Yield	
				5 m drawdown	20 m drawdown
ATL	0.11	0.00	0.11	Not applicable	
AWT	3.88	0.05	3.83	7.90	31.58
BRV	30.12	2.28	27.84	19.00	76.02
CFP	10.62	0.22	10.40	0.14	0.55
HEX	17.12	0.96	16.16	18.94	75.75
KGB	3.82	0.00	3.82	19.05	76.18
NUY	8.40	0.44	7.96	14.64	58.58
PKT	13.22	3.68	9.54	2.18	8.72
PUB	22.03	0.33	21.70	1.68	6.71
RBT	6.55	0.00	6.55	41.96	167.85
THK	26.75	0.04	26.71	22.69	90.75
TWR	6.22	0.25	5.97	7.32	29.29
VVT	3.90	0.13	3.77	1.63	6.53
WBK	3.44	0.15	3.29	20.46	81.85
WCT	0.10	0.05	0.05	Not applicable	
Total	**156**	**8.6**	**148**	**158**	**633**

Table 7-12 Groundwater yield for Nardouw Aquifer in IWRM domains based on recharge and baseflow estimation, compared with storage yield of Skurweberg Aquifer alone (all values in Mm^3/a)

IWRM Domain	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)	Storage Yield	
				5 m drawdown	20 m drawdown
ATL	0.00	0.00	0.00	Not applicable	
AWT	11.50	1.20	10.30	0.81	3.24
BRV	4.89	2.87	2.02	7.07	28.29
CFP	0.04	0.00	0.04	Not applicable	
HEX	30.27	8.13	22.14	3.13	12.53
KGB	16.39	0.22	16.17	2.09	8.38
NUY	17.27	0.41	16.86	2.66	10.64
PKT	2.21	0.00	2.21	Not applicable	
PUB	2.31	0.33	1.98	Not applicable	
RBT	25.73	1.07	24.66	10.23	40.93
THK	24.65	0.43	24.22	4.01	16.02
TWR	4.10	0.25	3.85	Not applicable	
VVT	1.21	0.00	1.21	Not applicable	
WBK	11.79	5.70	6.09	7.70	30.79
WCT	0.00	0.00	0.00	Not applicable	
Total	**152**	**20.6**	**132**	**37.71**	**150.83**

7.4 INPUT TO WRYM GROUNDWATER MODULE

The Inception Report (DWAF, 2005a) and subsequent instructions from the DWAF to all WAAS project teams state that the Sami Groundwater Module, as implemented in the WRSM and WRYM, should be used to evaluate the groundwater contribution to baseflow and the impacts of groundwater abstraction on stream flow and available surface water resources. Subsequently, it was decided to review the applicability of the Sami Groundwater Module in the Berg WAAS area.

The Technical Documentation for Surface-Groundwater Interaction for use in System Models (DWAF, 2006g) states the underlying assumptions and limitations of the model as follows:

> The proposed module for surface-groundwater interaction depends on several assumptions and encounters a number of limitations listed below:
>
> - Baseflow depletion due to groundwater abstraction as well as groundwater outflow from the catchment is calculated using a Darcian approach, i.e. assuming a porous media (primary aquifer). It has to be corroborated whether this approach is valid for a fractured/secondary or karstified aquifer system. Depending on the degree of fracturing and fracture interconnectivity a secondary or karstic aquifer can be represented as an equivalent porous media on a quaternary catchment scale.
> - The baseflow depletion calculation assumes that all abstraction takes place from the regional aquifer, not from perched aquifers.
> - Since the baseflow depletion calculation uses the weighted mean distance of abstraction points from the main channel, it is not applicable to assess the impact of a single groundwater abstraction point on baseflow. However, the cumulative effects of groundwater abstraction in the catchment can be addressed.
> - The hydrogeological parameters of the model are determined with water balance approaches and averaged over a quaternary catchment scale. Though they might resemble hydrogeological parameter determined on a local scale during hydrogeological field investigations, they usually differ from these physically based local parameters and should not be used as such.

Based on the above, and with reference to the applicability of the module, any quaternary in which it is used, must have the following characteristics:

- There is only one aquifer system present in the catchment or all aquifers that are in hydraulic contact with the river can effectively be modelled as one. This aquifer is
    - Unconfined
    - Homogeneous
    - Single layered, with constant thickness
    - Isotropic
    - Shallow and connected to the river in the vertical flow direction.
- The aquifer has a constant hydraulic gradient with flow lines perpendicular to the river bed and the same on both sides of the river;
- The aquifer is hydraulically connected with the river over the full river length and through the entire aquifer thickness

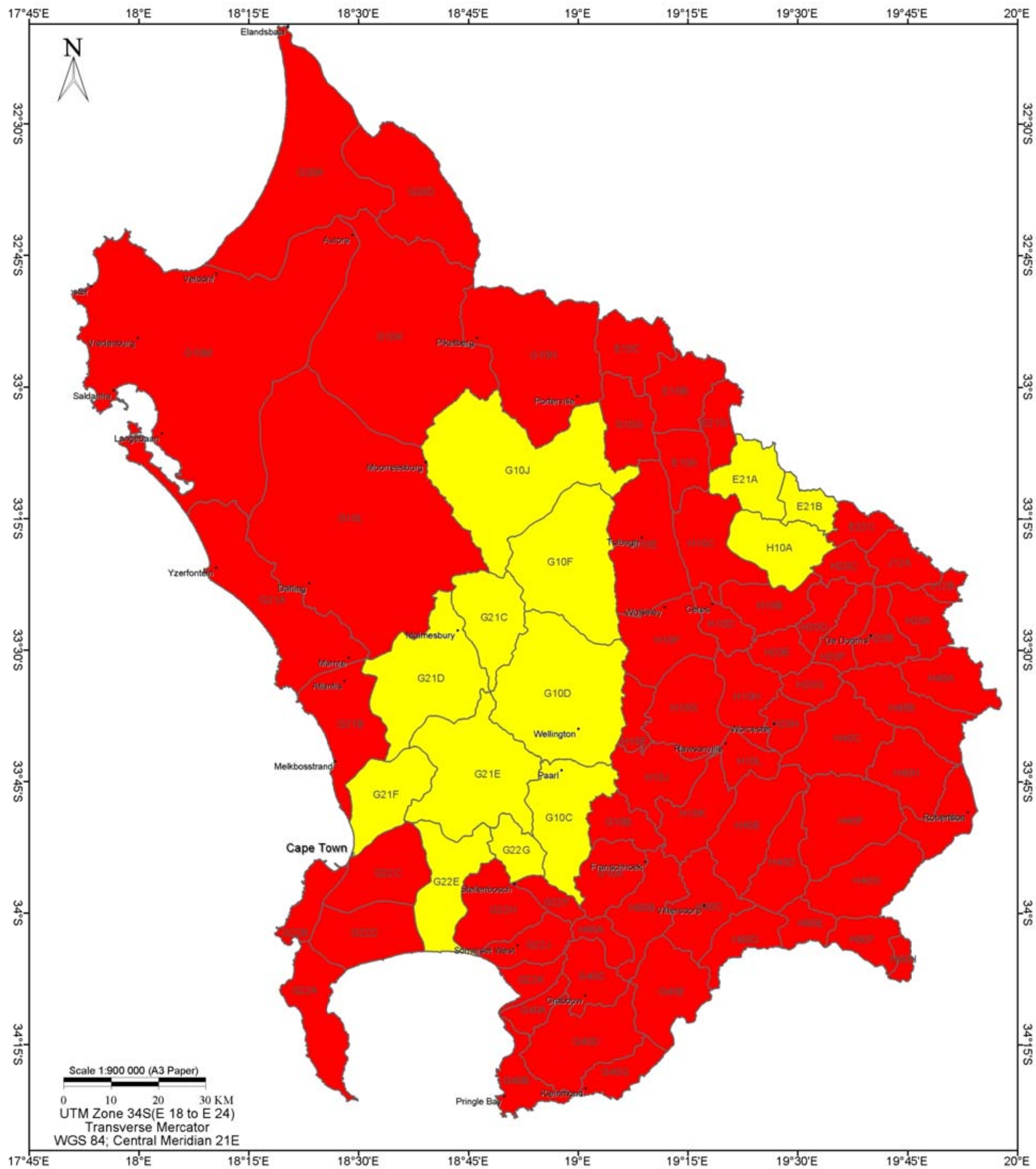
- Recharge to and discharge from the aquifer occurs in the same catchment and over one hydraulic year
- There is no endorheic drainage in the catchment
- Vertical flow is the primary direction of exchange between the river and the aquifer, i.e. the problem is 1 dimensional
- No horizontal groundwater inflow
- No perennial springs sustain low flow in the river bed
- Lateral recharge to downstream will happen at the same water table gradient as exists towards the river if this is actually catered for in the model, which is uncertain. The possibility for horizontal outflow is described, but appears to be contradictory to the required hydraulic gradient towards the river bed. The Technical Documentation does not elaborate on the calculation for the outflow.

These can be simplified into the following applicability criteria, which are used for the decision on whether the Sami Groundwater Module is applicable in any one quaternary catchment (see **Appendix E**):

1 Single homogenous aquifer in catchment, with uniform gradient and isotropic parameter distribution
2 Shallow aquifer, water table near surface, that is connected to surface water body along the whole length of the river reach
3 Unconfined aquifer
4 Well-established initial water level for starting month of simulation period
5 Groundwater flows directly towards single main stem; no asymmetry in perennial tributary pattern
6 Catchment free of endorheic drainage areas.

The review of the applicability of the Sami Module (DWAF, 2007d) revealed that the module has inherent assumptions that are not met in most of the study area. There are only a few catchments within the Berg WAAS area, where most of the assumptions are met and the module therefore might work (see **Figure 7-2**). Although the applicability of the module will be further tested in selected catchments, an alternative to the Sami Module was suggested:

- Modification of the Pitman model to incorporate groundwater
- Applying the aquifer-specific distribution of groundwater contribution to baseflow in the Pitman model
- Applying the aquifer-specific storage volumes in the WRYM.



LEGEND

- Towns
- Quaternary Catchments

Applicability

- Not
- Possible

PROJECT NAME

BERG WATER AVAILABILITY ASSESSMENT STUDY

CLIENT

DEPARTMENT OF WATER AFFAIRS & FORESTRY

CONSULTANT

UMVOTO

TITLE

SAMI MODEL APPLICABILITY

FIGURE 7.2

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

A robust water balance and yield model was developed to estimate the groundwater potential from different aquifers within the study area as well as to produce reasonable values for input parameters to the groundwater modules of the WRYM and WSAM. The model is based on the following components:

- Aquifer-specific recharge, calculated with a variety of GIS based methods and compared to results from previous studies;
- Modelled overland flow, based on slope distribution, as input to the recharge model;
- Modelled evapotranspiration, using the Turc (1954) approach, as input to the recharge model;
- Storage capacity in the Peninsula Aquifer, based on three dimensional (3D) modelling of the geological structure;
- Aquifer-specific natural discharge, based on groundwater contribution to baseflow and recharge per quaternary catchment;
- Aquifer-specific groundwater use, based on registered use on the WARMS database;
- Storage yield for the confined portion of the Peninsula Aquifer, based on the modelled storativity and reasonable values for specific storage;
- Groundwater potential, based on recharge, baseflow and groundwater use.

The water balance and yield model suggests a total remaining groundwater potential of 741 million m^3/a within the study area, applying the conservative map-centric recharge estimation (see **Table 8-1**). The recharge estimation for the Peninsula and Nardouw aquifers are considered very conservative and a higher groundwater potential from these aquifers can be expected, once the model is calibrated.

Table 8-1 Summary results of groundwater potential per aquifer

Aquifer	Method	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
Intergranular	Map-centric	350	41.1	309	92.6	217
	ISP	363	36.6	327	92.6	234
	Average	**355**	**41.1**	**314**	**92.6**	**222**
Intergranular fractured	Map-centric	348	54.1	294	58.4	236
	ISP	222	28.5	194	58.4	135
	Average	**267**	**39.2**	**228**	**58.4**	**170**
Fractured	Map-centric	10.8	0.6	10.2	0.6	9.6
	ISP	9.6	0.9	8.7	0.6	8.1
	Average	**8.0**	**0.7**	**7.3**	**0.6**	**6.7**
Nardouw	Map-centric	196	43.2	152	20.6	132
	ISP	275	49.3	226	20.6	205
	Average	**226**	**46.2**	**180**	**20.6**	**159**
Peninsula	Map-centric	214	57.9	156	8.6	148
	ISP	511	81.6	429	8.6	420
	Average	**390**	**69.7**	**320**	**8.6**	**312**
Total	Map-centric	1119	197	922	181	741
	ISP	1381	197	1184	181	1003
	Average	**1247**	**197**	**1050**	**181**	**869**

On the other hand, the recharge for the intergranular aquifer, and hence the groundwater potential, appears to be high, especially along the West Coast and the Cape Flats. These estimates need to be verified prior to further groundwater development, water allocation or licensing.

When applying the ISP method for the recharge estimation, the total groundwater potential amounts to 1003 million m^3/a, of which 420 million m^3/a are assigned to the Peninsula Aquifer alone (see **Table 8-1**). This can be considered the best-case scenario for the groundwater potential of the TMG aquifers. The potential for the intergranular aquifers remains similar at 234 million m^3/a, while the potential for the intergranular-fractured aquifers drops to 135 million m^3/a.

Using the average of the different recharge estimations, the total groundwater potential amounts to 869 million m^3/a (see **Table 8-1**).

The very high groundwater potential for the intergranular-fractured aquifers does not take into account the exploitability and the suitability for domestic or agricultural use. The groundwater quality in large areas of the Malmesbury and Granite regolith aquifers does not comply with the drinking water standards and is not or only to a degree suitable for consumption.

The intergranular aquifer is the most developed and utilised across the study domain. There are the following areas of concern:

- Overallocation of groundwater from the intergranular aquifer at least in the Hex River IWRM domains;
- Very high groundwater use (> 50% of Recharge – Baseflow) in the Atlantis, Brandvlei, Nuy and Warm Bokkeveld IWRM domains;
- High groundwater allocation (> 20% of Recharge – Baseflow) in the Atlantis, Kogelberg, Paarl-Upper Berg and West Coast IWRM domains;
- High groundwater use from the Nardouw Aquifer in the Brandvlei, Hex River and Warm Bokkeveld IWRM domains.

The Peninsula Aquifer and in certain catchments the Nardouw Aquifer are mostly un- or underutilised, but have the potential to supply significant quantities of water out of their evaporation-free storage, which is 2 to 3 orders of magnitude higher than the capacity of the surface water storage facilities in the study domain.

8.2 RECOMMENDATIONS

The results of the Water Balance Model shows that the uncertainty of the data input as well as the applied method has a significant impact on the reliability of the output and any decision that would be based on these results. It is therefore strongly recommended to initiate a data collection and monitoring programme, as outlined below.

It is also evident that the groundwater – surface water interaction and the integration of groundwater potential and use into the water resource planning cannot be achieved reliably with the current groundwater modules in the WRSM and WRYM. Hence, the development of alternatives to these modules is strongly suggested.

8.2.1 Monitoring

A monitoring programme and additional data collection is detailed in the recommendations of the Data Availability Report (DWAF, 2007a) and the Conceptual Model Report (DWAF, 2007b), of which the following activities are required for increasing the confidence in the model outputs:

- Spring hydrocensus including diverse hydrochemical sampling to verify discharge rates;
- Borehole hydrocensus to verify groundwater abstraction;
- Hydraulic testing in selected boreholes in both the Peninsula and Skurweberg Aquifer to improve the estimate for the specific storage;
- Hydrochemical sampling at specific river reaches to be used in mixing models for baseflow estimation.

The upgrade of the flow station network with regards to low flow and flood flow measurements at key points in the river network is suggested and detailed in the Flow Gauge Assessment Report (DWAF, 2006h). These recommendations need to be extended to the Hex and Nuy rivers for increasing the confidence in the reported MAR values for these catchments.

In addition to these data collection activities long-term monitoring should be initiated for the following aspects:

- Rainfall sampling and chemical / isotope analysis in selected recharge areas for calibration of the recharge model with the Chloride Mass Balance and Isotopes;
- Seasonal and event response sampling of rainfall, spring flow and groundwater for calculation of residence time and interflow/rejected recharge;
- Monitoring of key abstraction points for aquifer response to abstraction for considering the impact of existing groundwater use with regards to refining unused potential estimates;
- Monitoring of ambient boreholes in different aquifers to establish seasonal fluctuation of water levels for calibration of recharge estimation;

It is therefore suggested to develop a comprehensive monitoring programme for the Berg WAAS area that comprises all the above aspects in an integrated and optimised manner.

8.2.2 Model

Since the Sami Groundwater Module is not applicable throughout the study domain, it is recommended to develop an alternative to the Sami Groundwater Module that comprises:

- Applying the aquifer specific distribution of groundwater contribution to baseflow in the Pitman model
- Applying the aquifer specific storage volumes in the WRYM

It is further recommended to align the discretisation for the surface water modelling with the boundaries of the groundwater regime to ensure that the surface water modelling scale ties in with groundwater flow path scale effects within each relevant aquifer and to account for subsurface transfer across catchment boundaries. The proposed IWRM domains allow for this integration and are considered the scale for the WRYM, which would also allow for the design of groundwater or conjunctive use schemes. However, the WRSM modelling should be undertaken on the scale of sub-domains that are aquifer and quaternary-catchment specific.

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APPENDIX A

LIST OF HYDROLOGICAL PARAMETERS PER QUATERNARY CATCHMENT

APPENDIX A : LIST OF HYDROLOGICAL PARAMETERS PER QUATERNARY CATCHMENT

Table A-1: Catchment area and MAP in study domain

Quaternary catchment	Area	MAP *WR90*	MAP *CCWR*	MAP *GRAII*	MAP *Berg WAAS*	MAP *WR2005*	Difference *Berg WAAS / WR2005*
	km²	*mm*	*mm*	*mm*	*mm*	*mm*	
E10A	133.73	899	743	907	966	899	1.07
E10B	197.15	736	648	724	869	736	1.18
E10C	189.98	587	552	581	840	587	1.43
E21A	183.09	620	475	582	718	620	1.16
E21B	92.50	497	336	540	666	497	1.34
E21D	108.22	627	620	771	851	627	1.36
E22C	91.22	324	394	426	603	324	1.70
G10A	171.78	1580	1218	1555	1603	1610	1.00
G10B	125.97	1245	893	1237	1306	1306	1.00
G10C	328.07	1009	914	1000	874	877	1.00
G10D	687.55	625	574	640	690	691	1.00
G10E	394.10	640	656	660	767	764	1.00
G10F	539.36	515	549	533	581	582	1.00
G10G	185.58	912	672	935	995	997	1.00
G10H	674.52	411	404	406	404	404	1.00
G10J	867.50	447	454	450	494	494	1.00
G10K	1175.89	382	408	383	318	317	1.00
G10L	1754.55	390	387	390	305	306	1.00
G10M	2004.68	300	271	298	225	225	1.00
G21A	523.29	408	409	409	345	345	1.00
G21B	303.78	424	398	424	331	332	1.00
G21C	244.22	523	472	523	546	546	1.00
G21D	484.05	477	465	478	384	384	1.00
G21E	530.76	531	530	535	497	498	1.00
G21F	242.40	488	449	491	361	362	1.00
G22A	237.99	684	723	682	735	733	1.00
G22B	109.40	923	956	912	1073	1074	0.99
G22C	254.25	605	609	610	651	654	1.00
G22D	246.01	738	823	732	824	823	1.00
G22E	270.68	572	562	575	562	563	1.00
G22F	65.69	1465	1421	1527	1620	1630	0.99
G22G	106.36	754	717	750	785	785	1.00
G22H	227.30	669	678	680	814	815	1.00
G22J	128.19	1002	1027	1013	1152	1147	1.00
G22K	79.82	769	854	815	906	909	1.00
G30A	761.28	260	261	262	309	309	1.00
G30D	438.59	384	345	384	398	399	1.00
G40A	71.52	1121	1017	1146	1053	1054	1.00
G40B	122.42	937	1068	951	977	974	0.99
G40C	144.57	1367	1331	1312	1251	1244	1.01
G40D	327.17	984	1042	986	899	899	1.00
G40E	252.59	722	609	735	764	745	1.03
G40G	108.82	724	724	808	745	701	1.06

Quaternary catchment	Area	MAP *WR90*	MAP *CCWR*	MAP *GRAII*	MAP *Berg WAAS*	MAP *WR2005*	Difference *Berg WAAS / WR2005*
	km²	*mm*	*mm*	*mm*	*mm*	*mm*	
H10A	233.67	512	473	550	651	734	0.89
H10B	162.46	708	424	653	778	734	1.06
H10C	259.60	674	722	668	862	1064	0.81
H10D	96.96	1019	586	977	1146	2000	0.57
H10E	84.81	1404	813	1440	1241	2140	0.58
H10F	247.88	784	627	799	883	784	1.13
H10G	270.43	788	703	804	816	788	1.04
H10H	187.49	886	381	864	753	749	1.01
H10J	213.78	1595	856	1612	1226	1228	1.00
H10K	193.55	1225	678	1213	1106	1225	0.90
H10L	95.79	476	403	464	542	476	1.14
H20A	140.46	357	281	356	375	357	1.05
H20B	124.39	590	312	539	488	590	0.83
H20C	80.57	643	503	627	674	643	1.05
H20D	100.67	696	383	697	945	967	0.98
H20E	95.20	906	301	957	967	906	1.07
H20F	116.58	797	322	757	714	797	0.90
H20G	85.08	680	347	684	765	680	1.12
H20H	89.03	300	276	294	365	300	1.22
H40A	184.39	426	293	435	383	426	0.90
H40B	240.54	577	357	649	542	578	0.94
H40C	271.79	375	269	356	380	375	1.01
H40D	181.76	557	318	587	672	557	1.21
H40E	285.43	539	398	541	590	539	1.09
H40F	339.92	293	251	292	427	293	1.46
H40G	263.37	417	326	468	554	464	1.19
H40H	207.91	461	342	417	415	461	0.90
H40J	152.24	417	307	358	372	424	0.88
H60A	72.64	1895	1569	1723	1695	2141	0.79
H60B	210.00	1127	904	1094	1161	1241	0.94
H60C	216.89	891	631	879	869	994	0.87
H60D	137.75	652	512	751	809	652	1.24
H60E	84.52	640	412	814	849	640	1.33
H60F	115.52	582	418	677	731	582	1.26
H60H	35.64	464	402	549	600	464	1.29
J12A	127.96	437	326	469	731	437	1.22
J12B	38.72	268	258	274	322	268	1.05
Total	**22232.0**	**574.7**	**503.1**	**579.0**	**581.1**	**578.3**	

Table A-2: Catchment area in study domain, MAR and Run-off efficiency

Quaternary catchment	Area	MAR	MAR	Difference	Run-off Effciency		
		WR90	*WR2005*		*Berg WAAS / WR2005*	*WR2005*	*WR90*
	km²	*mm*	*mm*				
E10A	133.73	458	459	0.3%	0.48	0.51	0.51
E10B	197.15	346	340	1.8%	0.39	0.46	0.47
E10C	189.98	259	248	4.3%	0.30	0.42	0.44
E21A	183.09	184	186	1.1%	0.26	0.30	0.30
E21B	92.50	121	121	0.3%	0.18	0.24	0.24
E21D	108.22	188	190	1.2%	0.22	0.30	0.30
E22C	91.22	27	25	7.7%	0.05	0.08	0.08
G10A	171.78	1015	794	21.8%	0.49	0.49	0.64
G10B	125.97	726	750	3.3%	0.57	0.57	0.58
G10C	328.07	448	295	34.2%	0.34	0.34	0.44
G10D	687.55	168	181	7.6%	0.26	0.26	0.27
G10E	394.10	173	201	16.1%	0.26	0.26	0.27
G10F	539.36	113	47	58.4%	0.08	0.08	0.22
G10G	185.58	668	314	53.0%	0.32	0.32	0.73
G10H	674.52	31	61	96.0%	0.15	0.15	0.08
G10J	867.50	40	16	60.0%	0.03	0.03	0.09
G10K	1175.89	21	8	61.4%	0.03	0.03	0.05
G10L	1754.55	29	9	67.5%	0.03	0.03	0.07
G10M	2004.68	9	3	66.8%	0.01	0.01	0.03
G21A	523.29	32	15	53.5%	0.04	0.04	0.08
G21B	303.78	32	11	67.0%	0.03	0.03	0.08
G21C	244.22	62	58	5.7%	0.11	0.11	0.12
G21D	484.05	49	21	56.3%	0.06	0.06	0.10
G21E	530.76	68	60	12.4%	0.12	0.12	0.13
G21F	242.40	54	19	65.0%	0.05	0.05	0.11
G22A	237.99	133	167	25.9%	0.23	0.23	0.19
G22B	109.40	296	420	42.0%	0.39	0.39	0.32
G22C	254.25	92	122	33.1%	0.19	0.19	0.15
G22D	246.01	165	232	40.5%	0.28	0.28	0.22
G22E	270.68	77	76	1.0%	0.14	0.14	0.13
G22F	65.69	868	520	40.1%	0.32	0.32	0.59
G22G	106.36	155	138	11.2%	0.18	0.18	0.21
G22H	227.30	111	155	39.9%	0.19	0.19	0.17
G22J	128.19	459	549	19.6%	0.48	0.48	0.46
G22K	79.82	300	378	26.0%	0.42	0.42	0.39
G30A	761.28	6	13	115.5%	0.04	0.04	0.02
G30D	438.59	22	26	20.0%	0.07	0.07	0.06
G40A	71.52	538	468	13.0%	0.44	0.44	0.48
G40B	122.42	403	412	2.2%	0.43	0.42	0.43
G40C	144.57	728	709	2.6%	0.57	0.57	0.53
G40D	327.17	436	478	9.6%	0.53	0.53	0.44
G40E	252.59	135	110	18.2%	0.14	0.15	0.19
G40G	108.82	136	118	13.2%	0.16	0.17	0.19

Quaternary catchment	Area	MAR *WR90*	MAR *WR2005*	Difference	Run-off Effciency		
	km²	*mm*	*mm*		*Berg WAAS / WR2005*	*WR2005*	*WR90*
H10A	233.67	168	152	9.7%	0.23	0.21	0.33
H10B	162.46	288	152	47.4%	0.19	0.21	0.41
H10C	259.60	266	231	13.1%	0.27	0.22	0.39
H10D	96.96	520	1325	154.8%	1.16	0.66	0.51
H10E	84.81	1064	1495	40.5%	1.20	0.70	0.76
H10F	247.88	349	235	32.7%	0.27	0.30	0.45
H10G	270.43	353	239	32.3%	0.29	0.30	0.45
H10H	187.49	423	216	49.1%	0.29	0.29	0.48
H10J	213.78	859	897	4.4%	0.73	0.73	0.54
H10K	193.55	573	621	8.5%	0.56	0.51	0.47
H10L	95.79	94	8	91.9%	0.01	0.02	0.20
H20A	140.46	34	32	6.3%	0.09	0.09	0.10
H20B	124.39	33	91	176.1%	0.19	0.15	0.06
H20C	80.57	44	112	153.6%	0.17	0.17	0.07
H20D	100.67	277	247	10.9%	0.26	0.26	0.40
H20E	95.20	423	209	50.6%	0.22	0.23	0.47
H20F	116.58	97	117	20.5%	0.16	0.15	0.12
H20G	85.08	55	259	371.2%	0.34	0.38	0.08
H20H	89.03	29	1	95.7%	0.00	0.00	0.10
H40A	184.39	35	35	1.4%	0.09	0.08	0.08
H40B	240.54	15	12	21.2%	0.02	0.02	0.03
H40C	271.79	52	66	26.9%	0.17	0.18	0.14
H40D	181.76	136	114	16.1%	0.17	0.20	0.24
H40E	285.43	126	27	78.6%	0.05	0.05	0.23
H40F	339.92	27	24	10.3%	0.06	0.08	0.09
H40G	263.37	66	26	60.7%	0.05	0.06	0.16
H40H	207.91	88	46	47.8%	0.11	0.10	0.19
H40J	152.24	52	229	341.0%	0.62	0.54	0.12
H60A	72.64	1207	1633	35.3%	0.96	0.76	0.64
H60B	210.00	564	819	45.2%	0.71	0.66	0.50
H60C	216.89	386	197	48.9%	0.23	0.20	0.43
H60D	137.75	184	158	14.1%	0.20	0.24	0.28
H60E	84.52	174	148	15.1%	0.17	0.23	0.27
H60F	115.52	141	119	15.8%	0.16	0.20	0.24
H60H	35.64	78	69	11.8%	0.11	0.15	0.17
J12A	127.96	38	32	17.0%	0.06	0.07	0.09
J12B	38.72	10	7	26.3%	0.03	0.03	0.04
Total	**22232**	**156**	**147**		**0.25**	**0.25**	**0.27**

Table A-3: Baseflow, Groundwater Contribution to Baseflow and Recharge per catchment (after GRDM database)

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**

Table A-4: Groundwater use per catchment (after GRA II)

Quaternary Catchment	Groundwater Use [Million m^3/a]							
	Total	Rural	Municipal	Agric. Irrigation	Agric. Livestock	Mining	Industry	Aqua
E10A	3.4516	0.0000	0.0000	3.4440	0.0076	0.0000	0.0000	0.0000
E10B	3.7288	0.0070	0.0000	3.7143	0.0075	0.0000	0.0000	0.0000
E10C	0.3425	0.0000	0.0000	0.3346	0.0079	0.0000	0.0000	0.0000
E21A	5.3593	0.0130	0.0000	5.3397	0.0066	0.0000	0.0000	0.0000
E21B	1.3477	0.0010	0.0000	1.3389	0.0078	0.0000	0.0000	0.0000
E21D	7.3865	0.0070	0.0000	7.3710	0.0085	0.0000	0.0000	0.0000
E22C	0.2093	0.0170	0.0000	0.1752	0.0171	0.0000	0.0000	0.0000
G10A	0.0300	0.0060	0.0000	0.0100	0.0000	0.0000	0.0140	0.0000
G10B	0.0196	0.0000	0.0000	0.0196	0.0000	0.0000	0.0000	0.0000
G10C	0.5832	0.0030	0.0000	0.0000	0.0012	0.0000	0.5790	0.0000
G10D	1.7538	0.0040	0.0000	1.3551	0.0262	0.0000	0.2070	0.1615
G10E	11.1348	0.0000	0.0000	10.9800	0.0578	0.0000	0.0970	0.0000
G10F	0.1621	0.0170	0.0058	0.0745	0.0648	0.0000	0.0000	0.0000
G10G	0.0346	0.0000	0.0000	0.0000	0.0346	0.0000	0.0000	0.0000
G10H	1.4927	0.0050	0.2788	0.4034	0.1265	0.0000	0.6790	0.0000
G10J	6.6445	0.0080	0.0000	6.5628	0.0737	0.0000	0.0000	0.0000
G10K	2.6975	0.0240	0.0000	2.4656	0.2079	0.0000	0.0000	0.0000
G10L	0.4196	0.0100	0.2406	0.0000	0.1690	0.0000	0.0000	0.0000
G10M	1.9990	0.0070	0.0837	0.0000	0.4073	0.0000	1.5010	0.0000
G21A	0.1953	0.0020	0.0000	0.0000	0.1933	0.0000	0.0000	0.0000
G21B	14.8062	0.0000	8.5166	0.0000	0.1056	0.0000	6.1840	0.0000
G21C	0.0671	0.0000	0.0000	0.0000	0.0000	0.0181	0.0490	0.0000
G21D	2.5107	0.0670	0.0000	0.0000	0.0587	0.0000	2.3810	0.0040
G21E	1.3437	0.0160	0.0238	0.0000	0.0944	0.0000	1.1980	0.0115
G21F	1.3447	0.0000	0.0000	0.0000	0.0667	0.0000	1.2780	0.0000
G22A	0.0125	0.0000	0.0000	0.0000	0.0096	0.0000	0.0000	0.0029
G22B	1.2397	0.0000	1.1896	0.0000	0.0231	0.0000	0.0270	0.0000
G22C	0.0835	0.0000	0.0000	0.0000	0.0745	0.0000	0.0090	0.0000
G22D	9.9010	0.0000	5.9474	0.0000	0.0646	0.0000	3.8890	0.0000
G22E	0.4020	0.0000	0.0000	0.0000	0.0450	0.0000	0.3570	0.0000
G22F	0.3430	0.0000	0.0000	0.0000	0.0000	0.0000	0.3430	0.0000
G22G	0.0980	0.0000	0.0000	0.0000	0.0000	0.0000	0.0980	0.0000
G22H	0.1884	0.0090	0.0000	0.0000	0.0004	0.0000	0.1790	0.0000
G22J	0.5930	0.0000	0.0000	0.0000	0.0000	0.0000	0.3730	0.2200
G22K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
G30A	2.7694	0.0040	0.0000	2.6167	0.1487	0.0000	0.0000	0.0000
G30D	2.5644	0.0000	0.0000	2.4580	0.1064	0.0000	0.0000	0.0000
G40A	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
G40B	0.0020	0.0000	0.0000	0.0000	0.0020	0.0000	0.0000	0.0000
G40C	0.0227	0.0000	0.0000	0.0000	0.0027	0.0000	0.0200	0.0000
G40D	0.0062	0.0000	0.0000	0.0000	0.0062	0.0000	0.0000	0.0000
G40E	0.2912	0.0000	0.2857	0.0000	0.0055	0.0000	0.0000	0.0000
G40G	0.0124	0.0000	0.0091	0.0000	0.0033	0.0000	0.0000	0.0000

Quaternary Catchment	Groundwater Use [Million m^3/a]							
	Total	Rural	Municipal	Agric. Irrigation	Agric. Livestock	Mining	Industry	Aqua
H10A	3.2995	0.0000	0.0000	3.2913	0.0082	0.0000	0.0000	0.0000
H10B	4.5534	0.0000	0.0000	4.5477	0.0057	0.0000	0.0000	0.0000
H10C	13.3353	0.0000	1.4278	11.3790	0.0095	0.0000	0.5190	0.0000
H10D	0.0034	0.0000	0.0000	0.0000	0.0034	0.0000	0.0000	0.0000
H10E	0.0017	0.0000	0.0000	0.0000	0.0017	0.0000	0.0000	0.0000
H10F	8.9360	0.0000	0.0000	8.7940	0.0220	0.0000	0.1200	0.0000
H10G	8.4146	0.0000	0.0000	8.4110	0.0036	0.0000	0.0000	0.0000
H10H	1.4186	0.0000	0.0000	1.0500	0.0026	0.0000	0.3660	0.0000
H10J	0.4807	0.0000	0.0000	0.4600	0.0047	0.0000	0.0160	0.0000
H10K	0.3938	0.0000	0.0000	0.3901	0.0037	0.0000	0.0000	0.0000
H10L	2.5953	0.0000	0.1040	2.4170	0.0013	0.0000	0.0730	0.0000
H20A	0.4200	0.0030	0.0000	0.4082	0.0018	0.0000	0.0070	0.0000
H20B	2.1175	0.0190	0.0598	2.0340	0.0017	0.0000	0.0030	0.0000
H20C	1.8244	0.0000	0.0000	1.8216	0.0028	0.0000	0.0000	0.0000
H20D	0.1357	0.0000	0.0000	0.1337	0.0020	0.0000	0.0000	0.0000
H20E	0.1768	0.0000	0.0000	0.1753	0.0015	0.0000	0.0000	0.0000
H20F	2.1997	0.0060	0.0000	2.1920	0.0017	0.0000	0.0000	0.0000
H20G	0.4916	0.0080	0.0000	0.4825	0.0011	0.0000	0.0000	0.0000
H20H	0.7075	0.0000	0.0000	0.4863	0.0012	0.0000	0.2200	0.0000
H40A	0.0038	0.0000	0.0000	0.0000	0.0038	0.0000	0.0000	0.0000
H40B	0.7990	0.0130	0.0000	0.7805	0.0055	0.0000	0.0000	0.0000
H40C	4.2137	0.0140	0.0000	4.1960	0.0037	0.0000	0.0000	0.0000
H40D	1.5695	0.0000	0.0000	1.5671	0.0024	0.0000	0.0000	0.0000
H40E	1.6816	0.0000	0.0000	1.6778	0.0038	0.0000	0.0000	0.0000
H40F	1.7010	0.0110	0.0000	1.6801	0.0099	0.0000	0.0000	0.0000
H40G	0.2355	0.0000	0.0000	0.0000	0.0155	0.0000	0.2200	0.0000
H40H	0.0424	0.0070	0.0000	0.0000	0.0104	0.0240	0.0010	0.0000
H40J	0.0193	0.0000	0.0000	0.0000	0.0113	0.0000	0.0080	0.0000
H60A	0.0012	0.0000	0.0000	0.0000	0.0012	0.0000	0.0000	0.0000
H60B	0.0036	0.0000	0.0000	0.0000	0.0036	0.0000	0.0000	0.0000
H60C	0.5261	0.0120	0.4682	0.0333	0.0046	0.0000	0.0080	0.0000
H60D	0.0065	0.0020	0.0000	0.0000	0.0045	0.0000	0.0000	0.0000
H60E	0.0297	0.0260	0.0000	0.0000	0.0037	0.0000	0.0000	0.0000
H60F	0.3497	0.0000	0.3428	0.0000	0.0069	0.0000	0.0000	0.0000
H60H	0.0069	0.0000	0.0000	0.0000	0.0069	0.0000	0.0000	0.0000
J12A	0.4756	0.0000	0.0000	0.4707	0.0049	0.0000	0.0000	0.0000
J12B	0.0022	0.0000	0.0000	0.0000	0.0022	0.0000	0.0000	0.0000
Total	**150.8**	**0.3**	**19.0**	**107.5**	**2.4**	**0.0**	**21.0**	**0.4**

APPENDIX B

RECHARGE MODEL RESULTS

APPENDIX B : RECHARGE MODEL RESULTS

Table B-1 Recharge estimation with fixed percentage of MAP *)

Quaternary catchment	Peninsula Aquifer *Mm³*	Nardouw Aquifer *Mm³*	Other Fractured Aquifers *Mm³*	Intergranular fractured Aquifers *Mm³*	Intergranular Aquifers *Mm³*	**Total Recharge** *Mm³*	*mm*
E10A	4.09	5.41	0.00	0.68	0.00	10.17	76
E10B	3.81	7.29	0.00	0.96	0.31	12.38	63
E10C	9.84	5.47	0.02	0.33	0.00	15.65	82
E21A	0.13	0.78	0.69	3.14	0.11	4.87	27
E21B	0.00	0.01	0.19	1.47	0.36	2.03	22
E21D	1.98	2.05	0.00	1.46	0.00	5.49	51
E22C	0.00	0.24	0.00	1.20	0.28	1.71	19
G10A	25.17	0.54	0.00	0.77	2.40	28.88	168
G10B	13.32	1.80	0.01	0.49	0.97	16.58	132
G10C	9.47	0.19	0.01	2.53	5.28	17.48	53
G10D	5.20	0.16	0.02	9.41	4.85	19.64	29
G10E	10.43	2.28	0.08	3.23	3.43	19.46	49
G10F	7.82	0.26	0.09	4.73	3.49	16.39	30
G10G	12.53	5.32	0.22	0.43	0.04	18.55	100
G10H	3.47	0.19	0.47	6.59	0.69	11.41	17
G10J	7.73	0.00	0.37	7.76	4.34	20.20	23
G10K	14.83	1.60	0.69	3.85	4.22	25.19	21
G10L	0.00	0.00	0.00	8.27	10.40	18.68	11
G10M	0.01	0.00	0.05	1.63	15.79	17.48	9
G21A	0.00	0.00	0.00	1.94	4.64	6.58	13
G21B	0.00	0.00	0.00	0.51	3.35	3.86	13
G21C	0.56	0.00	0.00	3.84	0.06	4.46	18
G21D	0.00	0.00	0.00	3.04	3.40	6.43	13
G21E	0.00	0.00	0.02	4.22	4.92	9.16	17
G21F	0.00	0.00	0.00	1.20	1.89	3.10	13
G22A	17.48	0.00	0.00	0.35	1.56	19.39	81
G22B	5.87	0.00	0.04	1.14	1.41	8.47	77
G22C	0.24	0.00	0.00	0.83	5.45	6.52	26
G22D	1.00	0.00	0.00	0.58	6.86	8.44	34
G22E	0.00	0.00	0.00	0.99	4.76	5.75	21
G22F	6.86	0.00	0.00	0.75	1.30	8.90	136
G22G	0.28	0.00	0.00	0.96	1.98	3.22	30
G22H	2.74	0.00	0.00	1.63	4.40	8.78	39
G22J	3.30	0.04	0.00	1.45	2.98	7.77	61
G22K	2.00	0.04	0.00	0.87	1.14	4.05	51
G30A	1.15	0.00	0.74	0.08	8.48	10.44	14
G30D	3.59	0.00	1.24	0.90	3.94	9.67	22
G40A	1.66	3.53	0.00	0.18	0.00	5.37	75
G40B	8.20	1.59	0.00	0.20	1.20	11.19	91
G40C	7.90	5.09	0.00	1.45	0.04	14.48	100
G40D	4.51	12.54	0.00	2.46	0.04	19.54	60
G40E	2.10	5.92	0.00	2.58	0.30	10.90	43
G40G	0.07	3.79	0.00	0.17	0.78	4.82	44

Quaternary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Total Recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
H10A	0.00	0.32	0.00	3.56	1.15	5.03	22
H10B	0.00	6.41	0.00	0.92	0.16	7.49	46
H10C	0.30	7.65	0.00	2.71	0.82	11.49	44
H10D	10.49	2.07	0.00	0.20	0.00	12.76	132
H10E	10.70	1.00	0.00	0.25	0.16	12.11	143
H10F	12.40	2.08	0.00	1.13	2.52	18.12	73
H10G	9.81	0.24	0.00	0.88	4.81	15.74	58
H10H	11.65	0.13	0.02	0.52	1.54	13.86	74
H10J	28.31	0.79	0.00	0.65	1.09	30.83	144
H10K	24.61	0.84	0.00	0.42	0.49	26.36	136
H10L	0.81	0.86	0.02	0.13	0.91	2.73	28
H20A	0.00	0.77	0.00	1.17	0.10	2.04	15
H20B	0.00	2.96	0.00	0.24	0.42	3.62	29
H20C	0.23	2.26	0.00	0.34	0.31	3.15	39
H20D	9.49	1.27	0.00	0.22	0.08	11.05	110
H20E	8.82	1.38	0.00	0.18	0.13	10.51	110
H20F	3.24	3.04	0.00	0.17	0.44	6.89	59
H20G	5.76	0.62	0.00	0.21	0.32	6.91	81
H20H	0.01	0.00	0.00	0.42	0.73	1.16	13
H40A	0.00	2.42	0.00	1.02	0.08	3.52	19
H40B	1.35	5.10	0.00	1.32	0.13	7.91	33
H40C	4.22	0.37	0.03	1.11	1.22	6.94	26
H40D	1.38	4.49	0.32	0.97	0.42	7.57	42
H40E	6.96	2.18	0.19	1.40	1.35	12.08	42
H40F	0.00	0.35	1.28	2.78	1.05	5.46	16
H40G	0.58	5.54	0.00	1.33	0.72	8.18	31
H40H	3.29	0.18	0.07	1.45	0.43	5.42	26
H40J	0.79	0.55	0.00	0.79	0.67	2.80	18
H60A	10.48	1.45	0.00	0.52	0.40	12.85	177
H60B	12.33	5.03	0.00	1.07	0.89	19.32	92
H60C	5.71	4.39	0.00	1.60	0.59	12.30	57
H60D	6.27	2.73	0.00	0.67	0.21	9.88	72
H60E	7.23	0.41	0.00	0.30	0.17	8.11	96
H60F	5.86	0.94	0.00	0.66	0.30	7.76	67
H60H	1.33	0.00	0.00	0.26	0.12	1.71	48
J12A	0.49	2.90	0.00	0.30	0.52	4.21	33
J12B	0.00	0.34	0.00	0.12	0.09	0.54	14
Total	**404**	**140**	**7**	**123**	**147**	**822**	**37**

*) Peninsula Aquifer	14%
Nardouw Aquifer	7%
Fractured Aquifers	6%
Intergranular fractured	3%
Intergranular Aquifers	4%

Table B-2 Aquifer specific recharge estimation using the GRA II spatial distribution of recharge %, after DWAF (2005)

Quaternary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Aquifer specific recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
E10A	4.38	11.48	0.00	3.10		18.96	142
E10B	3.99	14.68	0.00	3.99	0.97	23.63	120
E10C	8.89	9.61	0.03	1.33	0.00	19.87	105
E21A	0.10	1.24	0.95	9.70	0.29	12.29	67
E21B		0.01	0.24	3.77	0.66	4.69	51
E21D	1.48	3.30	0.00	4.93	0.00	9.71	90
E22C		0.15	0.00	1.44	0.23	1.83	20
G10A	40.25	1.66	0.00	5.47	13.13	61.01	355
G10B	19.29	4.91	0.03	3.24	4.77	32.86	261
G10C	10.08	0.39	0.02	10.73	18.17	39.39	120
G10D	3.80	0.23	0.03	26.82	10.90	41.78	61
G10E	6.98	2.43	0.11	9.36	7.65	26.53	67
G10F	4.23	0.27	0.11	10.54	6.03	21.70	40
G10G	13.54	10.78	0.56	2.12	0.16	27.15	146
G10H	1.50	0.21	0.44	7.01	0.60	9.76	14
G10J	4.75		0.39	9.53	4.78	19.46	22
G10K	5.80	1.02	0.67	3.57	4.48	15.53	13
G10L			0.00	11.71	12.79	24.50	14
G10M	0.00		0.05	2.61	21.98	24.65	12
G21A			0.00	4.84	8.97	13.81	26
G21B			0.00	1.18	6.99	8.17	27
G21C	0.28		0.00	6.56	0.08	6.92	28
G21D			0.00	4.86	4.32	9.18	19
G21E			0.02	9.28	7.77	17.07	32
G21F			0.00	2.63	3.76	6.41	26
G22A	20.37		0.00	1.90	6.29	28.55	120
G22B	6.78		0.11	6.01	5.59	18.49	169
G22C	0.25		0.00	3.11	14.73	18.10	71
G22D	1.15		0.00	2.93	22.78	27.45	112
G22E			0.00	2.67	10.60	13.27	49
G22F	10.97		0.00	5.51	7.39	23.88	364
G22G	0.23		0.00	3.12	4.55	7.89	74
G22H	2.38		0.00	6.33	9.66	18.36	81
G22J	4.35	0.12	0.00	8.44	13.10	26.00	203
G22K	2.35	0.09	0.00	4.45	4.56	11.45	143
G30A	0.47		0.63	0.17	11.35	12.62	17
G30D	1.60		1.19	1.75	5.60	10.14	23
G40A	2.25	9.17	0.00	1.05	0.01	13.73	192
G40B	9.67	3.87	0.00	1.05	4.78	19.37	158
G40C	12.78	15.34	0.00	9.16	0.19	37.97	263
G40D	6.51	33.45	0.00	11.99	0.19	52.15	159
G40E	0.97	5.22	0.00	5.09	0.42	11.70	46
G40G	0.07	5.38	0.00	0.33	2.00	7.86	72

Quaternary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Aquifer specific recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
H10A		0.39	0.00	11.51	2.91	14.83	63
H10B		11.82	0.00	3.46	0.47	15.75	97
H10C	0.24	13.86	0.00	10.24	2.37	26.87	104
H10D	11.67	4.42	0.00	0.99	0.01	17.10	176
H10E	14.36	2.68	0.00	1.60	0.82	19.46	229
H10F	12.01	3.20	0.00	5.27	8.40	28.89	117
H10G	10.40	0.52	0.00	4.20	16.28	31.40	116
H10H	14.83	0.25	0.02	2.23	4.55	21.88	117
H10J	38.02	2.04	0.00	4.07	4.95	49.09	230
H10K	30.39	1.82	0.00	2.44	1.71	36.35	188
H10L	0.39	0.74	0.02	0.23	1.59	3.20	33
H20A		0.57	0.00	1.61	0.17	2.34	17
H20B		3.44	0.00	0.57	0.95	4.97	40
H20C	0.11	1.98	0.00	0.68	0.39	3.23	40
H20D	8.58	1.88	0.00	0.87	0.24	11.58	115
H20E	9.59	2.68	0.00	0.87	0.47	13.61	143
H20F	2.18	4.33	0.00	0.56	1.12	8.19	70
H20G	3.38	0.85	0.00	0.49	0.51	5.23	61
H20H	0.01		0.00	0.77	0.65	1.43	16
H40A		1.79	0.00	1.32	0.08	3.19	17
H40B	0.60	5.60	0.00	3.10	0.24	9.58	40
H40C	1.76	0.42	0.01	1.08	0.81	4.08	15
H40D	0.70	3.54	0.09	0.91	0.24	5.48	30
H40E	4.03	1.89	0.10	1.99	1.09	9.21	32
H40F		0.13	0.19	1.05	0.26	1.63	5
H40G	0.21	2.86	0.00	0.91	0.35	4.33	16
H40H	1.52	0.18	0.03	2.06	0.39	4.17	20
H40J	0.39	0.08	0.00	0.87	0.33	1.67	11
H60A	17.80	4.21	0.00	3.45	1.91	27.37	377
H60B	16.78	11.54	0.00	5.50	3.60	41.22	196
H60C	6.77	8.83	0.00	7.55	2.38	27.65	128
H60D	4.49	3.69	0.00	1.97	0.47	10.62	77
H60E	4.58	0.42	0.00	0.86	0.36	6.22	74
H60F	3.38	0.96	0.00	1.63	0.58	6.55	57
H60H	0.75	0.00	0.00	0.60	0.18	1.53	43
J12A	0.19	1.87	0.00	0.38	0.43	2.88	22
J12B		0.10	0.00	0.08	0.04	0.23	6
Total	**432.62**	**240.60**	**6.04**	**323.33**	**325.55**	**1338.84**	**60**

Table B-3 Aquifer specific recharge estimation using the variable rainfall % and aquifer specific recharge factors, after DWAF (2003)

Quaternary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Aquifer specific recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
E10A	4.06	8.46	0.00	1.87		14.39	108
E10B	3.23	10.87	0.00	2.48	1.05	17.63	89
E10C	7.55	7.47	0.03	1.23	0.00	16.28	86
E21A	0.11	1.30	0.60	5.84	0.38	8.24	45
E21B		0.01	0.16	2.62	0.94	3.75	41
E21D	1.64	3.19	0.00	3.61	0.00	8.45	78
E22C		0.24	0.00	1.99	0.66	2.90	32
G10A	40.46	1.01	0.00	2.86	12.24	57.03	332
G10B	15.53	3.38	0.01	1.91	4.56	25.87	205
G10C	11.98	0.37	0.01	5.58	19.98	37.91	116
G10D	5.25	0.33	0.02	16.82	15.32	37.73	55
G10E	10.37	3.41	0.05	5.87	11.16	30.87	78
G10F	6.91	0.45	0.14	6.25	8.09	22.37	41
G10G	11.92	7.60	0.42	1.62	0.19	21.75	117
G10H	2.64	0.27	0.71	8.03	1.54	13.19	20
G10J	7.17		0.64	9.77	9.87	27.45	32
G10K	7.87	1.49	0.72	3.54	5.07	18.69	16
G10L			0.00	9.43	14.99	24.42	14
G10M	0.00		0.06	1.35	18.61	20.03	10
G21A			0.00	2.72	9.08	11.80	23
G21B			0.00	0.62	6.89	7.51	25
G21C	0.48		0.00	5.28	0.13	5.89	24
G21D			0.00	4.02	6.98	11.00	23
G21E			0.02	6.71	12.02	18.75	35
G21F			0.00	1.28	4.29	5.60	23
G22A	12.18		0.00	1.08	4.84	18.11	76
G22B	5.92		0.10	3.60	5.93	15.56	142
G22C	0.28		0.00	2.01	19.62	21.91	86
G22D	1.00		0.00	1.94	24.37	27.88	113
G22E			0.00	1.77	12.00	13.77	51
G22F	11.53		0.00	3.29	7.85	22.67	345
G22G	0.32		0.00	2.20	6.57	9.08	85
G22H	3.42		0.00	5.51	13.90	22.82	100
G22J	5.45	0.15	0.00	5.00	14.81	25.41	198
G22K	2.12	0.06	0.00	2.10	4.54	8.83	111
G30A	0.57		0.76	0.19	14.80	16.32	21
G30D	2.52		1.61	1.65	6.71	12.48	28
G40A	1.56	6.14	0.00	0.63	0.01	9.10	127
G40B	7.29	2.69	0.00	0.71	4.62	15.30	125
G40C	10.03	10.76	0.00	4.76	0.17	26.03	180
G40D	3.76	19.80	0.00	5.43	0.11	29.10	89
G40E	1.67	8.64	0.00	5.51	0.83	16.64	66
G40G	0.04	5.38	0.00	0.25	2.29	8.05	74

Quaternary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Aquifer specific recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
H10A		0.40	0.00	7.02	2.97	10.40	45
H10B		9.74	0.00	1.62	0.44	11.81	73
H10C	0.30	13.55	0.00	5.86	2.62	22.40	86
H10D	10.07	3.89	0.00	0.80	0.01	14.78	152
H10E	10.95	2.13	0.00	1.26	0.80	15.14	179
H10F	11.47	3.41	0.00	2.87	8.18	25.92	105
H10G	9.82	0.42	0.00	2.02	15.03	27.28	101
H10H	10.96	0.22	0.01	0.90	3.62	15.70	84
H10J	29.93	1.36	0.00	2.30	4.77	38.36	179
H10K	24.02	1.31	0.00	1.21	1.54	28.08	145
H10L	0.64	1.16	0.01	0.26	2.08	4.65	49
H20A		0.80	0.00	1.44	0.15	2.39	17
H20B		3.52	0.00	0.33	0.64	4.49	36
H20C	0.20	3.01	0.00	0.61	0.76	4.67	58
H20D	7.75	1.99	0.00	0.85	0.21	10.80	107
H20E	7.85	2.04	0.00	0.74	0.33	10.95	115
H20F	2.79	4.39	0.00	0.69	0.78	8.66	74
H20G	4.41	0.93	0.00	0.47	0.76	6.56	77
H20H	0.01		0.00	0.57	1.20	1.77	20
H40A		2.12	0.00	1.30	0.15	3.58	19
H40B	0.84	6.02	0.00	1.96	0.33	9.16	38
H40C	2.86	0.59	0.01	1.13	1.51	6.11	22
H40D	1.26	6.62	0.24	1.56	0.91	10.59	58
H40E	5.54	2.98	0.15	2.22	2.82	14.03	49
H40F		0.45	0.94	3.55	1.57	6.50	19
H40G	0.49	7.10	0.00	2.02	1.49	11.09	42
H40H	2.13	0.22	0.04	1.69	0.55	4.64	22
H40J	0.52	0.48	0.00	1.03	0.98	3.02	20
H60A	17.92	3.34	0.00	2.18	1.82	25.27	348
H60B	14.03	9.78	0.00	3.73	3.63	34.22	163
H60C	5.31	7.28	0.00	3.78	1.93	19.50	90
H60D	5.15	3.78	0.00	1.39	0.50	10.82	79
H60E	5.86	0.68	0.00	0.63	0.38	7.55	89
H60F	4.46	1.57	0.00	1.35	0.67	8.05	70
H60H	1.03	0.00	0.00	0.45	0.27	1.75	49
J12A	0.33	3.75	0.00	0.59	0.92	5.60	44
J12B		0.27	0.00	0.09	0.14	0.51	13
Total	**406**	**215**	**7**	**223**	**375**	**1235**	**56**

Table B-4 Aquifer specific recharge estimations from Water Balance Model, as developed for the ISP project

Quaternary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	Aquifer specific recharge	
	Mm^3	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*mm*
E10A	5.28	9.82	0.00	0.95	0.00	16.05	120
E10B	3.81	9.53	0.00	1.47	0.72	15.52	79
E10C	10.56	7.67	0.02	0.82	0.00	19.06	100
E21A	0.17	2.04	1.10	6.23	0.34	9.88	54
E21B	0.00	0.02	0.33	3.16	0.67	4.17	45
E21D	2.56	5.31	0.00	2.88	0.00	10.75	99
E22C	0.00	0.32	0.00	1.84	0.64	2.80	31
G10A	45.58	1.02	0.00	2.41	7.89	56.90	331
G10B	14.99	2.85	0.02	1.28	2.68	21.82	173
G10C	16.62	0.48	0.02	4.75	14.90	36.77	112
G10D	10.15	0.62	0.03	19.69	15.22	45.71	66
G10E	20.32	4.08	0.08	6.75	10.76	41.99	107
G10F	13.35	0.88	0.19	7.24	8.03	29.70	55
G10G	15.94	8.86	0.51	1.29	0.18	26.78	144
G10H	3.58	0.39	0.91	4.67	0.73	10.28	15
G10J	13.89	0.00	0.80	6.26	10.50	31.46	36
G10K	10.32	2.23	0.89	3.12	5.15	21.72	18
G10L	0.00	0.00	0.00	6.68	12.60	19.28	11
G10M	0.00	0.00	0.07	1.34	19.47	20.88	10
G21A	0.00	0.00	0.00	1.54	5.55	7.10	14
G21B	0.00	0.00	0.00	0.41	4.06	4.47	15
G21C	0.94	0.00	0.00	5.71	0.13	6.78	28
G21D	0.00	0.00	0.00	28.38	42.22	70.59	146
G21E	0.00	0.00	0.06	14.99	20.80	35.86	68
G21F	0.00	0.00	0.00	0.95	2.24	3.19	13
G22A	16.38	0.00	0.00	0.76	5.10	22.24	93
G22B	9.44	0.00	0.13	3.01	5.60	18.18	166
G22C	0.52	0.00	0.00	1.91	18.82	21.25	84
G22D	1.90	0.00	0.00	1.79	20.93	24.62	100
G22E	0.00	0.00	0.00	2.43	10.29	12.72	47
G22F	16.68	0.00	0.00	3.15	8.17	28.00	426
G22G	0.61	0.00	0.00	2.25	6.92	9.78	92
G22H	7.93	0.00	0.00	3.73	15.15	26.82	118
G22J	6.14	0.16	0.00	3.27	10.10	19.68	153
G22K	3.09	0.08	0.00	1.44	2.84	7.44	93
G30A	0.79	0.00	0.47	0.13	10.15	11.54	15
G30D	4.07	0.00	1.54	1.40	4.60	11.61	26
G40A	1.71	7.29	0.00	0.42	0.00	9.43	132
G40B	8.79	3.40	0.00	0.51	2.93	15.63	128
G40C	12.14	11.59	0.00	2.70	0.11	26.54	184
G40D	3.92	21.82	0.00	3.26	0.07	29.07	89
G40E	3.33	12.25	0.00	6.22	1.08	22.87	91
G40G	0.04	7.65	0.00	0.24	2.76	10.70	98

Quaternary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Aquifer specific recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
H10A	0.00	0.62	0.00	8.00	2.28	10.90	47
H10B	0.00	12.35	0.00	2.07	0.33	14.74	91
H10C	0.63	22.24	0.00	6.02	2.74	31.62	122
H10D	6.57	2.59	0.00	0.29	0.01	9.46	98
H10E	8.52	1.59	0.00	0.46	0.32	10.89	128
H10F	16.12	5.41	0.00	2.24	7.49	31.26	126
H10G	18.07	0.62	0.00	1.73	14.24	34.66	128
H10H	15.42	0.34	0.01	1.04	2.75	19.55	104
H10J	20.16	0.79	0.00	0.75	1.90	23.60	110
H10K	22.52	1.54	0.00	0.90	1.02	25.98	134
H10L	1.48	2.06	0.01	0.22	2.23	6.00	63
H20A	0.00	1.00	0.00	0.89	0.12	2.01	14
H20B	0.00	6.08	0.00	0.17	0.45	6.69	54
H20C	0.36	4.53	0.00	0.47	0.65	6.01	75
H20D	13.13	3.50	0.00	0.70	0.14	17.47	174
H20E	12.60	2.57	0.00	0.61	0.25	16.03	168
H20F	5.14	6.29	0.00	0.64	0.47	12.54	108
H20G	4.33	0.93	0.00	0.37	0.50	6.12	72
H20H	0.01	0.00	0.00	0.70	0.91	1.62	18
H40A	0.00	1.59	0.00	0.78	0.09	2.46	13
H40B	1.61	12.14	0.00	1.08	0.33	15.16	63
H40C	4.22	1.13	0.02	0.76	1.26	7.38	27
H40D	2.03	8.67	0.33	1.29	0.41	12.74	70
H40E	12.28	5.04	0.24	2.22	1.61	21.38	75
H40F	0.00	0.77	1.56	2.13	1.21	5.67	17
H40G	1.02	12.70	0.00	1.05	0.85	15.62	59
H40H	3.60	0.40	0.04	1.09	0.48	5.61	27
H40J	0.44	0.36	0.00	0.30	0.38	1.49	10
H60A	8.88	1.82	0.00	0.54	0.62	11.86	163
H60B	11.08	6.35	0.00	1.58	1.96	20.98	100
H60C	8.50	13.08	0.00	3.64	2.03	27.25	126
H60D	8.82	5.02	0.00	1.44	0.39	15.68	114
H60E	10.32	1.17	0.00	0.65	0.33	12.47	148
H60F	5.66	2.77	0.00	0.87	0.60	9.91	86
H60H	1.38	0.00	0.00	0.36	0.13	1.87	52
J12A	0.55	6.53	0.00	0.46	0.60	8.15	64
J12B	0.00	0.23	0.00	0.09	0.11	0.44	11
Total	**511**	**275**	**9**	**222**	**363**	**1,381**	**62**

Table B-5 Aquifer specific recharge estimations from map centric simulation

Quaternary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Aquifer specific recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
E10A	1.66	5.69		1.98		9.33	70
E10B	1.59	8.33		2.23	0.61	12.75	65
E10C	4.13	5.24	0.01	0.71	0.00	10.09	53
E21A	0.06	0.49	1.02	7.01	0.17	8.75	48
E21B		0.02	0.19	3.67	0.63	4.52	49
E21D	1.15	2.79	0.00	4.36	0.00	8.29	77
E22C		0.42		5.62	1.16	7.19	79
G10A	13.37	0.65		1.20	5.86	21.09	123
G10B	6.84	2.47	0.01	0.49	2.45	12.27	97
G10C	4.66	0.23	0.01	5.33	12.65	22.88	70
G10D	2.82	0.20	0.02	17.80	10.19	31.03	45
G10E	3.48	1.63	0.07	5.65	5.22	16.05	41
G10F	2.26	0.17	0.07	7.72	4.83	15.05	28
G10G	4.50	3.41	0.22	0.63	0.08	8.84	48
G10H	1.25	0.17	0.39	14.46	0.91	17.18	25
G10J	2.31		0.18	15.55	5.70	23.74	27
G10K	10.27	2.21	1.11	12.89	12.86	39.34	33
G10L				20.66	23.70	44.35	25
G10M	0.01		0.09	5.58	49.82	55.50	28
G21A				4.43	10.34	14.77	28
G21B				1.37	6.13	7.50	25
G21C	0.14			8.60	0.10	8.84	36
G21D				7.99	6.27	14.25	29
G21E			0.02	12.02	9.80	21.85	41
G21F				2.42	2.65	5.07	21
G22A	6.22			0.23	0.36	6.81	29
G22B	1.95		0.03	1.06	1.17	4.22	39
G22C	0.08		0.00	1.96	11.03	13.07	51
G22D	0.28			1.21	11.59	13.08	53
G22E				2.50	9.77	12.27	45
G22F	3.87			1.95	2.72	8.54	130
G22G	0.14			2.32	4.12	6.57	62
G22H	1.43			4.06	8.55	14.03	62
G22J	1.62	0.04		3.75	5.87	11.28	88
G22K	0.59	0.01		2.13	2.06	4.78	60
G30A	0.80		1.33	0.25	25.50	27.88	37
G30D	2.24		1.65	2.75	8.97	15.61	36
G40A	0.84			3.24	0.00	4.08	57
G40B	3.52	1.78		0.28	2.15	7.72	63
G40C	4.51	7.04		4.25	0.11	15.91	110
G40D	2.39	15.34		6.30	0.07	24.11	74
G40E	1.38	8.59		9.61	0.83	20.41	81
G40G	0.05	4.62		0.38	2.02	7.07	65

Quaternary catchment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	**Aquifer specific recharge**	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
H10A		0.66		10.30	2.24	13.20	56
H10B		7.50		2.59	0.43	10.53	65
H10C	0.13	6.73		6.11	1.32	14.29	55
H10D	3.75	1.44		0.21	0.01	5.40	56
H10E	6.46	1.19		0.67	0.36	8.68	102
H10F	6.45	2.17		3.18	5.64	17.44	70
H10G	4.99	0.30		2.81	13.51	21.61	80
H10H	6.33	0.16	0.03	2.29	5.65	14.46	77
H10J	15.61	1.03		1.90	2.60	21.14	99
H10K	12.27	1.03		1.15	1.09	15.55	80
H10L	0.52	1.25	0.03	0.49	2.88	5.17	54
H20A		2.15		6.83	0.56	9.54	68
H20B		6.30		1.36	1.64	9.31	75
H20C	0.24	4.75		1.35	0.91	7.24	90
H20D	7.28	2.46		0.76	0.22	10.73	107
H20E	5.62	2.38		0.53	0.39	8.91	94
H20F	2.73	5.45		0.66	1.27	10.11	87
H20G	4.54	1.05		0.84	1.11	7.54	89
H20H	0.01			1.99	2.83	4.83	54
H40A		6.23		6.78	0.37	13.39	73
H40B	1.14	10.57		7.69	0.61	20.01	83
H40C	3.23	0.56	0.07	5.53	4.70	14.09	52
H40D	1.34	9.33	0.97	5.87	2.17	19.67	108
H40E	4.70	3.05	0.29	5.27	4.26	17.55	61
H40F		0.79	2.75	14.34	4.20	22.08	65
H40G	0.53	11.60		7.72	3.45	23.30	88
H40H	3.64	0.47	0.16	7.74	2.05	14.07	68
H40J	0.61	1.22	0.00	3.74	2.98	8.55	56
H60A	5.57	1.86		1.85	1.18	10.46	144
H60B	7.36	7.25		4.69	3.08	22.38	107
H60C	3.19	5.91		5.27	1.37	15.74	73
H60D	4.00	3.75		2.17	0.54	10.46	76
H60E	4.12	0.62		0.80	0.41	5.95	70
H60F	3.95	1.51		2.43	0.88	8.76	76
H60H	0.99	0.00		1.20	0.42	2.62	73
J12A	0.53	7.49		1.65	2.67	12.34	96
J12B		0.96		0.72	0.49	2.18	56
Total	**214**	**193**	**11**	**350**	**350**	**1,117**	**50**

APPENDIX C

STORAGE MODEL RESULTS

APPENDIX C : STORAGE MODEL RESULTS

Table C-1: Results of Storage Model for Peninsula Aquifer

Peninsula Aquifer			Area	Average Thickness	Rock Volume	Pore Volume
			km^2	m	Mm^3	Mm^3
ATL	**ATLANTIS**	*unconfined*	0.00	0.00	0	0
		confined	0.00	0.00	0	0
AWT	**AGTER WITZENBERG**	*unconfined*	45.21	832.00	37,618	1,881
		confined	229.05	1,149.00	263,267	13,163
BRV	**BRANDVLEI**	*unconfined*	518.13	787.00	407,823	20,391
		confined	540.98	1,171.00	633,442	31,672
CFP	**CAPE FLATS PENINSULA**	*unconfined*	45.46	170.00	7,736	387
		confined	3.27	1,411.00	4,608	230
HEX	**HEXRIVER**	*unconfined*	182.59	1,078.00	196,996	9,850
		confined	564.59	1,118.00	631,370	31,568
KGB	**KOGELBERG**	*unconfined*	91.92	946.00	87,049	4,352
		confined	568.36	1,117.00	634,989	31,749
NUY	**NUY**	*unconfined*	77.86	656.00	51,094	2,555
		confined	428.21	1,140.00	488,127	24,406
PKT	**PIKETBERG**	*unconfined*	55.76	650.00	36,231	1,812
		confined	55.00	1,321.00	72,633	3,632
PUB	**PAARL UPPER BERG**	*unconfined*	210.72	612.00	128,963	6,448
		confined	49.98	1,119.00	55,911	2,796
RBT	**ROBERTSON**	*unconfined*	59.27	1,096.00	64,975	3,249
		confined	1,193.47	1,172.00	1,398,494	69,925
THK	**THEEWATERSKLOOF**	*unconfined*	220.76	1,079.00	238,277	11,914
		confined	627.63	1,205.00	756,046	37,802
TWR	**24 RIVERS**	*unconfined*	101.21	649.00	65,712	3,286
		confined	189.37	1,289.00	244,123	12,206
VVT	**VOELVLEI-TULBAGH**	*unconfined*	80.87	543.00	43,933	2,197
		confined	47.47	1,146.00	54,393	2,720
WBK	**WARM BOKKEVELD**	*unconfined*	60.53	795.00	48,118	2,406
		confined	615.07	1,109.00	682,171	34,109
WCT	**WEST COAST**	*unconfined*	0.00	0.00	0	0
		confined	0.00	0.00	0	0
TOTAL		*unconfined*	1,750.27		1,414,523	70,726
		confined	5,112.44		5,919,575	295,979
		total	**6,862.71**		**7,334,098**	**366,705**

Table C-2: Results of Storage Model for Skurweberg Aquifer

Skurweberg Aquifer			Area	Average Thickness	Rock Volume	Pore Volume
			km^2	m	Mm^3	Mm^3
ATL	**ATLANTIS**	*unconfined*	0.00	0.00	0	0
		confined	0.00	0.00	0	0
AWT	**AGTER WITZENBERG**	*unconfined*	119.30	204.70	24,420	1,221
		confined	89.91	300.00	26,973	1,349
BRV	**BRANDVLEI**	*unconfined*	26.62	92.91	2,473	124
		confined	370.19	636.87	235,765	11,788
CFP	**CAPE FLATS PENINSULA**	*unconfined*	0.00	0.00	0	0
		confined	0.00	0.00	0	0
HEX	**HEXRIVER**	*unconfined*	157.47	317.62	50,016	2,501
		confined	368.19	283.70	104,453	5,223
KGB	**KOGELBERG**	*unconfined*	234.83	272.96	64,097	3,205
		confined	252.15	276.94	69,832	3,492
NUY	**NUY**	*unconfined*	81.87	352.79	28,885	1,444
		confined	300.12	295.42	88,661	4,433
PKT	**PIKETBERG**	*unconfined*	0.00	0	0	0.00
		confined	0.00	0	0	0.00
PUB	**PAARL UPPER BERG**	*unconfined*	9.04	64.19	580	29
		confined	0.00	0.00	0	0
RBT	**ROBERTSON**	*unconfined*	94.68	232.87	22,049	1,102
		confined	1,016.65	335.46	341,044	17,052
THK	**THEEWATERSKLOOF**	*unconfined*	133.36	214.00	28,539	1,427
		confined	444.54	300.38	133,530	6,677
TWR	**24 RIVERS**	*unconfined*	106.24	120.03	12,751	638
		confined	0.00	0.00	0	0
VVT	**VOELVLEI-TULBAGH**	*unconfined*	14.32	67.81	971	49
		confined	0.00	0.00	0	0
WBK	**WARM BOKKEVELD**	*unconfined*	142.40	256.13	36,473	1,824
		confined	803.18	319.51	256,624	12,831
WCT	**WEST COAST**	*unconfined*	0.00	0.00	0	0
		confined	0.00	0.00	0	0
TOTAL		*unconfined*	1,120.13		271,255	13,563
			3,644.94		1,256,882	62,844
			4,765.06		**1,528,137**	**76,407**

APPENDIX D

DISCHARGE MODEL RESULTS

APPENDIX D : DISCHARGE MODEL RESULTS

Table D-1 Groundwater Contribution to Baseflow per Aquifer, based on outcrop area (Total GW Contribution to Baseflow after GRDM [DWAF, 2006])

Quaternary catchment	Peninsula Mm^3	Nardouw Mm^3	Fractured Mm^3	Intergranular fractured Mm^3	Intergranular Mm^3	Total Mm^3	Total mm
E10A	0.69	2.43	0.00	0.77	0.00	3.89	29.1
E10B	0.77	3.45	0.00	1.12	0.32	5.66	28.7
E10C	1.80	2.34	0.01	0.27	0.00	4.41	23.2
E21A	0.01	0.14	0.21	1.74	0.05	2.15	11.7
E21B	0.00	0.00	0.05	0.79	0.17	1.01	10.9
E21D	0.16	0.38	0.00	0.73	0.00	1.27	11.8
E22C	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G10A	3.88	0.28	0.00	0.80	2.26	7.21	42.0
G10B	2.79	0.96	0.01	0.53	0.94	5.23	41.5
G10C	0.32	0.02	0.00	0.77	1.16	2.27	6.9
G10D	0.23	0.01	0.00	3.53	1.38	5.16	7.5
G10E	0.84	0.51	0.04	2.27	1.72	5.37	13.6
G10F	0.43	0.03	0.02	2.42	1.32	4.21	7.8
G10G	1.15	1.31	0.05	0.21	0.01	2.74	14.7
G10H	0.15	0.02	0.06	3.08	0.23	3.53	5.2
G10J	0.29	0.00	0.04	3.45	1.39	5.17	6.0
G10K	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G10L	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G10M	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G21A	0.00	0.00	0.00	0.09	0.21	0.30	0.6
G21B	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G21C	0.03	0.00	0.00	1.90	0.02	1.95	8.0
G21D	0.00	0.00	0.00	1.87	1.83	3.69	7.6
G21E	0.00	0.00	0.00	2.28	2.12	4.41	8.3
G21F	0.00	0.00	0.00	0.97	0.99	1.96	8.1
G22A	2.28	0.00	0.00	0.18	0.81	3.27	13.7
G22B	0.49	0.00	0.01	0.52	0.55	1.57	14.4
G22C	0.01	0.00	0.00	0.36	2.19	2.56	10.1
G22D	0.06	0.00	0.00	0.18	2.26	2.50	10.2
G22E	0.00	0.00	0.00	0.52	2.15	2.67	9.9
G22F	0.97	0.00	0.00	0.72	0.99	2.67	40.7
G22G	0.01	0.00	0.00	0.39	0.69	1.10	10.4
G22H	0.11	0.00	0.00	0.60	1.37	2.08	9.2
G22J	0.14	0.00	0.00	0.51	0.93	1.58	12.4
G22K	0.15	0.01	0.00	0.44	0.46	1.05	13.2
G30A	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G30D	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G40A	0.46	2.11	0.00	0.25	0.00	2.82	39.4
G40B	2.50	1.01	0.00	0.29	1.54	5.34	43.6
G40C	1.55	2.49	0.00	2.07	0.04	6.15	42.6
G40D	1.44	8.46	0.00	4.51	0.05	14.46	44.2
G40E	0.27	1.70	0.00	2.07	0.21	4.25	16.8
G40G	0.02	1.09	0.00	0.17	0.55	1.83	16.8

Quaternary catchment	Peninsula *Mm³*	Nardouw *Mm³*	Fractured *Mm³*	Intergranular fractured *Mm³*	Intergranular *Mm³*	Total *Mm³*	Total *mm*
H10A	0.00	0.02	0.00	0.57	0.16	0.75	3.2
H10B	0.00	2.18	0.00	1.03	0.14	3.35	20.6
H10C	0.04	2.11	0.00	2.53	0.61	5.28	20.4
H10D	1.37	0.55	0.00	0.13	0.00	2.05	21.1
H10E	2.37	0.40	0.00	0.23	0.13	3.13	36.9
H10F	1.69	0.66	0.00	0.93	1.95	5.22	21.1
H10G	1.20	0.07	0.00	0.72	3.75	5.75	21.3
H10H	1.54	0.04	0.01	0.60	1.78	3.96	21.1
H10J	6.07	0.43	0.00	0.74	1.09	8.33	39.0
H10K	5.96	0.53	0.00	0.55	0.69	7.73	39.9
H10L	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H20A	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H20B	0.00	0.30	0.00	0.09	0.17	0.56	4.5
H20C	0.01	0.34	0.00	0.15	0.11	0.61	7.6
H20D	1.55	0.44	0.00	0.16	0.07	2.23	22.1
H20E	1.35	0.53	0.00	0.14	0.16	2.17	22.8
H20F	0.27	0.64	0.00	0.07	0.41	1.39	11.9
H20G	0.44	0.10	0.00	0.10	0.17	0.81	9.5
H20H	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H40A	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H40B	0.06	0.50	0.00	0.46	0.03	1.05	4.4
H40C	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H40D	0.01	0.05	0.01	0.04	0.02	0.12	0.7
H40E	0.04	0.03	0.00	0.06	0.06	0.19	0.7
H40F	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H40G	0.00	0.11	0.00	0.10	0.05	0.25	1.0
H40H	0.02	0.00	0.00	0.08	0.03	0.13	0.6
H40J	0.01	0.01	0.00	0.06	0.05	0.14	0.9
H60A	1.16	0.49	0.00	0.50	0.32	2.47	34.0
H60B	2.21	2.13	0.00	1.17	0.80	6.31	30.1
H60C	0.33	0.59	0.00	0.63	0.19	1.74	8.0
H60D	0.19	0.21	0.00	0.14	0.04	0.57	4.2
H60E	0.23	0.02	0.00	0.07	0.03	0.35	4.2
H60F	0.20	0.06	0.00	0.16	0.07	0.49	4.2
H60H	0.05	0.00	0.00	0.08	0.03	0.16	4.4
J12A	0.00	0.00	0.00	0.00	0.00	0.00	0.0
J12B	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Total	**52**	**42**	**1**	**56**	**44**	**195**	**8.8**

Table D-2 Groundwater Contribution to Baseflow per Aquifer, based on equivalent recharge (Total GW Contribution to Baseflow after GRDM [DWAF, 2006])

Quaternary catchment	Peninsula	Nardouw	Fractured	Intergranular fractured	Intergranular	Total	
	Mm³	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*Mm³*	*mm*
E10A	0.69	2.37	0.00	0.83	0.00	3.89	29.1
E10B	0.71	3.70	0.00	0.99	0.27	5.66	28.7
E10C	1.80	2.29	0.01	0.31	0.00	4.41	23.2
E21A	0.01	0.12	0.25	1.72	0.04	2.15	11.8
E21B	0.00	0.01	0.04	0.83	0.14	1.02	11.0
E21D	0.18	0.43	0.00	0.67	0.00	1.27	11.8
E22C	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G10A	4.61	0.23	0.00	0.41	2.02	7.27	42.3
G10B	2.99	1.08	0.00	0.22	1.07	5.36	42.5
G10C	0.46	0.02	0.00	0.53	1.25	2.27	6.9
G10D	0.47	0.03	0.00	2.96	1.69	5.16	7.5
G10E	1.16	0.54	0.02	1.89	1.75	5.37	13.6
G10F	0.65	0.05	0.02	2.22	1.39	4.33	8.0
G10G	1.39	1.06	0.07	0.19	0.02	2.74	14.8
G10H	0.26	0.03	0.08	2.97	0.19	3.53	5.2
G10J	0.50	0.00	0.04	3.39	1.24	5.17	6.0
G10K	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G10L	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G10M	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G21A	0.00	0.00	0.00	0.09	0.21	0.30	0.6
G21B	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G21C	0.03	0.00	0.00	1.90	0.02	1.95	8.0
G21D	0.00	0.00	0.00	2.07	1.62	3.69	7.6
G21E	0.00	0.00	0.00	2.43	1.98	4.41	8.3
G21F	0.00	0.00	0.00	0.94	1.03	1.96	8.1
G22A	2.97	0.00	0.00	0.11	0.17	3.25	13.7
G22B	0.73	0.00	0.01	0.40	0.44	1.58	14.5
G22C	0.01	0.00	0.00	0.38	2.16	2.56	10.1
G22D	0.06	0.00	0.00	0.24	2.27	2.56	10.4
G22E	0.00	0.00	0.00	0.54	2.13	2.67	9.9
G22F	1.21	0.00	0.00	0.61	0.85	2.67	40.7
G22G	0.02	0.00	0.00	0.39	0.69	1.10	10.4
G22H	0.21	0.00	0.00	0.60	1.27	2.08	9.2
G22J	0.23	0.01	0.00	0.53	0.83	1.59	12.4
G22K	0.13	0.00	0.00	0.47	0.45	1.06	13.2
G30A	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G30D	0.00	0.00	0.00	0.00	0.00	0.00	0.0
G40A	0.65	0.00	0.00	2.50	0.00	3.15	44.1
G40B	2.44	1.23	0.00	0.19	1.49	5.35	43.7
G40C	1.77	2.76	0.00	1.67	0.04	6.25	43.2
G40D	1.44	9.20	0.00	3.78	0.04	14.46	44.2
G40E	0.29	1.79	0.00	2.00	0.17	4.25	16.8
G40G	0.01	1.21	0.00	0.10	0.53	1.85	17.0

Quaternary catchment	Peninsula	Nardouw	Fractured	Intergranular fractured	Intergranular	Total	
	Mm^3	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*Mm^3*	*mm*
H10A	0.00	0.04	0.00	0.59	0.13	0.75	3.2
H10B	0.00	2.39	0.00	0.83	0.14	3.36	20.7
H10C	0.05	2.51	0.00	2.28	0.49	5.32	20.5
H10D	1.42	0.55	0.00	0.08	0.00	2.05	21.2
H10E	2.37	0.44	0.00	0.25	0.13	3.19	37.6
H10F	1.93	0.65	0.00	0.95	1.69	5.22	21.1
H10G	1.32	0.08	0.00	0.74	3.57	5.72	21.1
H10H	1.73	0.04	0.01	0.63	1.55	3.96	21.1
H10J	6.15	0.40	0.00	0.75	1.03	8.33	39.0
H10K	6.10	0.51	0.00	0.57	0.54	7.73	39.9
H10L	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H20A	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H20B	0.00	0.38	0.00	0.08	0.10	0.56	4.5
H20C	0.02	0.41	0.00	0.12	0.08	0.63	7.8
H20D	1.51	0.51	0.00	0.16	0.05	2.23	22.2
H20E	1.37	0.58	0.00	0.13	0.10	2.17	22.8
H20F	0.37	0.75	0.00	0.09	0.17	1.39	11.9
H20G	0.49	0.11	0.00	0.09	0.12	0.81	9.5
H20H	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H40A	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H40B	0.06	0.56	0.00	0.40	0.03	1.05	4.4
H40C	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H40D	0.01	0.06	0.01	0.04	0.01	0.12	0.7
H40E	0.05	0.03	0.00	0.06	0.05	0.20	0.7
H40F	0.00	0.00	0.00	0.00	0.00	0.00	0.0
H40G	0.01	0.13	0.00	0.08	0.04	0.25	1.0
H40H	0.03	0.00	0.00	0.07	0.02	0.13	0.6
H40J	0.01	0.02	0.00	0.06	0.05	0.14	0.9
H60A	1.32	0.44	0.00	0.44	0.28	2.48	34.1
H60B	2.39	2.36	0.00	1.53	1.00	7.28	34.7
H60C	0.40	0.74	0.00	0.66	0.17	1.97	9.1
H60D	0.22	0.21	0.00	0.12	0.03	0.57	4.2
H60E	0.25	0.04	0.00	0.05	0.02	0.35	4.2
H60F	0.22	0.08	0.00	0.13	0.05	0.48	4.2
H60H	0.06	0.00	0.00	0.07	0.03	0.16	4.5
J12A	0.00	0.00	0.00	0.00	0.00	0.00	0.0
J12B	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Total	**58**	**43**	**1**	**54**	**41**	**197**	**8.9**

Table D-3 Groundwater use per aquifer, disaggregated according to outcrop area (Total groundwater use after GRA II [DWAF, 2005])

Quaternary catchment	Area	Groundwater Use [Million m³/a] Total after GRA II					
	km²	Total	Peninsula Aquifer	Nardouw Aquifer	Fractured Aquifer	Intergranular fractured	Intergranular Aquifers
E10A	133.73	3.45	0.50	1.92	0.00	0.64	0.00
E10B	197.15	3.73	0.47	0.74	0.00	0.06	0.00
E10C	189.98	0.34	0.09	0.14	0.00	0.01	0.00
E21A	183.09	5.36	0.01	0.22	0.00	0.14	0.00
E21B	92.50	1.35	0.00	0.00	0.00	0.00	0.00
E21D	108.22	7.39	0.00	0.00	0.00	0.00	0.00
E22C	91.22	0.21	0.00	0.00	0.00	0.00	0.00
G10A	171.78	0.03	0.02	0.00	0.00	0.00	0.01
G10B	125.97	0.02	0.01	0.00	0.00	0.00	0.00
G10C	328.07	0.58	0.08	0.00	0.00	0.20	0.30
G10D	687.55	1.75	0.08	0.00	0.00	1.20	0.47
G10E	394.10	11.13	1.74	1.05	0.08	4.70	3.56
G10F	539.36	0.16	0.02	0.00	0.00	0.09	0.05
G10G	185.58	0.03	0.01	0.02	0.00	0.00	0.00
G10H	674.52	1.49	0.06	0.01	0.02	1.30	0.10
G10J	867.50	6.64	0.37	0.00	0.05	4.43	1.79
G10K	1175.89	2.70	0.45	0.10	0.06	1.07	1.01
G10L	1754.55	0.42	0.00	0.00	0.00	0.19	0.23
G10M	2004.68	2.00	0.00	0.00	0.00	0.24	1.75
G21A	523.29	0.20	0.00	0.00	0.00	0.06	0.14
G21B	303.78	14.81	0.00	0.00	0.00	2.40	12.42
G21C	244.22	0.07	0.00	0.00	0.00	0.07	0.00
G21D	484.05	2.51	0.00	0.00	0.00	1.27	1.24
G21E	530.76	1.34	0.00	0.00	0.00	0.70	0.65
G21F	242.40	1.34	0.00	0.00	0.00	0.66	0.68
G22A	237.99	0.01	0.01	0.00	0.00	0.00	0.00
G22B	109.40	1.24	0.39	0.00	0.01	0.41	0.43
G22C	254.25	0.08	0.00	0.00	0.00	0.01	0.07
G22D	246.01	9.90	0.24	0.00	0.00	0.69	8.75
G22E	270.68	0.40	0.00	0.00	0.00	0.08	0.32
G22F	65.69	0.34	0.13	0.00	0.00	0.09	0.12
G22G	106.36	0.10	0.00	0.00	0.00	0.04	0.06
G22H	227.30	0.19	0.01	0.00	0.00	0.07	0.11
G22J	128.19	0.59	0.05	0.00	0.00	0.19	0.35
G22K	79.82	0.00	0.00	0.00	0.00	0.00	0.00
G30A	761.28	2.77	0.06	0.00	0.11	0.02	2.58
G30D	438.59	2.56	0.18	0.00	0.19	0.27	1.16
G40A	71.52	0.00	0.00	0.00	0.00	0.00	0.00
G40B	122.42	0.00	0.00	0.00	0.00	0.00	0.00
G40C	144.57	0.02	0.01	0.01	0.00	0.01	0.00
G40D	327.17	0.01	0.00	0.00	0.00	0.00	0.00
G40E	252.59	0.29	0.02	0.10	0.00	0.10	0.01
G40G	108.82	0.01	0.00	0.00	0.00	0.00	0.00

Quaternary catchment	**Area**	**Groundwater Use [Million m^3/a] Total after GRA II**					
	km^2	Total	Peninsula Aquifer	Nardouw Aquifer	Fractured Aquifer	Intergranular fractured	Intergranular Aquifers
H10A	233.67	3.30	0.00	0.09	0.00	2.51	0.69
H10B	162.46	4.55	0.00	2.95	0.00	1.40	0.20
H10C	259.60	13.34	0.09	5.28	0.00	6.33	1.54
H10D	96.96	0.00	0.00	0.00	0.00	0.00	0.00
H10E	84.81	0.00	0.00	0.00	0.00	0.00	0.00
H10F	247.88	8.94	2.89	1.13	0.00	1.59	3.33
H10G	270.43	8.41	1.72	0.11	0.00	1.06	5.52
H10H	187.49	1.42	0.55	0.01	0.00	0.22	0.64
H10J	213.78	0.48	0.35	0.02	0.00	0.04	0.06
H10K	193.55	0.39	0.30	0.03	0.00	0.03	0.04
H10L	95.79	2.60	0.17	0.45	0.02	0.23	1.22
H20A	140.46	0.42	0.00	0.06	0.00	0.33	0.03
H20B	124.39	2.12	0.00	1.12	0.00	0.35	0.64
H20C	80.57	1.82	0.04	0.98	0.00	0.43	0.33
H20D	100.67	0.14	0.09	0.03	0.00	0.01	0.00
H20E	95.20	0.18	0.11	0.04	0.00	0.01	0.01
H20F	116.58	2.20	0.43	1.02	0.00	0.11	0.64
H20G	85.08	0.49	0.27	0.06	0.00	0.06	0.10
H20H	89.03	0.71	0.00	0.00	0.00	0.21	0.49
H40A	184.39	0.00	0.00	0.00	0.00	0.00	0.00
H40B	240.54	0.80	0.05	0.38	0.00	0.35	0.02
H40C	271.79	4.21	0.62	0.09	0.02	1.63	1.85
H40D	181.76	1.57	0.07	0.64	0.08	0.54	0.24
H40E	285.43	1.68	0.31	0.24	0.03	0.52	0.51
H40F	339.92	1.70	0.00	0.03	0.19	1.03	0.44
H40G	263.37	0.24	0.00	0.10	0.00	0.09	0.04
H40H	207.91	0.04	0.01	0.00	0.00	0.03	0.01
H40J	152.24	0.02	0.00	0.00	0.00	0.01	0.01
H60A	72.64	0.00	0.00	0.00	0.00	0.00	0.00
H60B	210.00	0.00	0.00	0.00	0.00	0.00	0.00
H60C	216.89	0.53	0.09	0.16	0.00	0.17	0.05
H60D	137.75	0.01	0.00	0.00	0.00	0.00	0.00
H60E	84.52	0.03	0.01	0.00	0.00	0.00	0.00
H60F	115.52	0.35	0.00	0.00	0.00	0.00	0.00
H60H	35.64	0.01	0.00	0.00	0.00	0.00	0.00
J12A	127.96	0.48	0.02	0.11	0.00	0.01	0.01
J12B	38.72	0.00	0.00	0.00	0.00	0.00	0.00
Total	**22232.0**	**150.77**	**13.21**	**19.48**	**0.87**	**40.73**	**57.03**

Table D-4 Groundwater use per aquifer, calculated from WARMS database and linked with NGDB

Quaternary catchment	Area	Groundwater Use [Million m³/a] Total after WARMS and NGDB					
	km²	Total	Peninsula Aquifer	Nardouw Aquifer	Fractured Aquifer	Intergranular fractured	Intergranular Aquifers
E10A	133.73	0.48	0.00	0.03	0.00	0.45	0.00
E10B	197.15	0.02	0.00	0.00	0.00	0.00	0.00
E10C	189.98	0.00	0.00	0.00	0.00	0.00	0.00
E21A	183.09	2.61	0.00	0.17	0.00	2.04	0.40
E21B	92.50	0.24	0.00	0.00	0.00	0.24	0.00
E21D	108.22	0.00	0.00	0.00	0.00	0.00	0.00
E22C	91.22	0.83	0.00	0.00	0.00	0.00	0.00
G10A	171.78	3.31	0.14	0.14	0.00	0.37	2.66
G10B	125.97	0.26	0.20	0.02	0.03	0.00	0.02
G10C	328.07	2.80	0.00	0.00	0.00	0.46	2.34
G10D	687.55	4.07	0.00	0.00	0.00	2.14	1.93
G10E	394.10	3.63	0.13	0.00	0.00	1.21	2.28
G10F	539.36	1.27	0.00	0.00	0.04	1.11	0.12
G10G	185.58	0.53	0.22	0.25	0.01	0.04	0.00
G10H	674.52	2.69	0.07	0.00	0.07	2.18	0.37
G10J	867.50	0.54	0.00	0.00	0.00	0.42	0.11
G10K	1175.89	7.57	3.73	0.00	0.34	0.68	2.83
G10L	1754.55	5.98	0.00	0.00	0.00	1.68	4.30
G10M	2004.68	4.43	0.00	0.00	0.00	0.03	4.40
G21A	523.29	3.10	0.00	0.00	0.00	1.79	1.31
G21B	303.78	8.21	0.00	0.00	0.00	0.42	7.78
G21C	244.22	3.40	0.00	0.00	0.00	3.40	0.00
G21D	484.05	6.32	0.00	0.00	0.00	1.71	4.61
G21E	530.76	3.89	0.00	0.00	0.00	2.20	1.70
G21F	242.40	0.08	0.00	0.00	0.00	0.04	0.04
G22A	237.99	0.01	0.01	0.00	0.00	0.00	0.01
G22B	109.40	0.01	0.00	0.00	0.00	0.00	0.01
G22C	254.25	1.80	0.00	0.00	0.00	0.22	1.59
G22D	246.01	5.13	0.04	0.00	0.00	0.08	5.02
G22E	270.68	0.87	0.00	0.00	0.00	0.34	0.53
G22F	65.69	1.20	0.17	0.00	0.00	0.68	0.34
G22G	106.36	1.03	0.00	0.00	0.00	0.22	0.81
G22H	227.30	1.30	0.00	0.00	0.00	0.61	0.69
G22J	128.19	0.73	0.00	0.00	0.00	0.26	0.47
G22K	79.82	0.13	0.01	0.00	0.00	0.06	0.06
G30A	761.28	0.10	0.00	0.00	0.00	0.00	0.10
G30D	438.59	0.59	0.00	0.00	0.00	0.22	0.37
G40A	71.52	0.00	0.00	0.00	0.00	0.00	0.00
G40B	122.42	0.06	0.00	0.00	0.02	0.00	0.04
G40C	144.57	0.96	0.00	0.20	0.00	0.75	0.00
G40D	327.17	0.36	0.00	0.02	0.00	0.34	0.00
G40E	252.59	1.13	0.00	0.30	0.00	0.43	0.40
G40G	108.82	0.76	0.00	0.00	0.00	0.00	0.76

Quaternary catchment	**Area**	**Groundwater Use [Million m^3/a] Total after WARMS and NGDB**					
	km^2	Total	Peninsula Aquifer	Nardouw Aquifer	Fractured Aquifer	Intergranular fractured	Intergranular Aquifers
H10A	233.67	1.61	0.00	0.00	0.00	1.15	0.46
H10B	162.46	7.19	0.00	4.11	0.00	3.08	0.00
H10C	259.60	16.90	0.00	2.45	0.00	12.13	2.32
H10D	96.96	0.30	0.15	0.15	0.00	0.00	0.00
H10E	84.81	0.00	0.00	0.00	0.00	0.00	0.00
H10F	247.88	6.17	0.00	0.00	0.00	4.62	1.54
H10G	270.43	13.87	1.63	0.82	0.00	0.00	11.42
H10H	187.49	3.54	0.00	0.00	0.00	1.11	2.44
H10J	213.78	1.45	0.00	1.45	0.00	0.00	0.00
H10K	193.55	0.63	0.63	0.00	0.00	0.00	0.00
H10L	95.79	7.05	0.00	0.78	0.00	0.00	6.26
H20A	140.46	1.66	0.00	0.00	0.00	1.66	0.00
H20B	124.39	6.62	0.00	4.41	0.00	0.00	2.21
H20C	80.57	0.00	0.00	0.00	0.00	0.00	0.00
H20D	100.67	0.52	0.36	0.10	0.00	0.04	0.02
H20E	95.20	2.25	0.00	1.13	0.00	0.00	1.13
H20F	116.58	10.52	0.00	2.48	0.00	0.00	8.04
H20G	85.08	4.08	0.60	0.00	0.00	0.00	3.48
H20H	89.03	0.40	0.00	0.00	0.00	0.14	0.25
H40A	184.39	0.93	0.00	0.41	0.00	0.52	0.00
H40B	240.54	3.25	0.00	0.00	0.00	2.44	0.81
H40C	271.79	1.80	0.45	0.00	0.00	0.60	0.75
H40D	181.76	0.19	0.00	0.19	0.00	0.00	0.00
H40E	285.43	2.57	0.00	0.32	0.00	1.28	0.96
H40F	339.92	0.80	0.00	0.02	0.09	0.48	0.21
H40G	263.37	1.98	0.00	0.54	0.00	0.45	0.99
H40H	207.91	0.84	0.00	0.00	0.00	0.30	0.54
H40J	152.24	0.31	0.00	0.00	0.00	0.31	0.00
H60A	72.64	0.36	0.00	0.06	0.00	0.15	0.15
H60B	210.00	0.66	0.00	0.00	0.00	0.54	0.12
H60C	216.89	0.75	0.00	0.00	0.00	0.63	0.13
H60D	137.75	0.05	0.00	0.05	0.00	0.00	0.00
H60E	84.52	0.05	0.03	0.00	0.00	0.01	0.00
H60F	115.52	0.01	0.00	0.00	0.00	0.00	0.00
H60H	35.64	0.00	0.00	0.00	0.00	0.00	0.00
J12A	127.96	0.02	0.00	0.01	0.00	0.00	0.01
J12B	38.72	0.00	0.00	0.00	0.00	0.00	0.00
Total	**22232.0**	**181.71**	**8.58**	**20.60**	**0.60**	**58.44**	**92.63**

APPENDIX E

GROUNDWATER POTENTIAL AND UTILISATION

APPENDIX E : GROUNDWATER POTENTIAL AND UTILISATION

Table F-1 Groundwater potential per quaternary catchment, based on map-centric recharge estimation (in million m^3/a)

Quaternary Catchment	Peninsula	Nardouw	Intergranular-fractured	Interganular	Total Groundwater Potential
E10A	0.97	3.29	0.70	0.00	4.96
E10B	0.88	4.63	1.24	0.34	7.09
E10C	2.32	2.95	0.40	0.00	5.67
E21A	0.04	0.20	3.24	**-0.27**	3.21
E21B	0.00	0.02	2.60	0.49	3.11
E21D	0.97	2.36	3.69	0.00	7.02
E22C	0.00	0.42	5.62	1.16	7.19
G10A	8.62	0.29	0.42	1.18	10.51
G10B	3.65	1.37	0.28	1.36	6.66
G10C	4.20	0.21	4.34	9.06	17.81
G10D	2.35	0.16	12.70	6.57	21.79
G10E	2.19	1.08	2.55	1.20	7.01
G10F	1.61	0.12	4.39	3.32	9.44
G10G	2.89	2.11	0.39	0.05	5.44
G10H	0.92	0.13	9.31	0.35	10.72
G10J	1.81	0.00	11.74	4.35	17.90
G10K	6.54	2.21	12.21	10.03	30.99
G10L	0.00	0.00	18.98	19.40	38.37
G10M	0.01	0.00	5.55	45.42	50.98
G21A	0.00	0.00	2.55	8.82	11.37
G21B	0.00	0.00	0.95	**-1.65**	**-0.70**
G21C	0.11	0.00	3.30	0.08	3.49
G21D	0.00	0.00	4.21	0.03	4.24
G21E	0.00	0.00	7.39	6.12	13.52
G21F	0.00	0.00	1.44	1.58	3.02
G22A	3.24	0.00	0.12	0.18	3.54
G22B	1.22	0.00	0.67	0.72	2.61
G22C	0.06	0.00	1.35	7.28	8.69
G22D	0.19	0.00	0.90	4.30	5.38
G22E	0.00	0.00	1.62	7.11	8.73
G22F	2.49	0.00	0.66	1.53	4.67
G22G	0.12	0.00	1.71	2.62	4.44
G22H	1.21	0.00	2.84	6.59	10.65
G22J	1.39	0.03	2.96	4.57	8.96
G22K	0.45	0.01	1.60	1.54	3.60
G30A	0.80	0.00	0.25	25.40	26.45
G30D	2.24	0.00	2.53	8.60	13.37
G40A	0.19	0.00	0.74	0.00	0.93
G40B	1.08	0.54	0.08	0.62	2.32
G40C	2.74	4.07	1.83	0.06	8.71
G40D	0.96	6.12	2.18	0.03	9.29
G40E	1.09	6.50	7.18	0.25	15.02
G40G	0.04	3.41	0.28	0.73	4.46
H10A	0.00	0.62	8.57	1.65	10.84
H10B	0.00	1.00	**-1.31**	0.29	**-0.02**
H10C	0.08	1.77	**-8.29**	**-1.49**	**-7.93**
H10D	2.17	0.74	0.13	0.00	3.05
H10E	4.09	0.75	0.43	0.23	5.49

Quaternary Catchment	Peninsula	Nardouw	Intergranular-fractured	Interganular	Total Groundwater Potential
H10F	4.52	1.52	**-2.39**	2.41	6.06
H10G	2.04	**-0.60**	2.07	**-1.48**	2.02
H10H	4.59	0.12	0.55	1.66	6.93
H10J	9.46	**-0.83**	1.15	1.58	11.36
H10K	5.54	0.52	0.58	0.55	7.19
H10L	0.52	0.47	0.49	**-3.38**	**-1.90**
H20A	0.00	2.15	5.17	0.56	7.88
H20B	0.00	1.51	1.28	**-0.67**	2.12
H20C	0.22	4.33	1.23	0.83	6.61
H20D	5.41	1.85	0.56	0.16	7.98
H20E	4.25	0.67	0.40	**-0.83**	4.48
H20F	2.35	2.22	0.57	**-6.95**	**-1.80**
H20G	3.45	0.94	0.75	**-2.49**	2.65
H20H	0.01	0.00	1.85	2.58	4.44
H40A	0.00	5.82	6.26	0.37	12.46
H40B	1.08	10.02	4.85	**-0.23**	15.71
H40C	2.78	0.56	4.93	3.95	12.22
H40D	1.33	9.08	5.83	2.16	18.39
H40E	4.64	2.69	3.93	3.25	14.51
H40F	0.00	0.77	13.86	3.99	18.62
H40G	0.52	10.94	7.19	2.43	21.07
H40H	3.61	0.47	7.37	1.49	12.94
H40J	0.60	1.20	3.37	2.94	8.10
H60A	4.25	1.36	1.26	0.75	7.62
H60B	4.96	4.89	2.62	1.96	14.44
H60C	2.79	5.17	3.98	1.07	13.01
H60D	3.78	3.49	2.05	0.51	9.83
H60E	3.84	0.58	0.74	0.39	5.56
H60F	3.73	1.43	2.29	0.83	8.28
H60H	0.93	0.00	1.13	0.39	2.46
J12A	0.53	7.48	1.65	2.66	12.32
J12B	0.00	0.96	0.72	0.49	2.18
Total	**147.68**	**128.92**	**237.50**	**215.73**	**729.83**

Table E-2 Groundwater Utilisation, based on map-centric recharge estimation (given as groundwater use in % of recharge – baseflow)

Quaternary Catchment	Peninsula	Nardouw	Intergranular-fractured	Intergranular
E10A	0%	1%	39%	n/a
E10B	0%	0%	0%	0%
E10C	0%	0%	0%	0%
E21A	0%	46%	39%	310%
E21B	n/a	0%	8%	0%
E21D	0%	0%	0%	0%
E22C	n/a	0%	0%	0%
G10A	2%	33%	47%	69%
G10B	5%	1%	0%	1%
G10C	0%	0%	10%	21%
G10D	0%	0%	14%	23%
G10E	6%	0%	32%	66%
G10F	0%	0%	20%	3%
G10G	7%	11%	9%	0%
G10H	7%	0%	19%	51%
G10J	0%	n/a	3%	2%
G10K	36%	0%	5%	22%
G10L	n/a	n/a	8%	18%
G10M	0%	n/a	1%	9%
G21A	n/a	n/a	41%	13%
G21B	n/a	n/a	31%	127%
G21C	0%	n/a	51%	0%
G21D	n/a	n/a	29%	99%
G21E	n/a	n/a	23%	22%
G21F	n/a	n/a	3%	2%
G22A	0%	n/a	0%	5%
G22B	0%	n/a	0%	1%
G22C	0%	n/a	14%	18%
G22D	18%	n/a	8%	54%
G22E	n/a	n/a	17%	7%
G22F	6%	n/a	51%	18%
G22G	0%	n/a	11%	24%
G22H	0%	n/a	18%	9%
G22J	0%	0%	8%	9%
G22K	2%	0%	4%	4%
G30A	0%	n/a	0%	0%
G30D	0%	n/a	8%	4%
G40A	0%	n/a	0%	0%
G40B	0%	0%	0%	6%
G40C	0%	5%	29%	0%
G40D	0%	0%	13%	0%
G40E	0%	4%	6%	61%
G40G	0%	0%	0%	51%
H10A	n/a	0%	12%	22%
H10B	n/a	80%	174%	0%
H10C	0%	58%	316%	280%
H10D	6%	17%	0%	0%
H10E	0%	0%	0%	0%
H10F	0%	0%	207%	39%
H10G	44%	369%	0%	115%

Quaternary Catchment	Peninsula	Nardouw	Intergranular-fractured	Intergranular
H10H	0%	0%	67%	60%
H10J	0%	233%	0%	0%
H10K	10%	0%	0%	0%
H10L	0%	63%	0%	218%
H20A	n/a	0%	24%	0%
H20B	n/a	74%	0%	143%
H20C	0%	0%	0%	0%
H20D	6%	5%	7%	11%
H20E	0%	63%	0%	383%
H20F	0%	53%	0%	735%
H20G	15%	0%	0%	351%
H20H	0%	n/a	7%	9%
H40A	n/a	7%	8%	0%
H40B	0%	0%	33%	141%
H40C	14%	0%	11%	16%
H40D	0%	2%	0%	0%
H40E	0%	11%	25%	23%
H40F	n/a	3%	3%	5%
H40G	0%	5%	6%	29%
H40H	0%	0%	4%	27%
H40J	0%	0%	8%	0%
H60A	0%	4%	11%	17%
H60B	0%	0%	17%	6%
H60C	0%	0%	14%	11%
H60D	0%	1%	0%	0%
H60E	1%	0%	1%	0%
H60F	0%	0%	0%	0%
H60H	0%	0%	0%	0%
J12A	0%	0%	0%	0%
J12B	n/a	0%	0%	0%

APPENDIX F

SAMI GROUNDWATER MODULE

APPENDIX F : SAMI GROUNDWATER MODULE

Table F-1 Applicability of Sami Groundwater Module

IWRM	QUAT	Applicability Criteria 1	2	3	4	5	6	Possible / Not	Comments
ATL	G21A (S)	N	N	Y	N	N	Y	N	Granite regolith aquifer dominant
ATL	G21B	N	N	Y	N	N	N	N	Malmesbury-granite regolith aquifer dominant
ATL	G21C	Y	Y	Y	?	Y	Y	P	As above, only minor TMG on G10F border
ATL	G21D	Y	Y	Y	?	Y	Y	P	Malmesbury-granite regolith aquifer dominant
ATL	G21E	Y	Y	Y	?	Y	Y	P	As above
ATL	G21F	Y	Y	Y	?	Y	Y	P	Malmesbury regolith aquifer dominant, except near coast
ATL	G22C (N)	N	N	Y	N	N	N	N	As above
AWT	E10A	N	N	N	N	Y	Y	N	Confined, layered, TMG fractured rock aquifers dominate
AWT	E10B	N	N	N	N	Y	Y	N	As above
AWT	E10C (E)	N	N	N	N	Y	Y	N	As above
AWT	G10G (E)	N	N	N	N	Y	Y	N	As above
AWT	H10C (NW)	N	N	N	N	Y	Y	N	As above
BRV	H10E	N	N	N	N	Y	Y	N	Thick, unconfined TMG fractured-rock aquifer dominant
BRV	H10F	N	N	N	N	Y	Y	N	Confined, layered, TMG fractured rock aquifers dominate
BRV	H10G	N	N	N	N	Y	Y	N	Thick, unconfined TMG fractured-rock aquifer dominant
BRV	H10H	N	N	N	N	N	Y	N	As above
BRV	H10J (NE)	N	N	N	N	N	Y	N	As above
BRV	H10K	N	N	N	N	Y	Y	N	As above
BRV	H10L	N	N	N	N	N	Y	N	Confined, layered, TMG fractured rock aquifers dominate
BRV	H20G (S)	N	N	N	N	Y	Y	N	Thick, unconfined TMG fractured-rock aquifer dominant
BRV	H20H	Y	N	Y	N	N	Y	N	Alluvial and surrounding regolith aquifer dominate
BRV	H40C (S)	N	N	N	N	N	Y	N	Heterogeneous aquifers, TMG on NE border (H40B)
CFP	G22A	N	N	N	N	N	Y	N	Thick, unconfined TMG fractured-rock aquifer dominant
CFP	G22B	N	N	N	N	N	Y	N	As above
CFP	G22C (S)	N	N	Y	N	N	N	N	Malmesbury regolith aquifer dominant, except near coast
CFP	G22D	N	?	Y	N	N	N	N	Layered alluvial and aeolian aquifers; endorheic drainages
CFP	G22E	Y	Y	Y	N	Y	N	P	Malmesbury regolith aquifer dominant, except near coast
CFP	G22F	N	N	N	N	N	Y	N	Thick, unconfined TMG fractured-rock aquifer dominant
CFP	G22G	Y	Y	Y	N	Y	Y	P	Malmesbury-granite regolith aquifer dominant
CFP	G22H	N	N	Y	N	Y	Y	N	Regolith aquifers dominant, but unconfined TMG on borders
CFP	G22J	N	N	Y	N	Y	Y	N	As above
CFP	G22K	N	N	N	N	N	Y	N	Thick, unconfined TMG fractured-rock aquifer dominant

IWRM	QUAT	Applicability Criteria 1	2	3	4	5	6	Possible / Not	Comments
HEX	E22C (E)	N	N	Y	N	Y	Y	N	Post-TMG regolith aquifer(s) dominant
HEX	H20A	N	N	Y	N	Y	Y	N	As above
HEX	H20B	N	N	N	N	Y	Y	N	Confined, layered, TMG fractured rock aquifers dominate
HEX	H20C	N	N	N	N	Y	Y	N	As above
HEX	H20D	N	N	N	N	Y	Y	N	As above
HEX	H20E	N	N	N	N	Y	Y	N	As above
HEX	H20F	N	N	N	N	Y	Y	N	As above
HEX	H20G (N)	N	N	N	N	Y	Y	N	As above
HEX	J12A	N	N	N	N	Y	Y	N	As above
HEX	J12B	N	N	N	N	Y	Y	N	As above
KGB	G40A	N	N	N	N	Y	Y	N	Confined, layered, TMG fractured rock aquifers dominate
KGB	G40B	N	N	N	N	Y	Y	N	As above
KGB	G40C (S)	N	N	N	N	Y	Y	N	As above
KGB	G40D (S)	N	N	N	N	Y	Y	N	As above
KGB	G40E (S)	N	N	N	N	Y	Y	N	As above
KGB	G40G	N	N	N	N	Y	Y	N	As above
NUY	H40A	N	N	Y	N	Y	Y	N	Post-TMG regolith aquifer(s) dominant
NUY	H40B	N	N	N	N	Y	Y	N	Confined, layered, TMG fractured rock aquifers dominate
NUY	H40C (N)	N	N	N	N	N	Y	N	Thick, unconfined TMG fractured-rock aquifer dominant
NUY	H40H (N)	N	N	N	N	N	Y	N	As above
NUY	H40J (N)	N	N	N	?	N	Y	N	As above
PKT	G10K (NE)	N	N	N	N	Y	Y	N	Unconfined and confined TMG fractured-rock aquifer
PKT	G10M (NE)	N	N	N	N	N	N	N	TMG fractured-rock aquifer along fault
PKT	G30A (N)	N	N	N	N	N	N	N	Heterogeneous primary aquifers, with TMG on S border
PKT	G30D	N	N	N	N	Y	Y	N	Heterogenous TMG bedrock aquifers
PUB	G10A (NW)	N	N	N	N	N	Y	N	Thick, unconfined TMG fractured-rock aquifer dominant
PUB	G10B	N	N	N	N	N	Y	N	Unconfined and confined TMG fractured-rock aquifer
PUB	G10C	N	Y	Y	N	Y	Y	P	Regolith aquifers dominant, but unconfined TMG on E border
PUB	G10D	N	Y	Y	N	Y	Y	P	As above
PUB	H10J (SW)	N	N	N	N	N	Y	N	Thick, unconfined TMG fractured-rock aquifer dominant
RBT	H40D	N	N	N	N	Y	Y	N	Confined, layered, TMG fractured rock aquifers in S
RBT	H40E	N	N	N	N	Y	Y	N	Confined, layered, TMG fractured rock aquifers on S and E
RBT	H40F	N	N	N	N	Y	Y	N	Regolith-alluvial aquifers mostly, confined TMG in far S
RBT	H40G	N	N	N	N	Y	Y	N	Heterogeneous regolith-alluvial aquifers, with TMG on S and E
RBT	H40H (S)	N	N	N	N	N	Y	N	Asymmetric GW input from TMG on NE border
RBT	H40J (S)	N	N	N	N	N	Y	N	Asymmetric GW input from TMG on NE and SW border

IWRM	QUAT	Applicability Criteria 1	2	3	4	5	6	Possible / Not	Comments
THK	G10A (SE)	N	N	N	N	N	Y	**N**	Thick, unconfined TMG fractured-rock aquifer dominant
THK	G40C (N)	N	N	N	N	Y	Y	**N**	Confined, layered, TMG fractured rock aquifers dominate
THK	G40D (N)	N	N	N	N	Y	Y	**N**	As above
THK	G40E (N)	N	N	N	N	Y	Y	**N**	As above
THK	H60A	N	N	N	N	Y	Y	**N**	As above
THK	H60B	N	N	N	N	Y	Y	**N**	As above
THK	H60C	N	N	N	N	Y	Y	**N**	As above
THK	H60D	N	N	N	N	N	Y	**N**	Asymmetric GW input from TMG on N border
THK	H60E	N	N	N	N	N	Y	**N**	Asymmetric GW input from TMG on N border
THK	H60F	N	N	N	N	N	Y	**N**	Asymmetric GW input from TMG on N border
THK	H60H	N	N	N	N	N	Y	**N**	Asymmetric GW input from TMG on N border
TWR	E10C (W)	N	N	N	N	Y	Y	**N**	Confined, layered, TMG fractured rock aquifers dominant
TWR	G10G (W)	N	N	N	N	Y	Y	**N**	As above
TWR	G10H	N	N	Y	N	Y	Y	**N**	Malmesbury regolith aquifer, except unconfined TMG on E and W border
TWR	G10J	N	N	Y	N	Y	Y	P	Malmesbury regolith aquifer, except unconfined TMG on E salient
VVT	G10E	N	N	N	N	Y	Y	**N**	Malmesbury regolith aquifer, TMG fractured rock aquifers in SW
VVT	G10F	N	N	Y	N	Y	Y	P	Malmesbury regolith aquifer, except unconfined TMG on E side
WBK	E21A	Y	Y	Y	N	Y	Y	P	Post-TMG regolith aquifer(s) dominant; minor confined TMG in W
WBK	E21B	Y	Y	Y	N	Y	Y	P	Post-TMG regolith aquifer(s) dominant
WBK	E21D	N	N	N	N	N	Y	**N**	Confined, layered, TMG fractured rock aquifers in W (Hansiesberg)
WBK	E22C (W)	N	N	Y	N	N	Y	**N**	Post-TMG regolith aquifer(s) dominant
WBK	H10A	Y	Y	Y	N	Y	Y	P	Post-TMG regolith aquifer(s) dominant
WBK	H10B	N	N	N	N	Y	Y	**N**	Confined, layered, TMG fractured rock aquifers in S
WBK	H10C (SE)	N	N	N	N	Y	Y	**N**	Confined, layered, TMG fractured rock aquifers in W
WBK	H10D	N	N	N	N	Y	Y	**N**	Thick, unconfined TMG fractured-rock aquifer dominant
WCT	G10K (SW)	N	N	Y	N	N	N	**N**	Regolith aquifers dominant; Layered alluvial-aeolian in NW
WCT	G10L	N	N	Y	N	N	N	**N**	Regolith aquifers dominant; Layered alluvial-aeolian in NW
WCT	G10M (SW)	N	N	Y	N	N	N	**N**	Heterogenous bedrock and alluvial-aeolian aquifers
WCT	G21A (N)	N	N	Y	N	N	Y	**N**	Granite regolith aquifer dominant
WCT	G30A (S)	N	N	Y	N	N	N	**N**	Heterogeneous primary aquifers; ill-defined drainage

1) Quaternary catchments that are shared between IWRM domains are shaded turquoise
2) Catchments in which the Sami Module will be tested are highlighted in yellow

Table F-2 Parameters of Sami Groundwater Module

Item	Status	Not used	Default	Update GW	Update SW	Calibration
Catchment Characteristics						
Catchment Area (CATCHMENT)	D		x			
Aquifer thickness	P			x		
Storativity (S)	P			x		
Total Aquifer Storage (TAS)	C			calculated		
Initial groundwater store	I					x
MAP (RAIN)	D				x	
Static water level (SWL)	P		x	x		
Unsat Store (PMAX)	P		x	x		
Initial Store	I					x
MAXRECH	P			x		
Moving average of recharge (Rex)	P			calculated		
Mean annual baseflow	D	x				
Baseflow calculated	C	x				
Pitman Parameters						
FT	P		x		x	
ST	P		x		x	
SL	P		x		x	
POW	P		x		x	
GW	P		x		x	
GPOW	P		x		x	
GL	P		x		x	
Harvest Potential	D	x				
Est. recharge	C	x				
Groundwater – Surface water Interaction						
Max groundwater discharge (BFMAX)	P			x		
BPOW	P			x		
Groundwater Evapotranspiration and Outflow						
Hydraulic gradient (HGRAD)	D		x	x		
MAE	D		x		x	
GW evap. Area (AREA)	D		x	x		
Transmissivity	P		x	x		
Impacts of Abstraction						
GW abstraction	D	x				
Distance-river (X)	D		x	x		
Max % from groundwater (GWMAX)	P		x			
K2	P					x
K3	P					x
Time Series Data						
Discharge	D				x	
Pitman S (S)	D				x	
Rainfall (RAIN)	D				x	
% of MAE (MDIST)	D				x	
Crop factor (CROP)	D				x	
Abstraction	D			x		