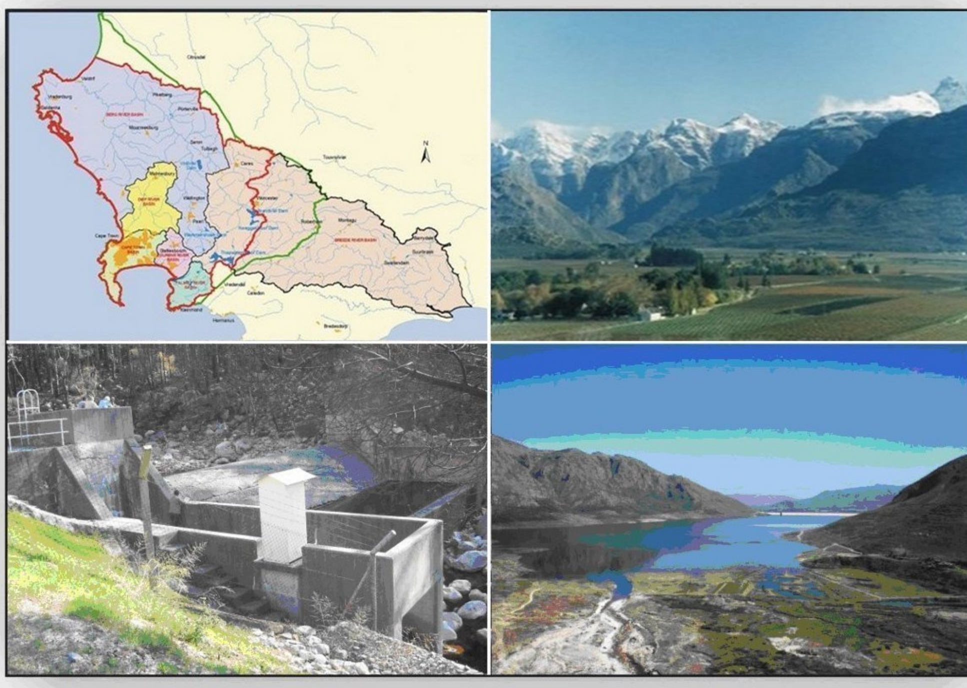
Ref No: P WMA19/000/00/1209

Department of Water Affairs and Forestry

Directorate: National Water Resource Planning

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

Report No. 1 : Summary Report



FINAL **May 2010**

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

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

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

Report No. 1

SUMMARY REPORT

FINAL

Submitted by:

Ninham Shand in association with Umvoto Africa (Pty) Ltd

May 2010

Department of Water Affairs and Forestry
Directorate National Water Resource Planning

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

APPROVAL

TITLE :	**The Assessment of Water Availability in the Berg Catchment (WMA 19) by Means of Water Resource Related Models:**
	Summary Report:
DWAF REPORT NO.:	**P WMA19/000/00/1209**
CONSULTANTS	**Ninham Shand in association with Umvoto Africa (Pty) Ltd**
AUTHORS	**G English**
REPORT STATUS	**Final**
DATE	**May 2010**

STUDY TEAM : Approved for Ninham Shand

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G ENGLISH **A H M GöRGENS**

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

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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
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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 Mhlatuze 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

SUMMARY REPORT

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ABBREVIATIONS

ASR	Aquifer Storage Recovery
BRBS	Breede River Basin Study
CAGE	Cape Artesian Groundwater Exploration
CCT	City of Cape Town
CCWR	Computing Centre for Water Research
CFA	Cape Flats Aquifer
CGS	Council for Geoscience
CMC	Cape Metropolitan Council
DEM	Digital Elevation Model
DWAF	Department of Water Affairs and Forestry
EAS	Elandsfontein Aquifer System
EC	Electrical Conductivity
EFR	Estuarine Flow Requirements
GIS	Geographical Information System
GRA II	Groundwater Resource Assessment (Phase II)
GRDM	Groundwater Resource Directed Measures
IAP	Invasive Alien Plants
IFR	In-stream Flow Requirements
ISP	Internal Strategic Perspective
IWRM	Integrated Water Resources Management
LAU	Lower Aquifer Unit
LRAS	Langebaan Road Aquifer System
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
NGBD	National Groundwater Database
NLC	National Land Cover
NWA	National Water Act
SAWS	South African Weather Service
SVF	Saturated Volume Fluctuations
TDS	Total Dissolved Solids
TMG	Table Mountain Group
TMGAA	Table Mountain Group Aquifer Alliance
UAU	Upper Aquifer Unit
WAAS	Water Availability Assessment Study
WARMS	Water Use Authorization and Registration Management System
WCSA	Western Cape System Analysis
WCWSS	Western Cape Water Supply System
WfW	Working for Water
WMA	Water Management Area
WR90	Water Resources of South Africa, 1990
WR-IMS	Water Resources Information Management System
WRSM	Water Resource Simulation Model
WRSM2000	Water Resources Simulation Model (2000)
WRPM	Water Resources Planning Model
WRYM	Water Resources Yield Model
WSAM	Water Situation Assessment Model
WUA	Water User Association

1. INTRODUCTION

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 plus industrial users on the West Coast, as well as irrigators and urban users in the Riviersonderend catchment of the Breede WMA.

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

- 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 requirements, as well as streamflow salinity increases, might place parts of the WCWSS in a water-stress condition during the foreseeable future.

- A Reconciliation Strategy Study which reviewed the future water requirements and the options for meeting these requirements. The Study has identified favourable augmentation options and has 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 requirements.

1.1 PURPOSE OF THIS REPORT

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

- 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 through the preparation of updated models for use in the assessment of water resource augmentation options.

Ninham Shand (Pty) Ltd was the Lead Consultant responsible for the surface water components of the Study, as well as study management, while Umvoto Africa (Pty) Ltd was responsible for the groundwater components. Figure 1-1 shows the footprint of the Study Area.

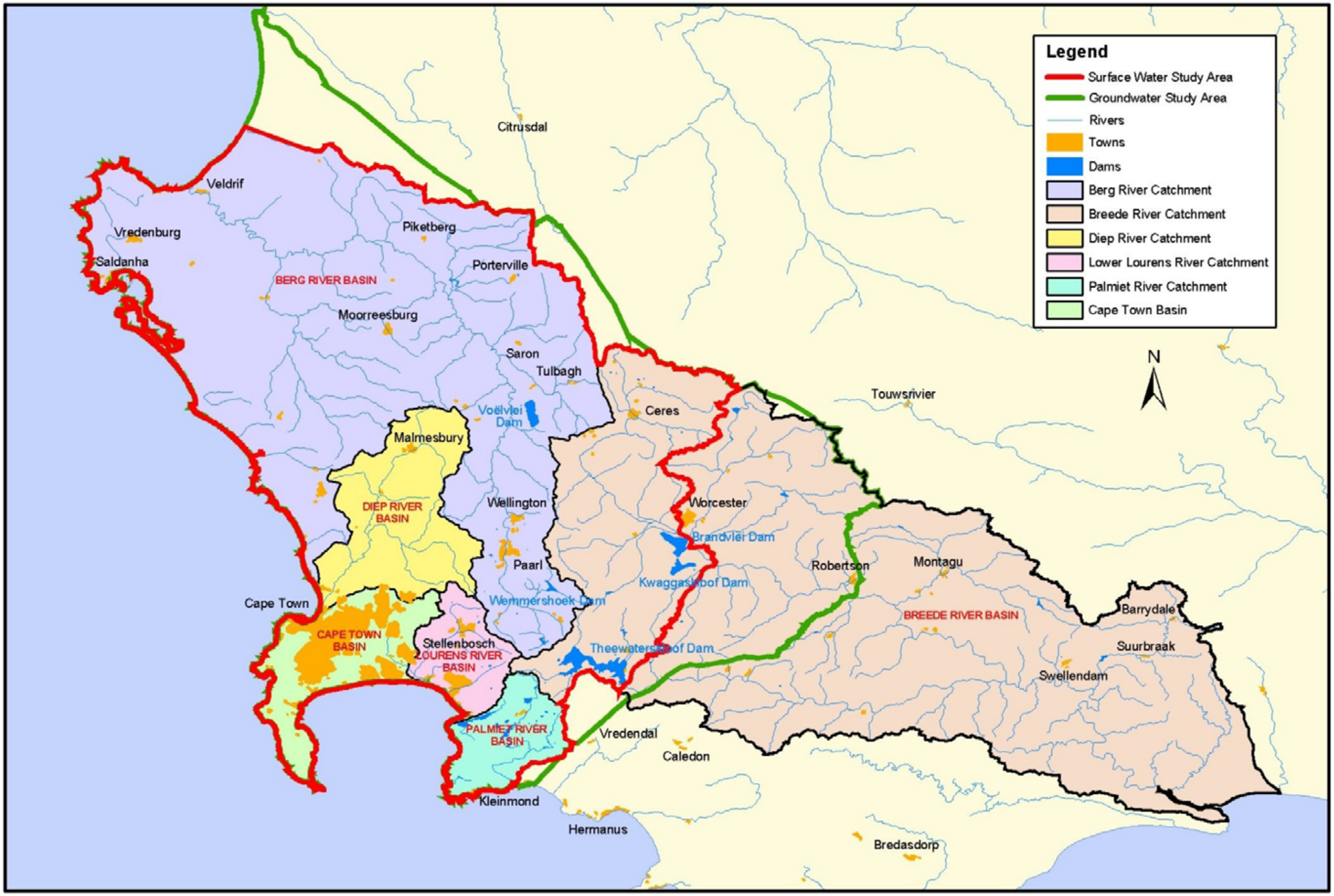

Figure 1-1: Footprint of Berg WAAS Area

1.2 SCOPE OF THIS REPORT

In the sections which follow in this report, a consolidated summary of the key findings, conclusions and recommendations synthesized from the Study's detailed technical reports will be presented, namely:

- Rainfall Data Preparation and MAP Surface
- The Assessment of Flow Gauging Stations
- Land Use and Water Requirements
  - Data in Support of Catchment Modelling
  - Invasive Alien Plant Mapping
  - Water Use and Water Requirements
- Update of Catchment Hydrology
  - Berg River
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  - Updating of the ACRU Salinity Model for the Berg River
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  - TMG Aquifer, Witzenberg – Nuy Model
  - Breede River Alluvium Aquifer Model
- Berg and Mhlathuze Assessment Studies - Review Report
- Applicability of the Sami Groundwater Model to the Berg WAAS Area

2. RAINFALL DATA PREPARATION AND MAP SURFACE

2.1 WATER RESOURCES INFORMATION MANAGEMENT SYSTEM

The Water Resources Information Management System (WR-IMS) is a database management system that was developed by DWAF. The rainfall database covered by the WR-IMS comprises 12 748 rainfall stations across southern Africa, of which the majority are located in South Africa. Those located within the footprint of the Berg WAAS area are shown in **Figure 2-1.**

The WR-IMS was used in this study as the database management tool to patch the monthly rainfall records of rainfall stations located in the Berg, Breede and peripheral river catchments.

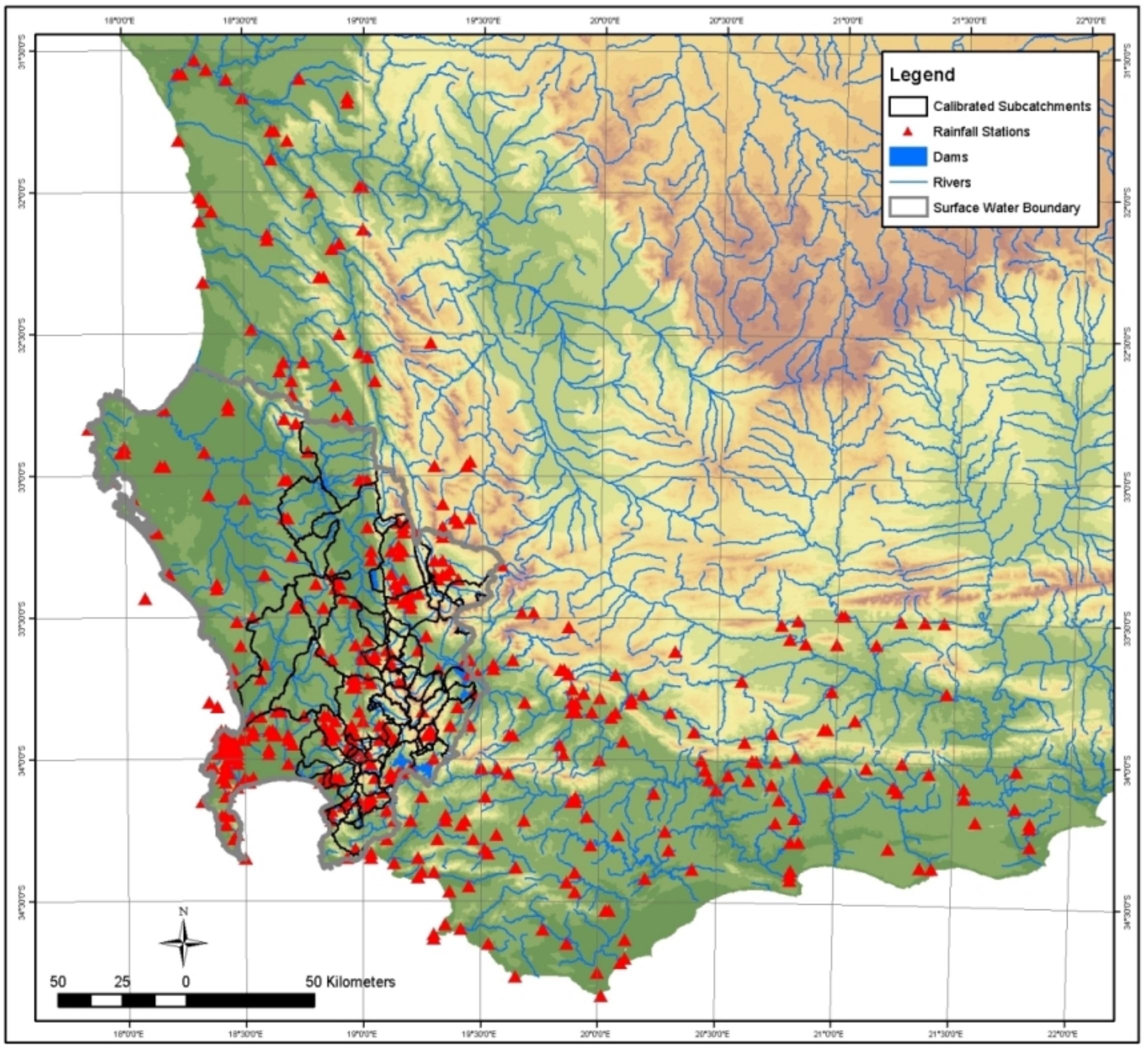

Figure 2-1 Location of all rainfall stations in the WAAS Study Area

2.2 SELECTION AND SCREENING OF MONTHLY RAINFALL RECORDS

Data from the WR-IMS and from the South African Weather Service (SAWS) were used for all rainfall stations located within or near the study area. As an initial screening, rainfall records with less than 10 years of data, with records ending prior to 1940 or with excessive missing data were eliminated.

Following this initial screening, tests of stationarity were conducted on all selected rainfall gauges. Cumulative mass plots were examined and rainfall station records were analysed for suitable use within groups of stations to ensure overlapping periods. Once the rainfall stations had been selected and the rainfall data had been screened, the ClassR and PatchR routines were used to group suitable rainfall stations together and infill missing or suspect values.

2.2.1 CLASSR

ClassR is a utility used to group hydro-meteorologically similar rainfall stations together, enabling the user to make a selection of well-correlated rainfall stations to be used in the patching process. This is achieved in an iterative procedure to optimize the best possible grouping of rainfall gauges for patching of data.

2.2.2 PATCHR

PatchR uses a linear regression in combination with expectation maximization to infill missing or suspect values which have been flagged in the input rainfall record. It performs a multiple patch on all rainfall stations contained within a group; the rainfall sequence is lengthened to the earliest and latest date that occurs in the input rainfall records. 98 rainfall station records in the Berg WAAS study area were patched. Problems in the high mountain areas were encountered relating to the limited number of rainfall stations and extent of missing data.

2.3 DEVELOPMENT OF AN UPDATED MEAN ANNUAL RAINFALL MAP FOR THE SOUTH-WESTERN CAPE

Anomalies in the Western Cape portion of the 1 minute x 1 minute rainfall surface were considered to be serious enough to warrant the re-generation of a more realistic surface for use in the WAAS hydrology.

2.3.1 General Approach

The approach that was followed to develop the updated rainfall surface is similar to the one used by Dent *et al* to generate the original 1 minute x 1 minute surface, i.e. development of a regression model that relates MAP to one or more physiographic variables, followed by interpolation of residuals, and combination of the two surfaces to form a composite mean annual rainfall surface.

2.3.2 Selection of Rainfall Stations

The selection of rainfall stations for use in the surface model was done by means of a complex screening process, taking cognisance of the fact that inclusion (or rejection) of a single station in an area where few other stations are present, could make a significant difference to the interpolated surface. The process that was followed enabled selection of 321 stations for inclusion in the South-western Cape rainfall surface.

2.3.3 Physiographic Data Sets

The following physiographic variables were considered for inclusion into the regression equations:

- Altitude,
- Continentality,
- Roughness,
- Aspect and rain-bearing wind index,
- Exposure, and
- Distance from barrier features.

2.3.4 Regression Analysis

The set of candidate physiographic variables and the measured point MAP values were used to develop a regression surface that explains a portion of the variability of rainfall in the region.

2.3.5 The Residual Surface

The regression equation was used to calculate predicted values of MAPs at each of the station points. Residuals were then calculated by subtracting predicted values from measured MAPs. The distribution of the residuals indicated that there is still a fair amount of unexplained drift in the residuals. To account for some of the remaining drift in the residuals, it was decided to construct the residual surface with an alternative method (kriging), rather than with a non-statistical interpolation method.

2.3.6 The Composite Surface

The interpolated regression and residual surfaces were added together (summed) to produce a composite surface. Predicted MAPs over a very small part (0.7%) of the modelled area were less than 60 mm per year and negative in some instances. These values were set equal to 60 mm. The maximum predicted value was 3 238 mm in the Jonkershoek valley, which is of the same order as the maximum measured MAP of 3 348 mm at a research station in the same valley.

2.3.7 Results

For comparative purposes, the new composite rainfall surface and the 2003 Agro-Hydrology Atlas are shown side-by-side in **Figure 2-2**.

The detailed technical report describing the full extent of the work can be found in *"Report No 2 : Rainfall Data Preparation and MAP Surface"*, of the Berg WAAS series of Study Reports.

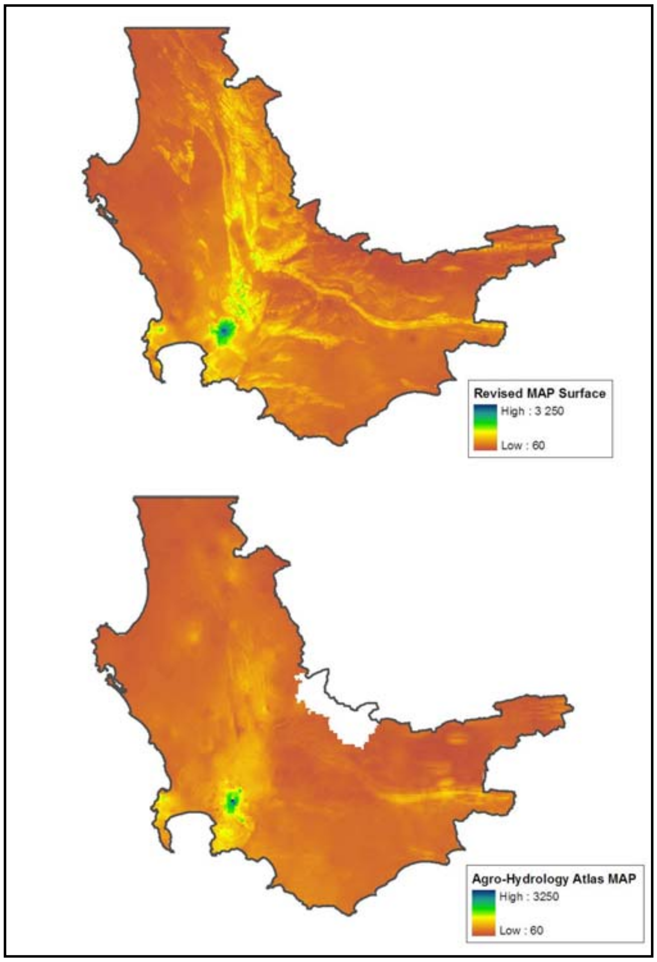

Figure 2-2 Comparison of the Revised MAP Surface (Top) and the Atlas Surface (Bottom)

Figure 2-3 shows the arithmetic difference (Revised minus Atlas) between the two surfaces indicating that the revised surface consistently predicts higher MAPs in the higher lying areas, and predicts lower values in the West Coast, Overberg and Little Karoo areas.

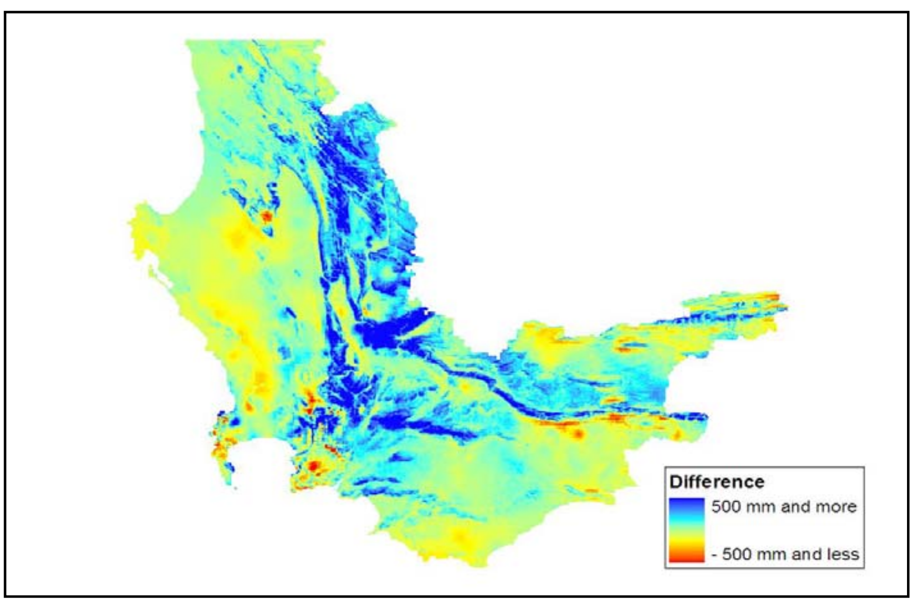

Figure 2-3 Difference (mm) Between the Revised MAP Surface and the Atlas Surface

3. THE ASSESSMENT OF FLOW GAUGING STATIONS

3.1 INTRODUCTION

The objective of this task is to document the extent of information available at each flow gauging station which could be considered for catchment calibration purposes, as well as to identify those stations that may warrant reinstatement. **Figure 3-1** shows the location of existing streamflow gauging stations in the Berg WAAS area.

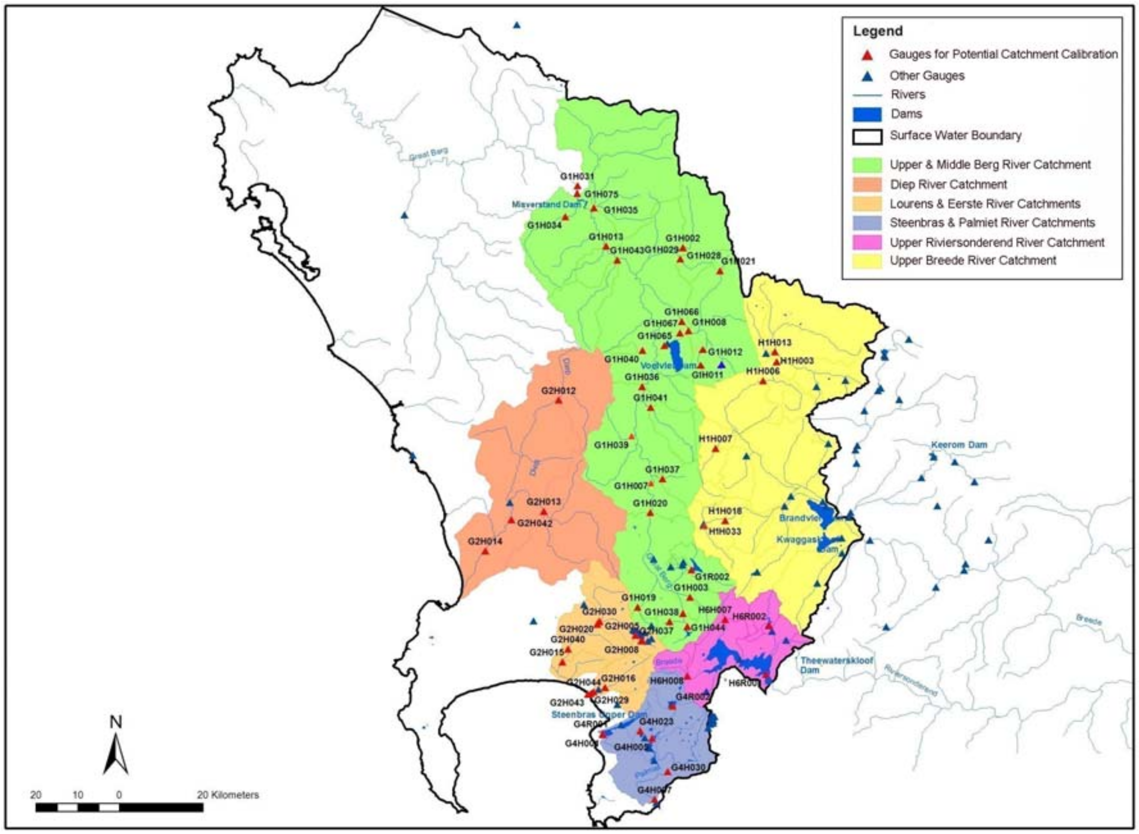

Figure 3-1 Location of Flow Gauging Stations in the Berg WAAS Area

A total of 71 stations were assessed in detail for the purposes of supporting surface water modelling. Of these, 18 were identified as also being important to support the understanding of the surface and groundwater interaction. A further six existing stations (primarily in the Wemmershoek River catchment) were identified as requiring refurbishment, to also support the better understanding of the surface and groundwater interaction.

3.2 THE EXISTING STREAMFLOW GAUGING NETWORK

The gauging stations on the Upper Breede River are very important due to the potential for the future development of water resource infrastructure in this region. The existing weirs on the Banhoek and Wolwekloof Rivers require structural attention and modification, whilst streamflow gauging on the Lourens River remains problematic despite the construction of two new stations in 1986 and in 2004.

3.3 GAUGES REQUIRED TO SUPPORT SURFACE WATER/GROUNDWATER INTERACTION

Surface water flow gauging stations can be used to monitor surface water/groundwater interaction. Considering the existing streamflow gauging station network in the Western Cape, several additional sites (and sites that can be reinstated) have been identified where streamflow data is required in order to be able to accurately model the surface water/groundwater interaction in this study area in the future. In some cases, these stations are no longer active and need to be reinstated in order to collect data suitable for future studies. In addition, some of the existing streamflow stations need to be upgraded and calibrated for accurate "low flow" measurements.

Where possible, the recommendations are focused on reinstatement of existing (yet inactive) stations as opposed to the siting of a new one, so as to reduce the likely capital cost. Providing that their low flow measurement is accurate, the existing streamflow gauging stations shown in **Table 3-1** are considered to be well suited to support surface water/groundwater interaction modelling.

Table 3-1 Existing Streamflow Gauges Suitable for Surface/Groundwater Monitoring

Existing Station	River	Place name
G1H002	Vier en Twintig	Driebosch
G1H008	Klein Berg	Nieuwkloof
G1H011	Watervals	Watervalsberge
G1H012	Waterval River	Voëlvlei Mountains
G1H014	Wemmershoek	Tributary
G1H015	Wemmershoek	Tributary
G1H016	Wemmershoek	Tributary
G1H017	Wemmershoek	Tributary
G1H018	Wemmershoek	Tributary
G1H019	Banhoek	Jonkershoek
G1H021	Klein Berg	Mountain View
G1H035	Matjies	Matjiesfontein
G1H066	Klein Berg	Nieuwkloof Pass
G2H005	Jonkershoek	Kleinplaas Dam
G2H008	Jonkershoek	Jonkershoek
G4H030	Palmiet	Krabbefontein
H1H003	Upper Breede	Ceres Golf Club
H1H006	Klein Berg	Michell's Pass
H1H007	Wit River	Drosterskloof
H1H013	Koekedouw	Ceres
H1H018	Molenaars	Hawequas Forest
H2H004	Sanddrif River	Zanddriftskloof
H6H007	Du Toits	Purgatory Outspan
H6H008	Riviersonderend	Nuweberg Forest

In addition to these existing streamflow gauging stations that can be used for groundwater modelling, 11 additional stations are recommended to expand the station network so as to support the surface water groundwater interaction assessment in future studies. These are as indicated in **Table 3-2**.

Table 3-2 Non-operational Streamflow Gauges Suitable for Surface/Groundwater Monitoring if properly reinstated

Site	Latitude	Longitude	River	Comment
1	-33.84751	19.01585	Berg	At proposed abstraction weir
2	-33.477300	19.175670	Breede	
3	-33.552490	19.220890	Breede	Or reinstating of H1H001
4	-33.589240	19.263540	Breede	
5	-33.318630	19.098090	Klein Berg	
6	-33.397410	19.290110	Breede	
7	-33.314790	19.298780	Skaap	
8	-33.409070	19.443540	Titus	
9	-33.506490	19.493220	Amandel	
10	-33.495940	19.530250	Sanddrif	Or utilising H2H004
11	-33.512220	19.534970	Amandel	

Within this study area, 13 spring locations have been identified during previous studies and initial measurements of temperature and flow have been taken. Natural springs provide a direct indication of the flow of water in the aquifer and it is important that flow stations capable of measuring “low” flow are set up at all springs known to be linked to the aquifer.

There are currently only a handful of springs in the study area that are being monitored. For this reason a full spring hydrocensus is recommended, aimed at locating and identifying all perennial springs in the western portion of the Western Cape, as relevant to this study area. Subsequent field verification will be required as a next phase to determine the validity of the identified potential spring locations and the suitability for installation of automated flow measurements (e.g. weirs, v-notches or flumes) as well as to determine parameters such as their water temperature and flow.

The detailed technical report describing the full extent of the work can be found in *“Report No 3 : The Assessment of Flow Gauging Stations”*, of the Berg WAAS series of Study Reports.

4. INVASIVE ALIEN PLANT MAPPING

4.1 INTRODUCTION

During the Inception Phase of this study, it was recognised that due to the resolution and quality of available aerial photography, the identification of certain individual Invasive Alien Plant (IAP) species in the study area would be a challenge. In collaboration with the regional Working for Water (WfW) office, a review was undertaken of the available aerial photography, to determine what could be achieved in terms of IAP mapping.

4.2 MAPPING CONSTRAINTS

It was agreed that species identification would, at best, only be possible at a coarse level. The species that could be recognised (requiring ground-truthing) included pines, eucalyptus, acacias and black wattle. From the photography, Hakea infestations could not be distinguished from natural fynbos.

4.3 APPROACHES ADOPTED

Age classification was based on consideration of the size of tree. Tall trees of a species would be considered as mature and smaller trees of the same species as young. Estimates of density were based on canopy cover. No attempt was to be made to identify Hakea. WfW have indicated that the spreading of Hakea has stabilized, and that the clearing of that species does not currently demand the same priority as other, more prominent invasive species.

4.4 EXTENT OF CURRENT INFESTATIONS

Table 4-1 and **Figure 4-1** show the extent of the current condensed areas and the interpretation of IAP species and characteristics for the Berg WAAS area.

Table 4-1 Extent of Present-day (2004) Invasive Alien Plant Infestations

IAP Type	Area of Infestation (km^2)
Black Wattle	19.4
Eucalypts	22.7
Pine	11.5
Poplar	0.1
Port Jackson	68.3
Rooikrans	6.1
Other	26.7
Total	**155.0**
Upland	114
Riparian	41
Upland (%)	74%
Riparian (%)	26%

Characteristic	Area of Infestation (km^2)
AGE	
Mature Trees	145.5
Young Trees	9.5
Total	**155.0**
DENSITY	
Dense Infestation	33.8
Moderate	36.5
Scattered	84.7
Total	**155.0**
SIZE	
Medium Tree	60.2
Tall Shrub	78.0
Tall Tree	16.8
Total	**155.0**

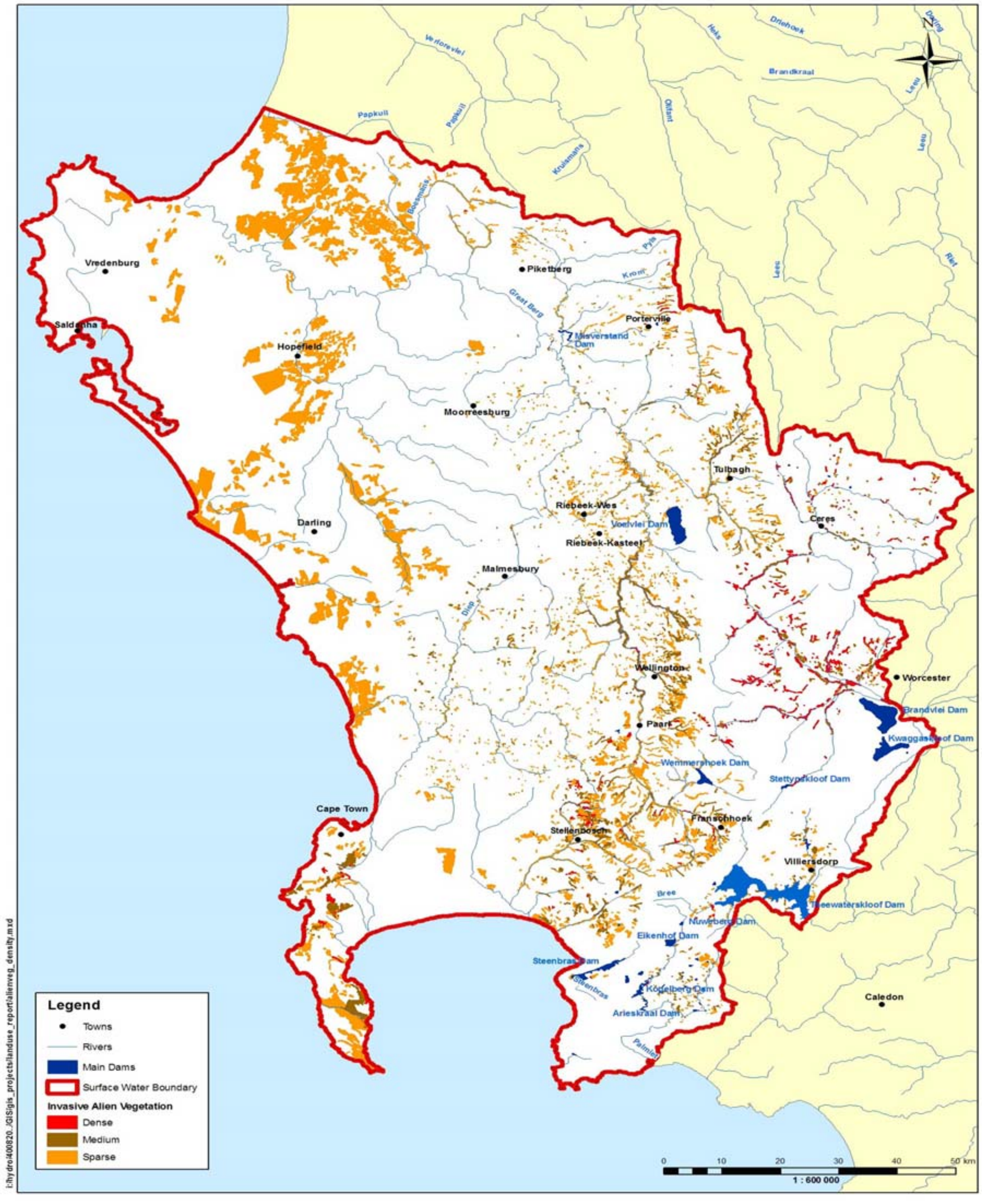

Figure 4-1 Extent of IAP Infestation in the Berg WAAS Area

The detailed technical report describing the full extent of the work can be found in *"Report No 4 : (Land Use and Water Requirements): Volume 2 (Invasive Alien Plant Mapping)"*, of the Berg WAAS series of Study Reports.

5. WATER USE AND WATER REQUIREMENTS

5.1 INTRODUCTION

Historical and current land and water use within the study area facilitate the calibration of the hydrological models and the subsequent naturalisation of flow sequences. The study area is characterised by extensive areas of irrigation, forestry and IAPs for which accurate information on land use is a prerequisite. The present-day water use information also supports the updating of the existing system model and includes actual irrigation and streamflow reduction requirement sequences, information on urban abstractions from reservoirs, and the water requirements of the Ecological Reserve.

5.2 APPROACH

Land use mapping and data collection from regulatory bodies, industries, DWAF, Water User Associations (WUAs) and municipalities were collated. Registered water use information was also acquired and processed from the Water Use Authorisation and Registration Management System (WARMS) database. The present-day water use and water requirements for the Berg WAAS surface water study area were then determined, taking the above into consideration.

5.3 EXISTING WATER USE AND WATER REQUIREMENT CHARACTERISTICS

Water use in the Berg River catchment is primarily for irrigation of vineyards and orchards, requirements for afforestation as well as riparian and upland alien vegetation infestations. Municipal abstractions supply Paarl, Wellington, Tulbagh and Saron, as well as the West Coast Towns of Darling, Moorreesburg, Yzerfontein, Riebeek-Wes, Riebeek-Kasteel, Koringberg, Hermon, Gouda, Malmesbury, Saldanha Bay, Langebaan, Parternoster, Laaiplek, Velddrif, Vredenburg, Hopefield, and Piketberg.

In the Eerste and Lourens River catchments irrigation of vineyards and orchards is dominant, with some afforestation in the upper catchment areas. Part of municipal water requirement from Stellenbosch is also supplied.

There is a significant quantity of irrigated agriculture (fruit farming and vineyards) in the upper Palmiet catchment and extensive areas of afforestation in the Steenbras and Palmiet catchments. IAP concentrations in the Palmiet and Steenbras catchments are small. There is a municipal water requirement for Elgin and Grabouw in this catchment.

In the Diep River catchment most of the agricultural water use is for vineyards, fruit and vegetables. IAP species include Black Wattle, Pines, Eucalyptus and Port Jackson.

The primary irrigation water requirement in the Upper Breede River catchment is for vineyards and orchards, while pasture constitutes most of the remaining requirement. There is widespread, scattered to dense areas of alien vegetation and a municipal water requirement for Ceres and Worcester.

In the uppermost Riviersonderend there is little formal landuse, but in the lower lying areas agricultural water use is primarily for fruit farming. The Upper Riviersonderend catchment exhibits extensive areas of IAPs, mainly Pines, which occur mostly in the upland areas. Theewaterskloof Dam is situated in the Riviersonderend catchment.

5.3.1 Irrigation Water Requirements

Figure 5-1 shows the extent of 2004 (present day) irrigation

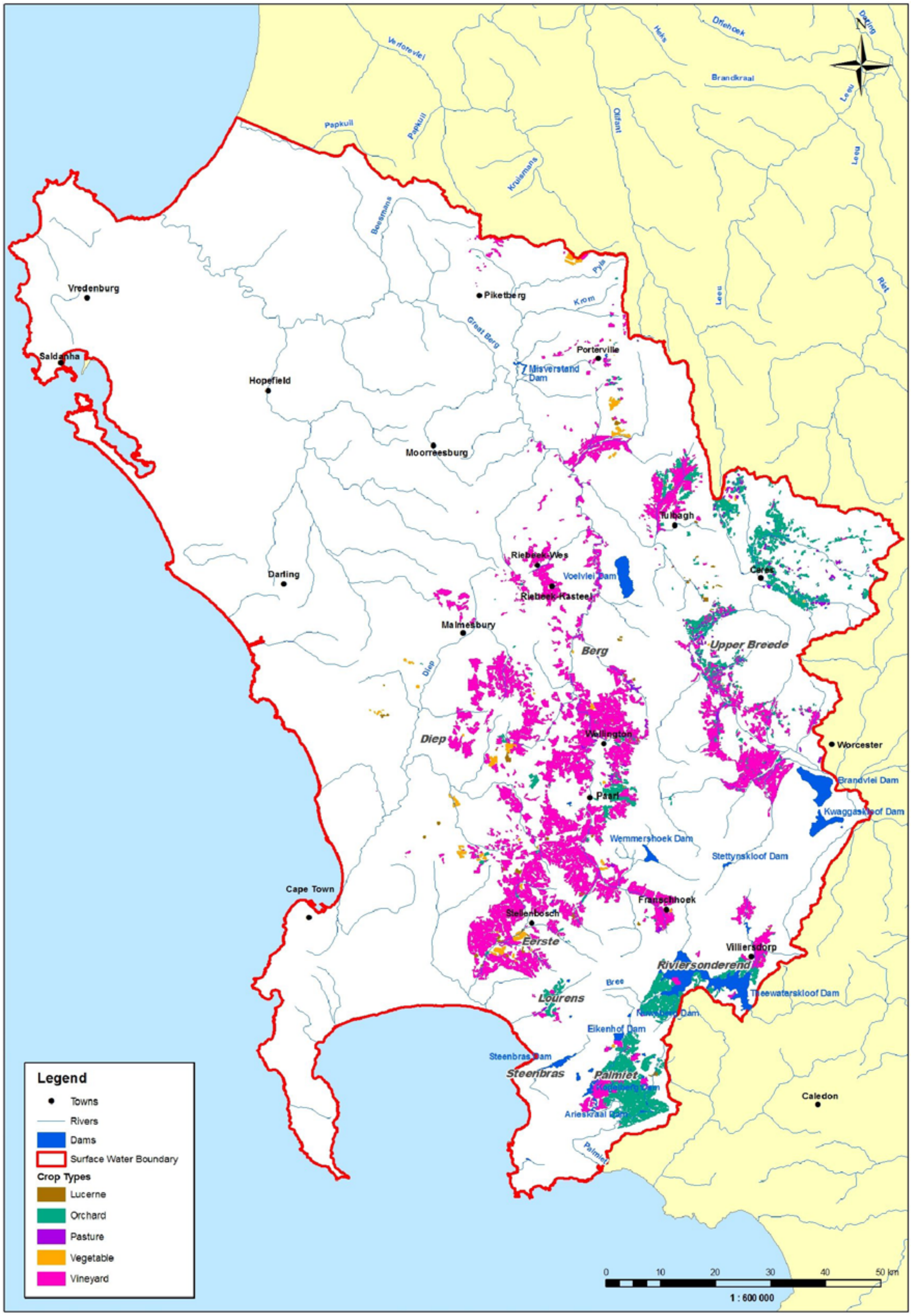

Figure 5-1 Present-day (2004) extent of irrigation

Table 5-1 summarises the current water requirements and sources for diffuse irrigation in the Berg WAAS area.

Table 5-1 Diffuse irrigation water requirements in the Berg WAAS area (2004)

Subcatchment	Irrigation area (km^2)	Source: Farm dams ($10^6m^3/a$)	Source: River ($10^6m^3/a$)	Total ($10^6m^3/a$)
Upper Berg	104.4	32.1	34.0	66.1
Middle Berg	216.3	81.8	70.7	152.5
Lower Berg	7.3	3.5	2.0	5.5
Berg Total	328.0	117.4	106.7	224.0
Diep	109.2	42.4	24.9	67.3
Eerste and Lourens	119.7	57.2	9.6	66.8
Palmiet and Steenbras	96.2	38.1	11.9	50.0
Riviersonderend	45.7	42.2	4.6	46.8
Upper Breede	65.4	7.2	6.4	13.6
TOTAL	**787.1**	**304.4**	**164.1**	**468.5**

The bulk of the diffuse water requirements (48%) occur in the Berg River catchment and the remainder within the Diep (14%), Eerste and Lourens (14%), Palmiet and Steenbras (11%), Upper Riviersonderend (10%), and Upper Breede (3%). In addition, an estimated further 93 million m^3/a is abstracted by Water User Associations and Irrigation Boards.

5.3.2 Urban Requirements

Bulk water requirements for the City of Cape Town total approximately 300 million m^3/a, supplied from the Western Cape System and some local sources falling outside of the Berg WAAS area. The current supply volumes to the other urban centres (of which Paarl, Wellington, Stellenbosch, Worcester and Ceres are the largest) total about 55 million m^3/a.

5.3.3 Afforestation Water Use

There is approximately 185 km^2 of commercial forestry in the Berg WAAS area which equates to an estimated present-day water use of 31.4 million m^3/a. Of this 43% occurs in the Berg catchment area and 33% in the Palmiet and Steenbras areas.

5.3.4 Alien Vegetation Requirements

There is approximately 54 km^2 of IAPs (equivalent to 100% density) in the study catchment, which corresponds to an estimated present-day streamflow reduction of about 12 million m^3/a. 58% of this occurs within the Berg catchment area and 23% within the Eerste and Lourens River catchments.

5.3.5 Ecological Reserve

Provisional estimates of Instream and Estuarine Flow Requirements (IFR and EFR) have been made for the Berg and Breede River catchments. These are summarised in **Table 5-2**.

Table 5-2 Ecological Reserve requirements in the Berg WAAS Catchment ($10^6m^3/a$)

Subcatchment	Reserve Classification	Maintenance Low Flows	Maintenance High Flows	Reserve MAR ($10^6m^3/a$)
Berg: Site 1 (IFR 1/96) Site 2 (IFR 3/96)	 - -	 31.3 116.2	 20.1 62.4	 51.4 178.6
Upper Breede: Site 1 Site 2	 Class D Class B	 42.8 78.5	 41.4 45.3	 103.0 35.4

5.3.6 Groundwater Use

Information on groundwater use in the study area indicates that the total existing groundwater use in the Berg WAAS area is estimated to be 93 million m^3/a, of which the majority (58%) takes place in the Upper Breede catchment area, followed by the Berg catchment area (20%) and the Diep River catchment (15%).

5.4 PRESENT-DAY FLOW SEQUENCES

The present-day flow sequences representing all water requirements in the study area for the current level of development, i.e. 2004 land use areas and water requirements, were generated using the calibrated WRSM2000 Pitman model. The most downstream main stem results are summarised in **Table 5-3** below.

Table 5-3 Summary of Cumulative Present Day and Naturalised MARs

Catchment	Present day ($10^6m^3/a$)	Naturalised ($10^6m^3/a$)
Berg	685	880
Diep	42	70
Eerste and Lourens	87	126
Palmiet and Steenbras	215	251
Upper Riviersonderend	337	355
Upper Breede	221	266
Molenaars Tributary	148	149
Holsloot Tributary	87	99

The detailed technical report describing the full extent of the work can be found in *"Report No 4 : (Land Use and Water Requirements): Volume 3 (Water Use and Water Requirements)"*, of the Berg WAAS series of Study Reports.

6. UPDATE OF BERG RIVER HYDROLOGY

6.1 INTRODUCTION

The objective of the catchment hydrology tasks for the Berg WAAS is to present updated hydrology for subcatchments in the study area in order to support the determination of allocable water quantification, as well as to provide model-based assessment of water resource augmentation options in support of the Western Cape Reconciliation Strategy Study. Monthly simulated runoff sequences are produced which are used in the system yield analyses relating to present and future land-use development scenarios and scheme development options.

6.2 GENERAL APPROACH

The hydrology of the Western Cape System Analysis (WCSA) (DWAF, 1990) was evaluated and updated where necessary by re-configuring and re-calibrating the existing catchment model with current day land and water use, representing the 2004 hydrological year. The general approach followed in order to generate monthly flow sequences is outlined as follows:

- Capturing and processing spatial data for use in the Pitman model including rainfall, evaporation, irrigated areas and crop types, afforested areas and alien vegetation areas, water requirements, abstractions and return flows, transfers and farm dam information.
- Subcatchment configuration informed by previous studies and availability of spatial data and observed flow gauge data.
- Calibration of the Pitman model in WRSM2000.
- Produce long-term naturalised flow sequences.

6.3 RESULTS

The streamflow gauges used for catchment calibration purposes in the Berg River catchment are shown on Figure 6-1.

A summary of the calibration results for the Berg River subcatchments is shown in **Table 6-1** and the final Pitman parameters for each subcatchment are presented in **Table 6-2**. The calibrated flows are based on longer flow records, wherever possible than in previous studies and the naturalised flow sequences (1927-2004) for the Berg River subcatchments appear to be higher for the upper to middle reaches of the Berg and lower for the lower reaches compared to previous estimates (1928-1990).

The detailed technical report describing the full extent of the work can be found in *"Report No 5 (Update of Catchment Hydrology), Volume No. 1 (Berg River)"*, of the Berg WAAS series of Study Reports.

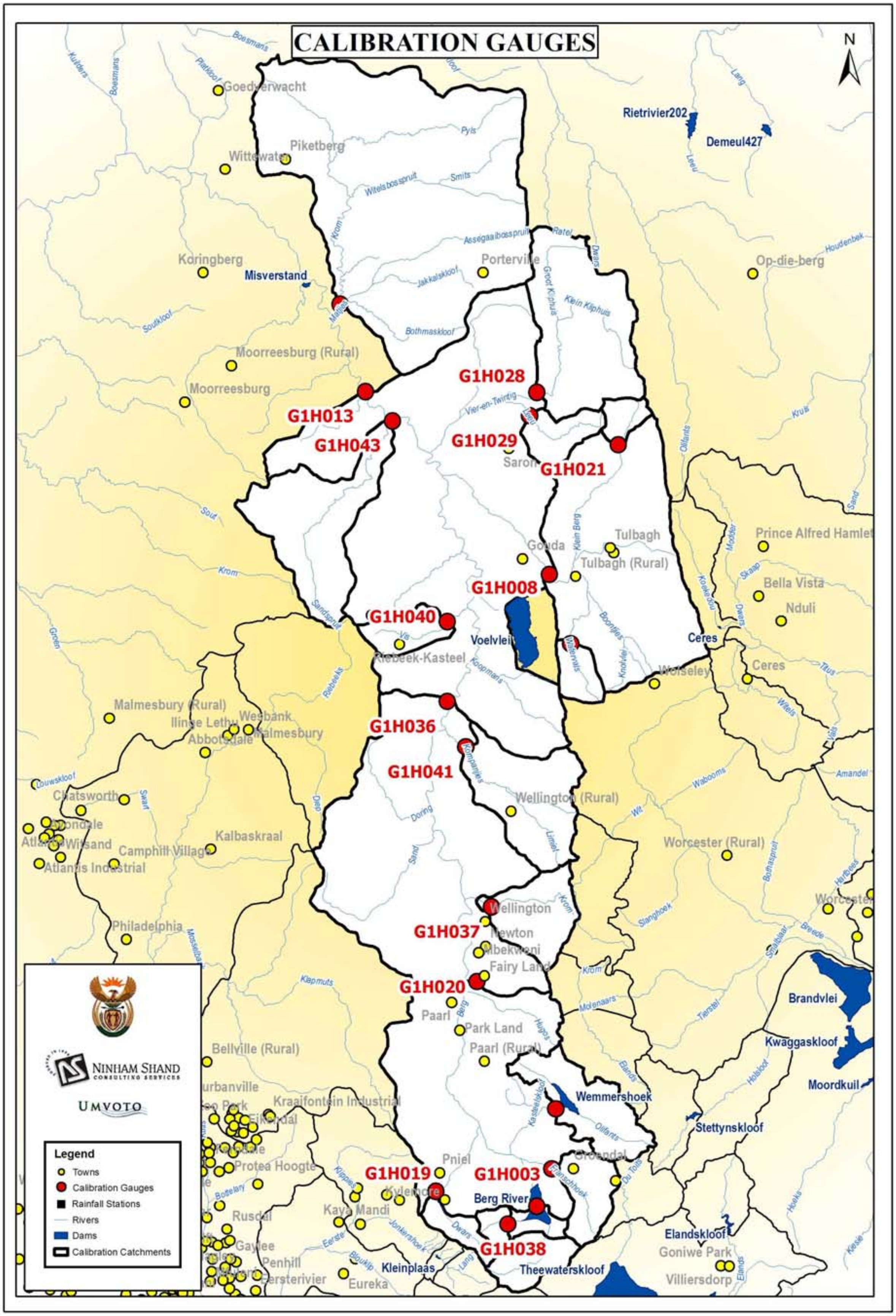

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Figure 6-1 Calibration Streamflow Gauges in the Berg River Catchment

Table 6-1 Summary of Berg River subcatchment calibration results

Flow gauge	MAP (mm)	Catchment area (km^2)	Patched observed MAR ($10^6 m^3/a$)	Calibration period	Naturalised MAR ($10^6 m^3/a$) 1927-2004	Naturalised runoff coefficient
G1H003	1114	46.2	22.1	1959-2004	24.8	48%
G1H004	2576	68.9	157.7	1980-2004	137.2	77%
G1H008	732	347.9	43.8	1967-2004	53	21%
G1H011	1100	26	13.7	1963-2004	16.1	56%
G1H013	559	797.5	72.4	1987-2004	67.9	15%
G1H019	1577	22.8	18.6	1967-2004	21.3	59%
G1H020	929	407.1	139.4	1967-2004	162.8	43%
G1H021	1200	18.6	15.1	1975-2004	17.7	79%
G1H028	1278	185.2	130.6	1971-2004	131	55%
G1H029	1138	36.2	18.9	1975-2004	21.4	52%
G1H035	404	674.2	31.6	1975-1997	32.8	12%
G1H036*	642	497.8	406.4	1979-2004	61.9	19%
G1H037	920	70	22.3	1978-1991	19.6	30%
G1H040	578	36	2.5	1979-2004	3.3	16%
G1H041	764	120.6	23.5	1979-2004	24.7	27%
G1H043	494	154.9	5.2	1979-2001	5.3	7%
G1R002	1373	85.3	77.5	1973-2004	83.4	71%

* Cumulative calibration

Table 6-2 Summary of Berg River Pitman parameters

Flow Gauge	POW	SL	ST	FT	GW	ZMIN	ZMAX	PI	TL	GL	R
G1H003	2	0	370	65	0	75	580	1.5	0.25	0	0
G1H004	2	0	100	55	0	30	170	1.5	0.25	0	0
G1H008	3	0	410	45	0	80	650	1.5	0	0	0
G1H011	3	0	130	70	0	35	250	1.5	0.5	0	0
G1H013	2	0	270	15	0	60	480	1.5	0	0	0
G1H019	2	0	205	65	0	0	420	1.5	0.25	0	0
G1H020	2	0	210	30	0	50	500	1.5	0	0	0
G1H021	2	0	100	65	0	0	175	1.5	0.99	0	0
G1H028	1	0	215	40	0	0	450	1.5	0.4	0	0
G1H029	2	0	180	40	0	0	340	1.5	0.25	0	0
G1H035	2	0	195	10	0	30	350	1.5	0	0	0
G1H036	2	0	315	25	0	50	650	1.5	0	0	0
G1H037	2	0	350	35	0	55	600	1.5	0	0	0
G1H040	2	0	235	7	0	30	650	1.5	0	0	0
G1H041	2	0	245	12	0	65	560	1.5	0	0	0
G1H043	3	0	270	5	0	100	600	1.5	0	0	0
G1R002	2	0	120	75	0	0	200	1.5	0.5	0	0

7. UPDATE OF UPPER BREEDE RIVER HYDROLOGY

7.1 GENERAL APPROACH

The hydrology of previous studies, i.e. the Breede River Basin Study (BRBS) (DWAF, 2002) was evaluated and updated where necessary by re-configuring and re-calibrating the existing catchment model with present-day land and water use. The Upper Breede River is defined as the catchment of the Breede River to Brandvlei Dam at flow gauge H4H006. The general approach followed in order to generate monthly flow sequences is outlined as follows:

- Capturing and processing spatial data for use in the Pitman model including rainfall, evaporation, irrigated areas and crop types, afforested areas and alien vegetation areas, water requirements, abstractions and return flows, transfers and farm dam information.
- Subcatchment configuration informed by previous studies and availability of spatial data and observed flow gauge data.
- Calibration of the Pitman model in WRSM2000.
- Produce long-term naturalised flow sequences.

7.2 RESULTS

The streamflow gauges used for catchment calibration purposes in the Upper Breede River catchment are shown on Figure 7-1.

A summary of the calibration results for the Upper Breede River subcatchments is shown in **Table 7-1** and the final Pitman parameters for each subcatchment are presented in **Table 7-2**. An acceptable calibration at flow gauge H4H006 was not possible due to the low accuracy rating of the flow gauge at this location. Therefore, the final Pitman parameters from the BRBS for catchment H4H017 were transferred to this catchment in order to generate naturalised and present-day flows for the WRYM.

The calibrated flows are based on longer flow records, wherever possible, than in previous studies and the naturalised flows (1927-2004) for the Upper Breede River subcatchments compare reasonably well (within about 10%) of the BRBS figures for subcatchments H1H006, H1H007 and H1H013. The incremental naturalised flows in subcatchments H1H003 and H1H018 are considerably lower than in the previous study, and there are no comparable flows for the rest of the catchment to H4H006.

The detailed technical report describing the full extent of the work can be found in *"Report No 5 (Update of Catchment Hydrology), Volume No. 2 (Upper Breede River)"*, of the Berg WAAS series of Study Reports.

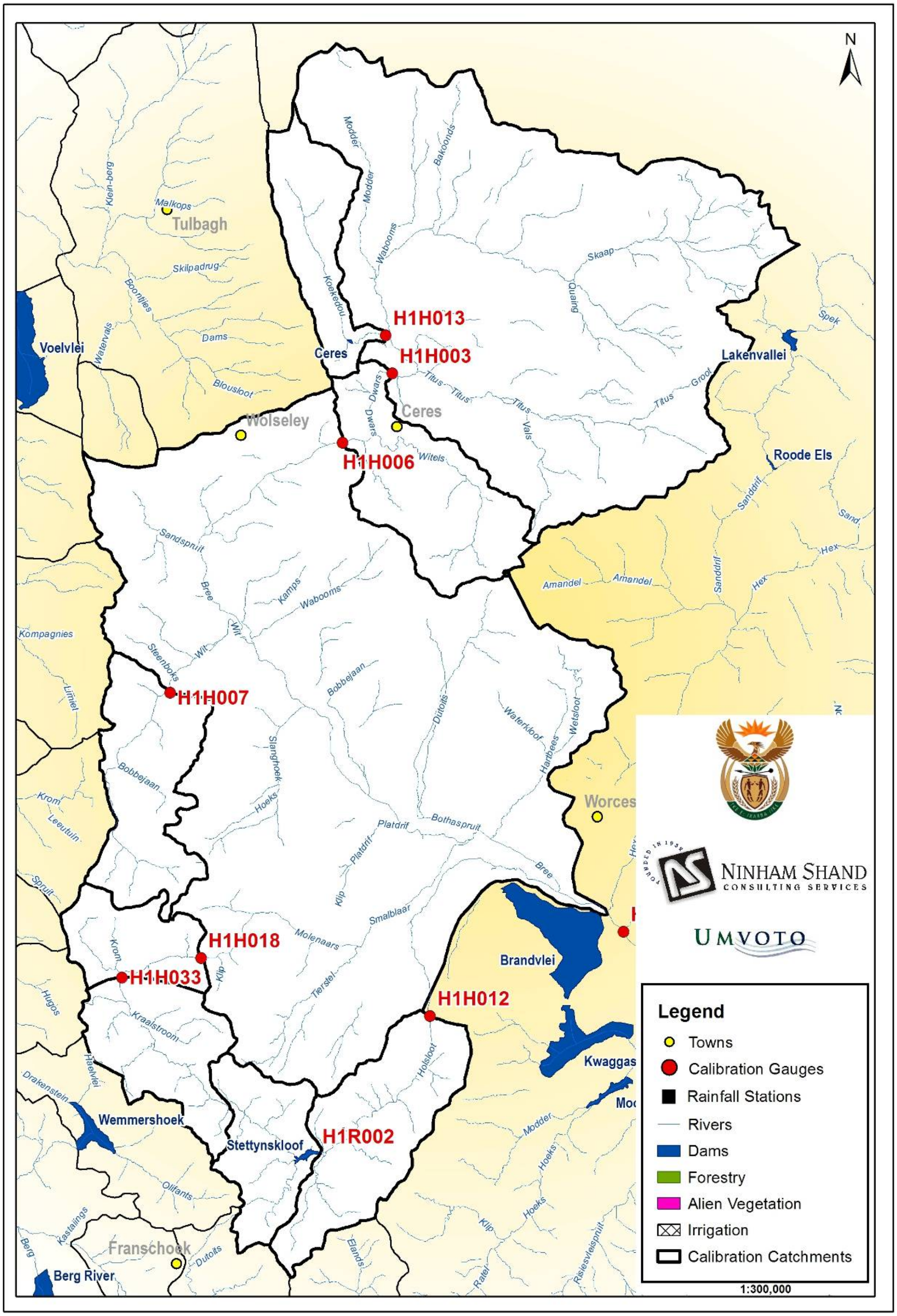

Figure 7-1 Calibration Streamflow Gauges in the Upper Breede River Catchment

Table 7-1 Summary of the Upper Breede River subcatchment calibration results

Flow gauge	MAP (mm)	Catchment area (km^2)	Patched observed MAR ($10^6 m^3/a$)	Calibration period	Naturalised MAR ($10^6 m^3/a$) 1927-2004	Naturalised runoff coefficient
H1H003	732	592.3	63.5	1964 - 2004	81.8	19%
H1H006	2300	96.5	136.4	1964 - 2004	150.2	68%
H1H007	2080	85.5	126.8	1961 - 2004	131.7	74%
H1H012	1187	151.8	71.9	1963 - 1974	98.8	55%
H1H013	1042	53	22.6	1964 - 1997	34.2	62%
H1H018	1945	44.3	68.6	1991 - 2004	62.4	72%
H1H033	1945	68.4	97.5	1991 - 2004	86.8	65%
H4H006	863	875.4	62.8	1980 – 1989	215.0	26%

Table 7-2 Summary of the Upper Breede River final Pitman parameters

Flow Gauge	POW	SL	ST	FT	GW	ZMIN	ZMAX	PI	TL	GL	R
H1H003	2	0	650	21	0	0	550	1.5	0.25	0	0
H1H006	2	0	200	50	0	100	400	1.5	0.25	0	0
H1H007	2	0	150	90	0	0	250	0	0.2	0	0
H1H012	2	0	400	80	0	0	400	1.5	0	0	0
H1H013	2	0	100	55	0	0	200	1.5	0.99	0	0
H1H018	2	0	250	50	0	0	200	1.5	0.5	0	0
H1H033	2	0	250	20	0	0	300	1.5	0	0	0
H4H006*	2	0	300	4	0	100	900	1.5	0	0	0

* Parameters transferred from H4H017 in BRBS

8. UPDATE OF HYDROLOGY OF PERIPHERAL RIVERS

8.1 RESULTS

The streamflow gauges used for catchment calibration purposes in the catchments of the peripheral rivers are shown in Figure 8-1.

A summary of the calibration results is shown in **Table 8-1** and the final Pitman parameters for each subcatchment are presented in **Table 8-2**.

Table 8-1 Summary of Peripheral Rivers calibration results

Basin	Flow gauge	MAP (mm)	Catchment area (km^2)	Patched observed MAR ($10^6m^3/a$)	Calibration period	Naturalised MAR ($10^6m^3/a$) 1927-2004	Naturalised runoff coefficient
Diep	G2H012	546	245.8	11.1	1964-2004	13.6	10%
Diep	G2H013	521	471.5	20.5	1965-1985	30.4	12%
Diep	G2H014*	350	1391.8	44.6	1966-1981	63.2	13%
Diep	G2H042	369	586.6	39.4	1998-2004	25	12%
Eerste	G2H015*	844	333.2	104.1	1967-1976	120.4	42%
Lourens	G2H016	1124	92.3	44.4	1969-1990	48.2	46%
Eerste	G2H020	873	147	21	1980-2004	37.8	29%
Eerste	G2H037	1900	24	22.3	1988-2004	25.7	56%
Palmiet	G4H005	1073	83	41.6	1978-1997	49.9	56%
Palmiet	G4H007	925	319.3	141.7	1987-2004	146.1	48%
Steenbras	G4R001	1169	60.5	44.8	1927-1987	46.6	66%
Palmiet	G4R002	1671	65.3	54.9	1978-1997	54.6	50%
Riviersonderend	H6H007	1455	46	39.5	1963-1991	38.6	58%
Riviersonderend	H6H008	2320	39.1	63.9	1963-1991	63.2	70%
Riviersonderend	H6R001*	1099	441.2	316	1987-2004	354.5	73%
Riviersonderend	H6R002	1042	49.9	22	1979-2004	22.1	43%

* Cumulative calibration

The detailed technical report describing the full extent of the work can be found in *"Report No 5 (Update of Catchment Hydrology), Volume No. 3 (Peripheral Rivers)"*, of the Berg WAAS series of Study Reports.

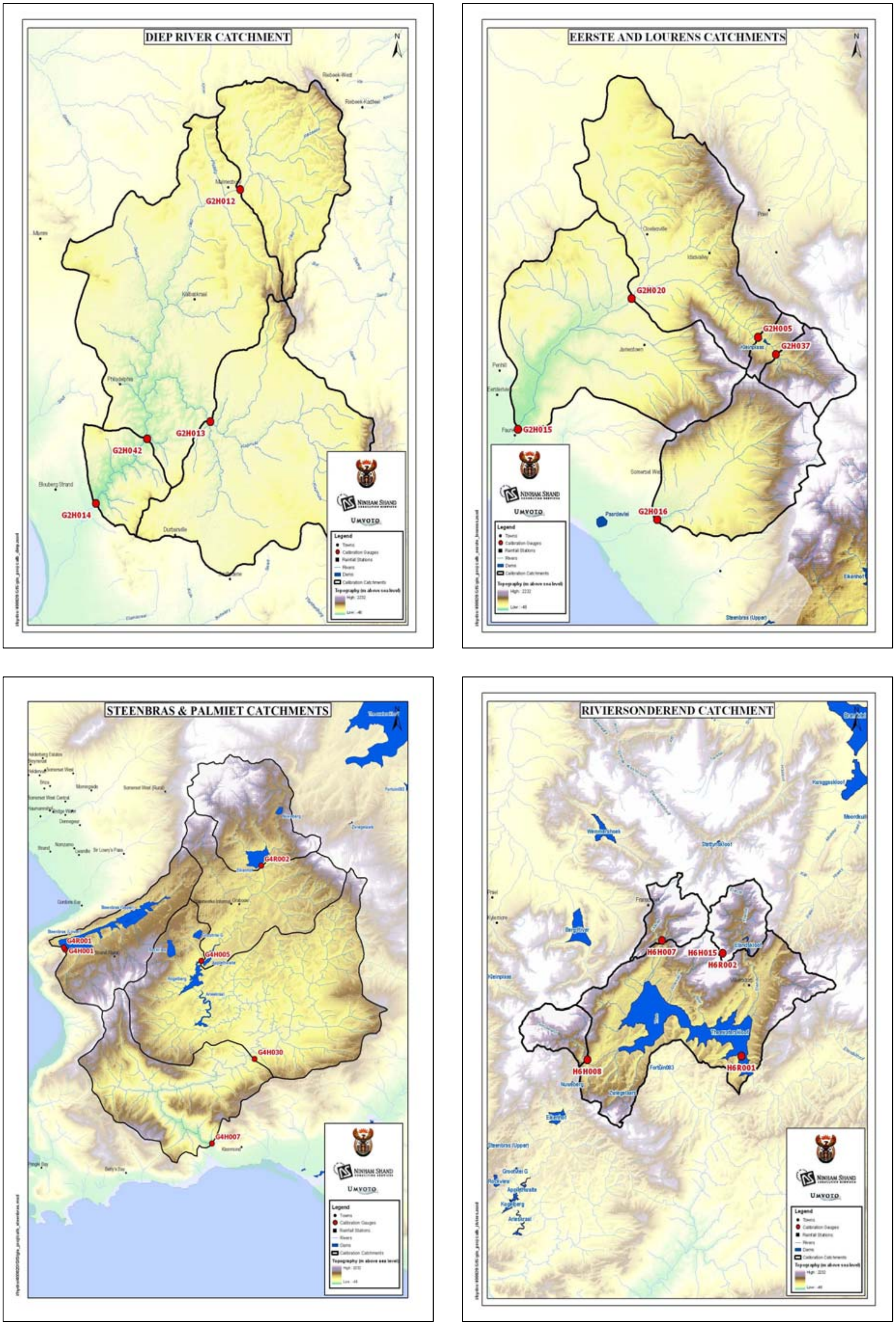

Figure 8-1 Calibration Streamflow Gauges in the Catchments of the Peripheral Rivers

Table 8-2 Summary of Peripheral Rivers final Pitman parameters

Flow Gauge	POW	SL	ST	FT	GW	ZMIN	ZMAX	PI	TL	GL	R
G2H012	2	0	285	5	0	85	500	1.5	0.2	0	0
G2H013	2	0	220	5	0	40	500	1.5	0	0	0
G2H014	2	0	500	1	0	100	750	1.5	0	0	0
G2H042	2	0	230	24	0	60	475	1.5	0	0	0
G2H015	2	0	250	65	0	20	500	1.5	0	0	0
G2H016	2	0	260	60	0	50	650	1.5	0	0	0
G2H020 High	2	0	320	35	0	35	600	1.5	0	0	0
G2H020 Low	2	0	400	35	0	40	700	1.5	0	0	0
G2H037	2	0	340	15	0	50	650	1.5	0.15	0	0
G4H005	2	0	120	60	0	35	280	1.5	0.25	0	0
G4H007	2	0	150	45	0	0	300	1.5	0.35	0	0
G4R001	2	0	150	80	0	0	180	1.5	0.25	0	0
G4R002	2	0	510	35	0	0	800	1.5	0	0	0
H6H007	2	0	400	99	0	0	500	1.5	0	0	0
H6H008	2	0	400	30	0	0	200	1.5	0.25	0	0
H6R001	2	0	100	75	0	0	165	1.5	0.25	0	0
H6R002	2	0	375	50	0	0	500	1.5	0	0	0

The calibrated flows in the Berg WAAS are based on longer flow records wherever possible, than in previous studies and naturalised flows have been generated for a 78-year period which extends the previous naturalised flow sequences by ten years. In the Diep River catchment, the cumulative naturalised flow sequences for the current study are higher overall by 41% than in the WCSA. In the Eerste and Lourens catchments, the cumulative naturalised flows on the Eerste River are lower overall by 11% and on the Lourens, higher overall by 12% than in the WCSA. In the Palmiet and Steenbras catchments, the cumulative naturalised flows on the Palmiet River compare favourably with the previous study and are only 5% lower overall. Flows in the Steenbras catchment are 8% lower than in the WCSA. Finally, in the Riviersonderend catchment, the cumulative naturalised inflows to the Theewaterskloof Dam are 24% higher than in the WCSA.

9. OVERVIEW OF WATER QUALITY IN THE BERG WMA

9.1 INTRODUCTION

Water quality in the Berg WMA, varies not only between the individual river basins but also within individual river systems. The natural geology, agricultural practises and point source polluters all play a role in determining the quality of water in this WMA. Water quality management in the Berg WMA should aim to address the problems associated with water quality and to recommend steps that can be taken to improve the quality where problems currently exist.

Although the CCT's recreational waters are generally considered safe for contact recreation, water quality in many of the major watercourses is of concern. This could be attributed primarily to rapid urbanization and capacity constraints on both water services and waste management infrastructure and services. Closer co-operation at a strategic level between those responsible for management of all three sectors of the urban water cycle (water supply, wastewater, stormwater) in accordance with the principles of integrated urban water management is required to effect change in this regard.

9.2 GOVERNANCE

Certain wastewater treatment works within the Berg Water Management Area are not treating their sewerage to the quality standards required under their authorisations. Co-operative governance between the Department of Water Affairs and municipalities (local authorities) must be focussed on this problem, to ensure that the local authorities accept responsibility for the quality of effluent from all wastewater treatment works in their areas of jurisdiction.

9.3 FACTORS INFLUENCING DETERIORATING WATER QUALITY

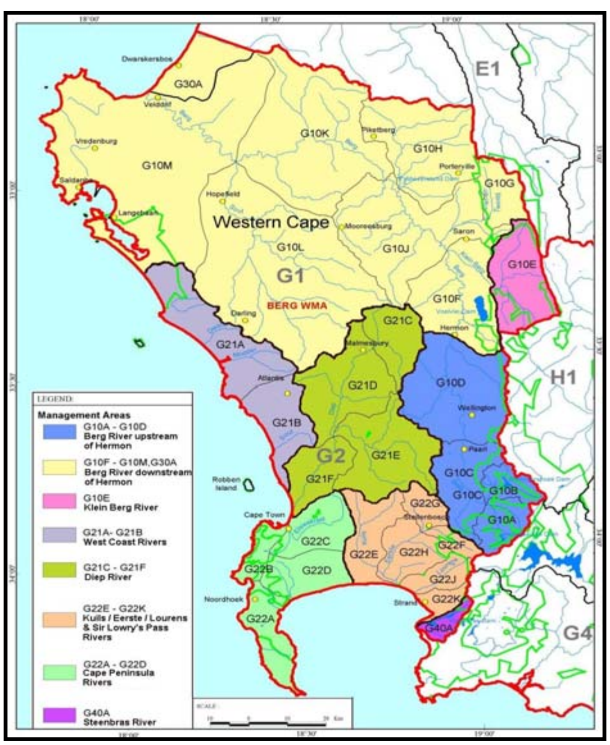

Figure 9-1 Berg WMA - Sub-catchment areas

Most of the rivers in the water management area rise from the Table Mountain Group mountain catchments which provide very good quality water with total dissolved solids concentrations of less than 60 mg/l.

The quality of water however, generally deteriorates further downstream as follows:

- The upper reaches of the Berg River has remained unpolluted.

- The water quality in the Berg River and the lower reaches of the tributaries have shown substantial declines which could be attributed to increased organic loading rates (wastewater discharges) to the river between Paarl and Wellington, agricultural return flows, urban and industrial runoff and irrigation releases from Voëlvlei Dam during summer, resulting in increases in conductivity during that period.
- In the Upper Middle Berg area, which corresponds largely to the southern portion of the Drakenstein Municipal Area, the water quality of the Berg River has been severely impacted as a result of agricultural activities (coupled with river modification, water abstraction and runoff of pollutants) and general urban development.
- In the Lower Middle Berg area, which corresponds mainly to the northern part of the Drakenstein Municipal Area (north of Hermon), the water quality has been severely affected by diversion weirs which resulted in disruption of flow patterns in the Klein Berg and Vier-en-Twintig Rivers, and as a result of agricultural activities (largely the building of flood-protection levees and the use of pesticides).

The middle reaches of the Berg River receive effluent from various wastewater treatment works as well as agricultural return flows and occasionally high salinity runoff from tributaries underlain by Malmesbury shales of marine origin. This has resulted in water quality problems in the lower Berg River. Industrial users (steel manufacturers) in the Saldanha area need to pre-treat this water before being able to utilise it in their industrial processes. Irrigators are limited to the types of crops they can cultivate, due to increased salinity levels.

Effluent return flows and stormwater washoff from Stellenbosch enters the Eerste River. This will have an impact on the costs associated with treating water if the Eerste River Diversion scheme is ever implemented.

Runoff in the lower reaches of the Diep River arising from the Malmesbury formation is also saline and wastewater is discharged into the river from two of the City of Cape Town's wastewater treatment works. The Rietvlei wetland, a highly valued ecosystem, receives treated effluent being discharged from wastewater treatment works and the potential impacts are of particular concern with respect to water quality.

The Lourens River, most of the Peninsula rivers, the Cape Flats rivers and vleis have been impacted by urban runoff. The Kuils River and Salt River are also impacted by large, wastewater return flows that have changed these seasonal rivers into perennial rivers. These urban rivers cannot be rehabilitated but their condition must at least be maintained at levels that will not introduce social, health and aesthetic problems.

The detailed technical report describing the full extent of the work can be found in *"Report No 6 (Water Quality), Volume No. 1 (A Literature Review of Water Quality Related Studies in the Berg WMA, 1994-2006)"*, of the Berg WAAS series of Study Reports.

10. UPDATING THE BERG ACRU SALINITY MODEL

10.1 INTRODUCTION

The daily ACRU*Salinity* model for the Berg River was previously configured under the WRC project no. K5/1301 entitled "Improvements to the ACRU*Salinity* Model and Upgrading of the Berg River Water Quality Information System". In the aforementioned study the model was configured for the river reach between gauging stations G1H020 (Paarl) and G1R003 (Misverstand Dam).

Further extension to the catchment area configured in the model was undertaken as part of the West Coast Study commissioned by the Department of Water Affairs and Forestry (DWAF) (DWAF, 2006). In this study, the model configuration was extended from the gauging station G1R003 (Misverstand Dam) to the head of the estuary.

The objective of this component of the study was to configure an up-to-date calibrated ACRU*Salinity* model that could be used as a water resource management tool in the Berg River Catchment. Specific aims required to meet the objective were as follows:

- Extend the daily rainfall and observed streamflow records for use in verification
- Produce naturalised flows to be compared the Pitman-based monthly flows
- Enable quantification of salt loads from the dryland portions of the catchment
- Configuration of the upper Berg catchment in ACRU*Salinity*
- To combine the loosely coupled models of the Berg into one configuration.

10.2 RESULTS

In this component of the study no further adjustment of the flow-related parameters were required after extension of the calibration periods and resulted only in extended rainfall and observed flow records.

An ACRU*Salinity* configuration for generating natural flows was, however, prepared using the Acocks (Acocks, 1975) veld types. The output from this simulation compared to those from previous studies is presented in the detailed technical report describing the full extent of the work, found in *"Report No 6 (Water Quality), Volume No. 2 (Updating of the ACRUSalinity Model for the Berg River)"* of the Berg WAAS series of Study Reports.

Table 10-1 A comparison of simulated naturalised flows from selected studies

Gauge	WR 90 MAR ($10^6 m^3$) (1920 – 1989)	WCSA MAR ($10^6 m^3$) (1926 -1988)	ACRU MAR ($10^6 m^3$) (1921-1999)	WR2005 ($10^6 m^3$) (1920 -2004)
G1H020	412	384	403	329
G1H036	528	521	493	453
G1H013	Approx 782	871	789	Approx 615
G1R003	825	904	832	728
Head of Estuary	895	Not calculated	914	738

11. UPDATING THE MONTHLY FLOSAL MODEL TO WQT

11.1 INTRODUCTION

The water quality model (WQT) is a monthly time-step model describing salt generation, accumulation and transport in the catchment, using parameters with physical meaning to simulate catchment salt wash-off and the effects of irrigation and impoundments. The model developed to integrate with the Water Resources Planning Model (WRPM), is defined as a network of routes connecting a variety of node types or sub-model elements, each node or feature representing a specific feature in water quality modeling.

Calibration of the WQT model takes place by iteratively calibrating the model parameters until the simulated TDS loads and/or concentrations match the corresponding observations as closely as possible at calibration points (water quality and flow gauging sites) in the system. The parameters governing the salt wash-off and irrigation sub-models are calibrated in particular, these being the two most active elements in accumulating and releasing TDS in the catchment.

For this component of the Berg WAAS the WQT model was configured from the origin of the Berg River to the gauging station G1R003 (Misverstand Dam).

11.2 RESULTS

The WQT model was calibrated at nine gauging stations. A summary of results is presented in **Table 11-1**. The detailed technical report describing the full extent of the work can be found in *"Report No 6 (Water Quality), Volume No. 3 (Update of Monthly FLOSAL Model to WQT)"*, of the Berg WAAS series of Study Reports.

Table 11-1 WQT Calibration Results

Gauge		Flow ($10^6 m^3$/month)		Concentration (mg/l)		Load (ton/month)	
		Observed	Simulated	Observed	Simulated	Observed	Simulated
G1H020	Mean	28.91	25.40	59.74	90.07	1612	1662
	Std. Dev.	35.13	30.80	14.68	30.80	1958	2056
G1H037	Mean	2.13	2.17	103.9	176.90	169	175
	Std. Dev.	2.32	2.92	58.6	121.8	219	234
G1H041	Mean	2.13	2.17	103.90	176.99	169	174
	Std. Dev.	2.32	2.92	58.60	121.77	219	234
G1H036	Mean	35.32	35.39	112.93	214.33	3719	4080
	Std. Dev.	46.37	45.26	38.56	146.23	5073	5276
G1H008	Mean	5.70	7.14	107.23	121.80	595	696
	Std. Dev.	8.26	10.40	34.98	28.34	900	808
G1H043	Mean	0.45	0.59	2003	3109	1222	1451
	Std. Dev.	1.26	0.92	2452	1324	3067	2394
G1H013	Mean	49.76	45.28	148.69	503.58	7919	8618
	Std. Dev.	67.61	61.80	59.04	579.11	11592	12902
G1H035	Mean	3.93	3.20	1566	3311	5630	5607
	Std. Dev.	10.40	5.32	1055	2810	15924	8493
G1R003	Mean	Not calculated	48.72	Not calculated	995	Not calculated	14072
	Std. Dev.		66.8		1732		20189

12. SYSTEM ANALYSIS STATUS

12.1 INTRODUCTION

The purpose of this Berg WAAS System Analysis Status task is to present the verification of the hydrology and the updated system model for the Western Cape Water Supply System (WCWSS). This will be taken forward for use in current and future water resource availability assessments of the system (or parts thereof). For example, the study to undertake pre-feasibility and feasibility studies of six potential surface water development options in the Western Cape will utilize these updated models during the detailed assessments of the schemes.

The incorporation of the updated Berg WAAS hydrology into the system model for the Western Cape System Configuration represented the last opportunity (under the Berg WAAS) to check and, if necessary modify, the streamflows prior to their incorporation and use in the modelling of the yields of the Western Cape Water Supply System. During the determination of the hydrology a number of factors were identified that required further investigation to address anomalies. Furthermore, the updated yield estimates were also compared with those from the original Western Cape System Analysis (1990s) to identify and explain any notable discrepancies between the two sets of results.

12.2 KEY OUTCOMES

The outcomes of the above investigations were that a number of modifications to the updated hydrology were deemed necessary in order to ensure confidence in the final outcomes. These modifications included the following:

- Farm dam volumes were re-evaluated.
- The crop types were refined, for instance by differentiating between table and wine grapes.
- The irrigation water requirements were calculated using the ""Original WRSM Method" as the WQT method, which was used originally, did not work in high-rainfall winter-rainfall areas.
- The following streamflows were corrected / adjusted:
    - Theewaterskloof (H6R001)
    - Hermon (G1H036)
    - Drieheuwels (G1H013)
    - Campanula (G4H030)
- The rainfall stations used for a number of catchments were changed to improve the calibrations obtained at the following flow gauges:
    - Driefontein (G1H004)
    - Wemmershoek (G1R002)
    - Hermon (G1H036)
    - Drieheuwels (G1H013)
    - Campanula (G4H030)

The hydrological analysis identified some key streamflow gauges and flow meters that should be checked as a matter of priority, namely:

- The transfers from Theewaterskloof Dam into the tunnel and the transfers to Kleinplaas Dam
- Streamflow gauge G1H036
- Streamflow gauge G1H013

It should be noted that the streamflow gauge record at G4H030 was also found to be problematic, but the rating curve was checked and corrected during the analysis period.

12.3 INCORPORATING THE GROUNDWATER / SURFACE WATER INTERACTION

One of the goals of the Berg WAAS was to model the groundwater / surface water interaction, specifically the conjunctive use of the Table Mountain Group aquifer and the Breede River Alluvium. Details describing the incorporation of these features into the WRYM have also been included.

The Western Cape System WRYM configuration was updated to incorporate the refinements of the current study including groundwater / surface water interaction, additional farm dams and modifications to the system operating rules. The updated hydrology for the Berg, Riviersonderend and Palmiet catchments was imported to the modified configuration and run in the Water Resources Information Management System version of the yield model. **Table 12-1** below presents a summary of the historical firm yield obtained for individual system components as well as for the integrated system, and also the change in natural incremental MAR for the components of the hydrology that were revised as part of the yield modelling analysis.

Table 12-1 Comparison of Revisions of Historical Firm Yield and MARs

Component	Historical Firm Yield (HFY)	WAAS Post-review HFY	% Change
	(million m³/a)		
Theewaterskloof / Kleinplaas	197	219	11%
Voëlvlei	94	88	-6%
Wemmershoek	47	49	4%
Steenbras	37	36	-3%
Palmiet	20	19	-5%
Berg River Dam	77	67	-13%
Berg River Supplement	22	20	-9%
Wemmershoek Exchange	32	32	0%
Summer streamflows at Siphon			
Kleinplaas compensation			
Riviersonderend Compensation			
Winter abstraction from the Berg River	5	5	
Total of sub-systems	529	535	1%
Additional yield from integrating sub-systems	20	15	-25%
Total System Yield	**549**	**550**	**+1%**
	(million m³/a)		
Driefontein G1H004 (incremental)	105	112	7%
Hermon G1H036 (incremental)	136	126	-8%
Drieheuwels G1H013 (incremental)	127	100	-21%
Campanula (cumulative)	73.6	81	10%

A number of refinements will be included in the WRYM tasks of the Western Cape Pre-feasibility and Feasibility Studies of potential surface water development options, currently being undertaken. These enhancements will include:

- Incorporating the updated environmental streamflow requirements for the rivers and estuaries;
- The updated diversion at the Berg River Supplement Scheme, incorporating the latest reserve environmental water requirements;
- The development of a refined diversion function at Kleinplaas Dam. This will take into account the actual spillage occurring at the dam, so as to confirm the annual volumes of water than can be abstracted from it.
- Evapotranspiration losses in the Lower Berg River;
- Incorporating the most viable development options from the outcomes of the preliminary assessment of the Western Cape Pre-feasibility and Feasibility Studies. The six schemes being assessed as part of the preliminary assessment are:
    - Voëlvlei Augmentation Phase 1 (from Berg River);
    - Voëlvlei Augmentation Phase 2 (from Berg River);
    - Upper Wit River Diversion (Breede River);
    - Michell's Pass Diversion (Breede River);
    - Upper Molenaars River Diversion (Breede River);
    - Augmentation of the Steenbras dams (Steenbras and Palmiet rivers), including the potential Campanula Dam on the Palmiet River.
- The evaporation from Theewaterskloof and Voëlvlei dams will be set equal to the average evaporation over a three year drought period.

The detailed technical report describing the full extent of the work can be found in "*Report No 8 : System Analysis Status Report",* of the Berg WAAS series of Study Reports.

13. OVERVIEW OF GROUNDWATER MODELLING: METHODOLODY AND RESULTS

Table 13-1 lists the key groundwater task deliverables for the Berg WAAS and the corresponding Volumes comprising the **Report Set No.9** (Groundwater Models).

Table 13-1 Key Groundwater Deliverables

Key Deliverable	Vol No.	Volume Title
GIS database for groundwater component	2	Data Availability and Evaluation
Digitise Geological Maps		
Regional model development	3	Regional Conceptual Model
Conceptual model for study domain		
GIS based water balance model for study domain	4	Regional Water Balance Model
Water balance and storage model for TMG Aquifer(s)		
Configuration of a numerical model for Cape Flats Aquifer	5	Cape Flats Aquifer Model
Quantification of surface water – groundwater interaction		
Calibration of recharge estimation and water balance		
Scenario for augmentation to bulk water supply to Cape Town (as support of Western Cape Reconciliation Study)		
Scenario for flood management (as support of Western Cape Reconciliation Study)		
Review and update conceptual model for West Coast Aquifers and Configure a numerical groundwater model for Langebaan Road Aquifer	6	Langebaan Road Aquifer and Elandsfontein Aquifer Model
Review and revise recharge and yield estimation as well as water balance		
Refine understanding and Quantify surface water – groundwater interaction		
Scenario for artificial recharge schemes (support to Western Cape Reconciliation Study)		
Configuration of a numerical TMG groundwater model for Piketberg	7	Table Mountain Group Aquifers – Piketberg area
Configuration of a numerical TMG groundwater model for Tulbagh - Ceres	8	Table Mountain Group Aquifers – Witzenberg - Nuy area
Configuration of a numerical TMG groundwater model for Hex River Mountains		
Refinement of recharge and yield estimation as well as water balance on regional scale	7 & 8	As above
Configuration of a numerical TMG groundwater model for Worcester	9	Breede River Alluvium Model
Quantification of surface water groundwater interaction		

13.1 SUMMARY OF KEY FINDINGS AND RESULTS

13.1.1 Conceptual model – IWRM domains

An aquifer-specific conceptual model across the study area was developed with the aim to generate a three-dimensional (3D) view of the aquifer geometry, hydraulic properties and preferred flow paths, and to identify zones of surface water / groundwater interaction and interaction between aquifers. To meet one of the core requirement of the study, viz. to understand and map surface and groundwater interaction and to quantify it as far as possible, to be able to integrate groundwater into the Pitman and the WRYM models, the groundwater study boundaries were defined by areas called Integrated Water Resource Management Domains (IWRM Domains).

13.1.2 Water availability

The water balance and yield model suggests a total remaining groundwater potential of 869 million m^3/a within the study area (see **Table 13-2**). 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. 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.

Table 13-2 Summary results of groundwater potential per aquifer for study area

Aquifer	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
	(million m^3/a)				
Intergranular	355	41.1	314	92.6	222
Intergranular fractured	267	39.2	228	58.4	170
Fractured	8.0	0.7	7.3	0.6	6.7
Nardouw	226	46.2	180	20.6	159
Peninsula	390	69.7	320	8.6	312
Total	1247	197	1050	181	869

13.1.3 Over allocated catchments

The intergranular aquifer is the most developed and utilised across the study domain. The following areas are of concern (refer to **Table 13-3**):

- Over allocation of groundwater from the intergranular aquifer at least in the Hex River IWRM domains;
- Very high groundwater use (> 50% of Recharge – Base flow) in the Brandvlei, Nuy and Warm Bokkeveld IWRM domains;
- High groundwater allocation (> 20% of Recharge – Base flow) in the 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.

Table 13-3 Estimated groundwater potential and over allocation of groundwater in selected quaternary catchments

Quaternary Catchment	Peninsula	Nardouw	Intergranular-fractured	Intergranular	Total Groundwater Potential
	(million m^3/a)				
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

13.1.4 Yield not function of recharge

Under natural conditions and on a time-scale of centuries, aquifers evolve towards a state of dynamic equilibrium in which wet years, when recharge exceeds discharge, are offset by dry years, when discharge exceeds recharge. Development of and abstraction from groundwater wells upsets this natural equilibrium by inducing a loss from aquifer storage and an approach to a new state of dynamic equilibrium when there is no further loss or minimal loss from storage. The new equilibrium is accomplished either by an increase in recharge, a decrease in natural discharge, or a combination of the two, in other words, by capture.

13.1.5 Dynamic storage

A dynamic storage model was developed, which provides annual base flow sequences for each of the different abstraction scenarios in the WRYM. The spreadsheet model is based on the understanding of the TMG Aquifer behaviour and considers the potential impact of temporal variation in rainfall and abstractions in the TMG Aquifer system having time lags of a number of years on this base flow. The fluctuation in hydraulic head was calibrated against the available data and detailed groundwater model results.

13.1.6 Integration with WRYM

The second outcome of the dynamic storage model is an annual sequence of base flow that is used in the WRYM to refine the initial estimates of the contribution to the yield from groundwater. Pumping groundwater into dams might maximize the yield but could result in unnecessary spillage during wet periods, if conveyed via the existing dam infrastructure. Different operating rules for maximizing the yield and minimizing the pumping from the groundwater were investigated. For the scenario of intermittent groundwater abstraction during dryer periods, the yield increase is about twice the average abstraction from groundwater.

13.2 MODEL APPROACH

Based on the lessons learned, the recommended approach to modelling follows discrete steps to allow for an increasing level of confidence during the process, while the scale of investigation is refined from regional / basin scale to local wellfield and borehole scale. The main elements of this approach are:

- Good conceptual models are tested numerically to design and detail monitoring networks;
- Simple box and/or other storage models are constructed as being most cost-effective for aquifer-specific reconnaissance level;
- 3D aquifer-specific flow models are established for preliminary resource evaluation and assessment of impact of abstraction on surface water regime and existing lawful use;
- Transient (4D space-time) wellfield models to evaluate wellfield design and management scenarios for all commercial or urban use.

As summarised in the following sections of this report, an iterative approach is proposed, as the models are updated with new and more detailed data and information while the scale of investigation gets more detailed.

The greatest error in groundwater resource evaluation and prediction of impacts on surface water and the environment is in unwarranted reduction of a 4D problem to 1D or 2D. To quantify a process in 2D it is necessary to have a 3D conceptual model and insight into the long term temporal patterns.

To quantify in 3D (numerical models) it is necessary to have a physically real and verifiable insight into the likely variations in volumes, area and, at least the range in, expected seasonal variations and other factors that could influence this. A rule of thumb is that one can predict future behaviour of a system for double the number of years that one has data available, provided one clearly understands (even conceptually) the spatial detail and temporal pattern that is mapped by that data.

The recommended approach relies on three critical aspects, viz.

- data collection at appropriate spatial position and frequency intervals relevant to the decisions to be taken;
- team interaction between surface water and groundwater specialists that have the necessary skills and knowledge of the earth and water processes, and good communication between the disciplines; and
- timely implementation of relevant monitoring infrastructure and model upgrade.

The applicability and outcome of these models are summarised in **Table 13-4** with reference to the objectives of this study, i.e. water resource evaluation and compulsory licensing.

Table 13-4 Applicability and outcome of the various models

	Conceptual Model	Water Balance Model	Numerical flow model	Wellfield model
General (applicable to all themes)				
Design of 2D & numerical models	X			
Design of monitoring networks	X		Refinement	
Evaluation & Assessment of data	X			
Evaluation & Assessment of Model Results	X			
Water Resource Evaluation				
First order ‘planning’ numbers		X		
First order impact assessment,		X		
First Order loss/gain to rivers to update WRYM			X	
Operational yield assessment			X	X
Rapid Reserve determination		X	X	
Compulsory Licensing (requires Water Resource Evaluation)				
Intermediate or comprehensive Reserve determination			X	X
Aquifer yield estimate for license (not of borehole)			X	
Estimate of impact of surface water usage on groundwater in storage			X	
Estimate of impact of groundwater abstraction on surface water flow			X	
Wellfield / Borehole licensing				X
Conjunctive Scheme Development (requires Water Resource Evaluation and Licensing)				
Scheme Concept & Design	X		X	X
Scenario testing for (conjunctive) scheme options			X	
Wellfield management				X

In order to facilitate the upgrade of models and further studies, the recommendations are grouped into activity groups and structured according to priorities and logical sequence of activities:

- Data Acquisition and Database Compilation.
- Design and Implementation of Monitoring Network.
- Ongoing Monitoring.
- Data Analysis and Interpretation.
- Modelling.
- Review and Revision.

The detailed technical report describing the full extent of the work can be found in *“Groundwater Model Report Volume 1 – Overview of methodology and Results”,* of the Berg WAAS series of Study Reports.

14. GROUNDWATER DATA AVAILABILITY AND EVALUATION

14.1 INTRODUCTION

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. The evaluation and availability of data for use in the models is described hereafter and have informed the conceptual model, which in turn informs the selection of data for model input and calibration.

14.2 DATA SETS

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

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

14.2.1 Topography

The 20 m Digital Elevation Model (DEM) was purchased for this project and this level of detail is considered adequate for use in supporting the groundwater tasks.

14.2.2 Hydrology

Catchments

Current surface water catchment areas are defined by hydrological divides or watersheds. However, surface and groundwater catchment areas may not coincide and there is not a formally accepted delineation of how, in the IWRM context, these differences can be addressed when establishing a water balance for any one quaternary catchment. The delineation of IWRM domains for use as model domains for this study is addressed in Section 15, describing the Regional Conceptual Model.

River flow and water level

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

There are a number of rivers in which no flow gauges are available. Data from existing flow gauges was used in model calibration for those quaternary catchments without gauging stations.

Geometry and geological context of surface water bodies

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

Run-off

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

Baseflow

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

In the fold terrain of the Western Cape it is unlikely that the aquifer, which outcrops on the valley sides, is in direct hydraulic contact with the river, except along specific reaches of a river where either the Skurweberg or the Peninsula Formation comprise both the valley sides as well as the valley floor and or the Rietvlei Formation is not overlain by the Gydo Formation of the Bokkeveld Group in the valley floors. These circumstances were established from aerial photos, 1:50 000 topographical and geological maps or at a more local scale from an orthophoto, if available.

The methodology adopted for this study comprises the following:

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

14.2.3 Hydroclimatology

Rainfall

There is sufficient rainfall data available, both as spatial distribution of mean annual and mean monthly values and as time series (daily or monthly) at several rainfall stations. However, due to inconsistencies between the MAP distribution from the Computing Centre for Water Research (CCWR) in the high mountainous areas and the MAR values for these catchments, it was decided to develop a revised spatial distribution of MAP, based on additional rainfall data and rainfall stations (see **Section 2**). This revised MAP distribution will be used in the study.

Temperature

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

Evapotranspiration

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

14.2.4 Geology

Lithology

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

Structural Features

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

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

Aquifer geometry

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

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

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

14.2.5 Hydrogeology

Hydraulic Parameters

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

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

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

Recharge

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

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

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

Groundwater levels

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

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

Springs

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

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

Hydrochemistry

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

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

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

Thermal Data

There is no comprehensive mapping of thermal springs available. There are also no time series data of temperature changes at hot springs. Use was made of the limited thermal data for the groundwater flow modelling as follows:

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

14.2.6 Land Cover

Soil Cover

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

Vegetation Cover

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

14.2.7 Water Use

Groundwater

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

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

- Spatial disaggregation of water use data per catchment with respect to aquifers, based on registered usage, borehole distribution, land use, aquifer properties and local knowledge;
- Estimation of seasonal fluctuation of groundwater use, based on the assessment of irrigation requirements and percentage split between sectors;

- Indication of historical change in groundwater use, based on boreholes drilled per year, increase in agricultural areas, population growth and general development.

Surface water

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

A summary of the parameters and data sources used in the groundwater assessment in this Study are summarised in **Table 14-1**.

Table 14-1 Summary Table of Parameters and Data Sources used in the Project

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

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

14.2.8 Critical Data Gaps

The assessment of the data available for use in this study and the development of the conceptual models and approach at a regional and at an individual aquifer scale (see **Section 15**) have highlighted the following data gaps:

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

Recommendations regarding addressing of the data gaps are provided in **Section 24**.

The detailed technical report describing the full extent of the work can be found in "*Groundwater Model Report Volume 2 – Data Availability and Evaluation",* of the Berg WAAS series of Study Reports.

15. GROUNDWATER REGIONAL CONCEPTUAL MODEL

15.1 AQUIFER PRINCIPLES

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

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

15.2 STUDY DOMAIN

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

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

15.3 REGIONAL CONCEPTUAL MODEL

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

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

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

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

15.4 INTEGRATED WATER RESOURCE MANAGEMENT

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

15.5 DETAILED MODEL DOMAINS

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

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

15.6 CONCLUSIONS

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

Recommendations are provided in **Section 24**.

The detailed technical report describing the full extent of the work can be found in "*Groundwater Model Report Volume 3 – Regional Conceptual Model",* of the Berg WAAS series of Study Reports.

16. GROUNDWATER REGIONAL WATER BALANCE MODEL

16.1 STUDY DOMAIN

The study domain for the groundwater component extends beyond the boundary of the Berg WAAS area. It 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.

16.2 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.

16.2.1 Recharge

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 16-1**), which are 2 to 3 orders of magnitude higher than the capacity of the surface water storage facilities in the study domain.

Table 16-1 Rock Volume vs Pore Volume for Peninsula Aquifer, given a porosity of 0.05 (5%)

Peninsula Aquifer	Area (km^2)	Rock Volume ($10^6 m^3$)	Pore Volume ($10^6 m^3$)
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**

16.2.2 Aquifer-Specific 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 (SVF) method, are applied in localised areas to compare with the regional estimation.

From the comparison of the different recharge methods, as shown in **Table 16-2**, 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 16-2 Comparison of recharge estimations

Aquifer type	Recharge [million m^3/a]					
	Fixed %	BRBS	ISP	GRA II	Map-centric	SVF confined
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**

16.2.3 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 16-3**). The data from the WARMS are considered conservative and will be used in determining the groundwater potential.

Table 16-3 Estimated groundwater use per aquifer

Source and Method	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	Total Groundwater use
	($10^6 m^3/a$)	($10^6 m^3/a$)	($10^6 m^3/a$)	($10^6 m^3/a$)	($10^6 m^3/a$)	($10^6 m^3/a$)
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**

16.3 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 16-4**). 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 16-4 Summary results of groundwater potential per aquifer [million m^3/a]

Aquifer	Method	Recharge	Baseflow	Recharge Less 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 million m^3, depending upon the acceptable average drawdown of between 5 m and 20 m 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 a 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.

16.4 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 regarding the results of the Water Balance Model are presented in **Section 24.**

The detailed technical report describing the full extent of the work can be found in "*Groundwater Model Report Volume 4 – Regional Water Balance Model",* of the Berg WAAS series of Study Reports.

17. CAPE FLATS AQUIFER MODEL

17.1 THE CAPE FLATS STUDY AREA

The Cape Flats covers an area in excess of 400 km^2 (Hay, 1981; DWAF, 2005). The topography is relatively flat with elevations ranging from 0 mamsl in the south to only 110 mamsl in the northeast. Drainage patterns are controlled by the surface topography and the main rivers (the Kuils and the Lotus) flow in a north-south direction towards False Bay. The Elsieskraal River flows from the northeast to the west and discharges to the north of Table Bay.

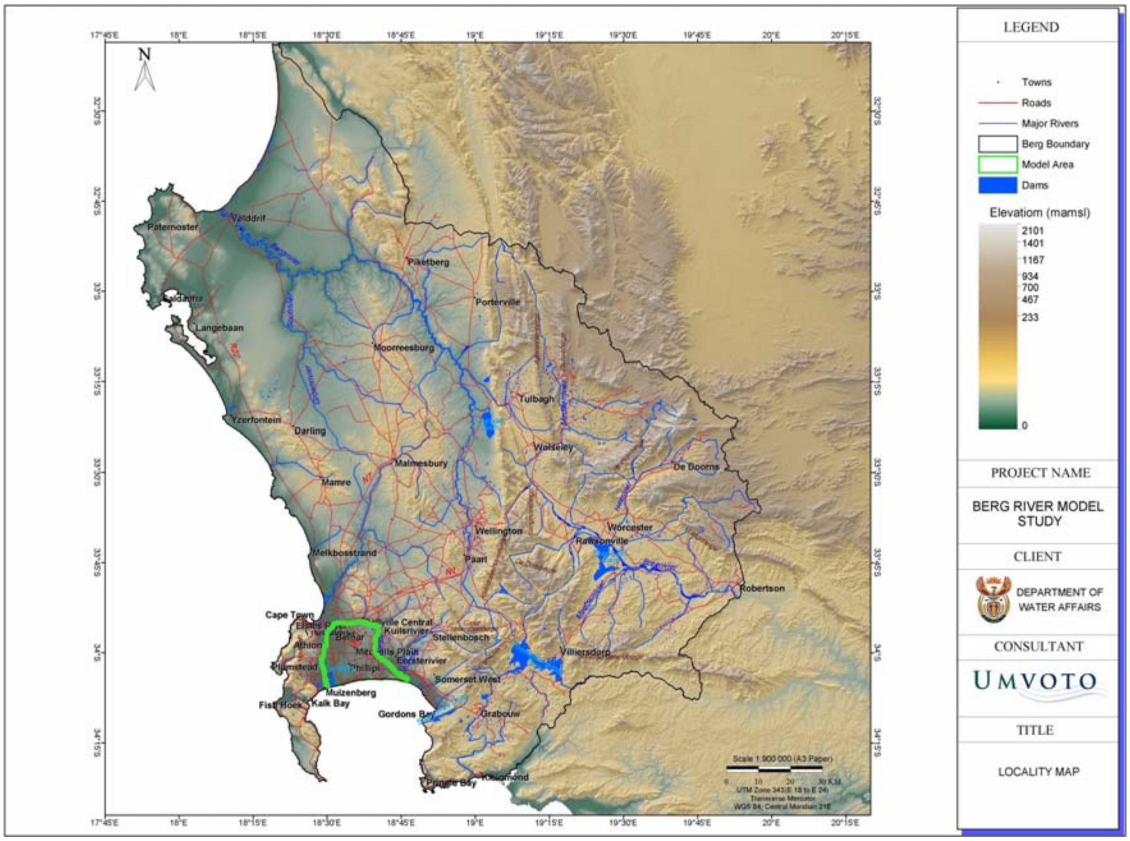

Figure 17-1 Location of the Cape Flats Aquifer Study Area

Mean annual evaporation exceeds precipitation by more than double. The rain falls in the winter and April to September is the wettest 6-month period. Analysis of monthly rainfall data within the Cape Flats model area shows 82% of the rainfall occurs in these months.

The Quaternary Sands that form the relatively thin Cape Flats Aquifer comprise fluvial, marine and aeolian deposited sands. The sands overlie the weathered Malmesbury and granite basement rocks which act as an aquiclude. The Quaternary Sands are heterogeneous multi-layered sands, consisting of interbedded sands, clay, clayey sand, limestone, sandstone, coarse gravels and peats. Distinct stratigraphic groups have been described within the Quaternary Sands but the lateral continuity across the Cape Flats is questionable. A summarised general geological section is presented detailing basal fluvial channel gravels present in palaeochannels, overlain by a fining upward sequence, overlain by a sand unit which has an interbedded calcrete layer.

Focussing on geological features salient to the hydrogeology, and on the basis that the Cape Flats model is a large-scale model, it is accepted that at the largest scale a broad distinction of 2 discrete layers is possible. Below the approximate depth of sea level, the sand unit has a greater abundance of coarse sediment layers. Above this level, the sands have more peat.

The near-surface groundwater-flow direction parallels the surface water drainage. Groundwater generally flows in a semi radial fashion from the higher lying basement in the northeast near Durbanville, toward Table Bay to the northwest and the False Bay coast to the south. The basement topography shows a palaeochannel of the Kuils River aligned north-south roughly in the west of the model domain. Coarser-grained deposits of fluvial sands and gravels in this palaeochannel provide a preferred flow-path southwards. The hydraulic nature of the aquifer is scale dependent. The sands are considered to be dominantly unconfined with regard to the largest spatial scale. At the smaller scale the aquifer will have a complex multi layered semi confined nature.

There is direct interaction between surface water and groundwater flow. In winter, elevated rainfall and surface water run-off recharges the groundwater in the aquifer. As the water table rises the groundwater begins to recharge the overlying rivers. During summer the groundwater levels reduce as recharge ceases and discharge continues, and in due course the rivers recharge the aquifer again until the next winter. The main rivers (the Kuils, the Elsieskraal, and the Lotus) that flow through the Cape Metropolitan Area have in part been channelized and lined with concrete but are not necessarily impermeable to the aquifer. This direct interaction between surface water flow in the rivers and groundwater flow in the aquifer has implications with regard to contamination of the aquifer by pollution in the form of industrial and urban waste in the rivers.

17.2 CONCEPTUAL MODEL

The conceptual model assumes that:

- The aquifer is dominantly unconfined. The degree to which any confinement may exist is dictated by the difference in hydraulic conductivity between layers, which is a calibration parameter.
- The aquifer is underlain by impermeable basement.
- Water is sourced by rainfall, and leaves the aquifer through outflow to the ocean, abstraction and rivers. Recharge is assumed net (accounting for evapotranspiration).
- Canalised reaches of rivers are hydraulically disconnected from the aquifer.
- Deep groundwater flows to the south discharging to False Bay, shallow groundwater and surface water flows to the northwest discharging to Table Bay.

17.3 NUMERICAL MODEL

A fully 3D finite element model is developed of an ~350 km^2 area with >61 000 nodes and ~100 000 prismatic elements. The elements are 450 – 60 m in length. The landward boundaries of the numerical model lie along rivers as transfer boundary conditions. The ocean acts as a constant head in the south. The model is 4-layered and the following data sets were used to construct the bedrock topography:

- Borehole depths from the 1:50 000 geological map series,
- Borehole depths provided by Wessels and Greeff, 1980, Henzen 1973, and Rogers 1980.
- Spot height on bedrock outcrops as shown in the 1:250 000 geological maps.

The recharge data used in the model is generated through a modified version of the BRBS method (DWAF, 2002). Recharge over the modelled area is 31 000 m^3/d or 11 million m^3/a. WARMS data was used for abstractions. The total abstraction over the modelled area is 10 000 m^3/d or 3 million m^3/a.

As per the model assumptions that the rivers act as sinks to the aquifers the river stages were set below the groundwater level. River stages were set on average at 4.5 m below topography in the river node. A calibration standard of modelled water levels within 10% average error to observed point data is set. The model is calibrated to this standard with the use of groundwater fluxes and groundwater as compared to topography as an additional guide.

The numerical model results confirmed what was assumed in the conceptual model viz. that the basal gravels are higher hydraulic conductivity than the rest of the aquifer as the model calibrated with higher hydraulic conductivity in the basal layer, existing only within palaeochannels. The model basal layer within the palaeochannels calibrated with a horizontal hydraulic conductivity of 84 m/d.

Above the high hydraulic conductivity palaeochannels an area of low horizontal hydraulic conductivity was input to the model, of 0.1 m/d. The remainder of the model has a horizontal hydraulic conductivity of 10 m/d. The model calibrated with the vertical hydraulic conductivity an order of magnitude less than the horizontal hydraulic conductivity.

17.4 MODEL RESULTS

Three model scenarios are developed:

- Scenario A: the base case, attained through calibration of K and transfer rate. All canalised rivers in the real world are assumed hydraulically disconnected in the model.
- Scenario B: tested the uncertainties in efficacy of canalisation and the uncertainty in flow out of the model domain along the western boundary by making selected rivers in the northwest and along the western boundary able to transfer water into or out of the model.
- Scenario C: tests the model sensitivity to the application of observed point data as known groundwater levels in the model.

The results show the ocean as a dominant sink to the aquifer, and that on average the rivers behave as sinks. The modelled groundwater fluxes are shown in Table 17-1.

Table 17-1 Modelled Groundwater Fluxes

Scenario	Mass Balance (m^3/day)		
	To Ocean	Model to rivers	Rivers to model
Model Scenario A	16 000	6 610	2 320
Model Scenario B	17 100	7 500	4 180
Model Scenario C	19 200	8 590	3 960

Surface water- groundwater fluxes are presented per quaternary (see Table 17-2). The fluxes differ significantly between Scenario A, B and C (by up to 70%).

Table 17-2 Surface water - groundwater fluxes per Quaternary Catchment

(% are given as compared to the total flux to surface water for that model scenario)

Quaternary Catchment	Rivers	Model Scenario	Flux into Model (m^3/d)	Flux out of Model (m^3/d)	Net (m^3/d)
G22C	Elsieskraal and Vyekraal	A	0	-3783 57% of flux to SW from aquifer	-3783
		B	0	-4094 55% of flux to SW from aquifer	-4090 -
		C	0	-4843 56% of flux to SW from aquifer	-4843
G22D	Lotus, Rondevlei and Zeekoevlei	A	1572 68% of flux from SW to aquifer	-1074 16% of flux to SW from aquifer	+498
		B	+3441 82% of flux from SW across aquifer	-1700 23% of flux to SW from aquifer	+1741 -
		C	+3232 82% of flux from SW across aquifer	-1833 21% of flux to SW from aquifer	+1399
G22E	Kuils	A	+743 32% of flux from SW across aquifer	-1755 27% of flux to SW from aquifer	-1012
		B	+743 18% of flux from SW across aquifer	-1720 23% of flux to SW from aquifer	-977 -
		c	+729 18% of flux from SW across aquifer	-1958 22% of flux to SW from aquifer	-1229

The effect of abstraction is shown in Table 17-3.

Table 17-3 The effect of abstraction on modelled water balance fluxes

The difference is calculated as a % change, from no abstraction to abstraction.

Scenario	Abstraction	Flux into Model (m^3/d)		Flux out of Model (m^3/d)			Balance (m^3/d)
		Recharge	Rivers	Rivers	Ocean	Abstraction	
A	Abstraction	+31022	+2320	-6610	-16,000	-10,794	-225
	Zero Abstraction	+31022	+1735	-8830	-23,900	0	-1
	Difference caused by abstraction	-	Increase of 33%	Decrease of 25%	Decrease of 33%	-	-
B	Abstraction	+31022	+4189	-7495	-17,172	-10,794	-250
	Zero Abstraction	+31022	+3067	-9897	-24,200	0	-8
	Difference caused by abstraction	-	Increase of 37%	Decrease of 24%	Decrease of 29%	-	-
C	Abstraction	+31022	+3960	-8590	-19,200	-10,794	0
	Zero Abstraction	+31022	-2890	-11,000	-26,000	0	0
	Difference caused by abstraction	-	Increase of 37%	Decrease of 22%	Decrease of 26%	-	-

The seasonal variation of the aquifer was simulated in transient modelling. The best fit was achieved using a specific yield of 3%, very low for a dominantly sand aquifer. Scenario testing on the transient model suggests that there is a resource available for additional abstraction, and that additional abstraction could be effective in reducing water levels enough that winter flooding is reduced or mitigated. The results suggest an additional "safe yield" of ~2 million m^3/a is available, from the northern palaeochannel areas.

Recommendations regarding the future upgrading of the Cape Flats Model are presented in **Section 24.**

The detailed technical report describing the full extent of the work can be found in "*Groundwater Model Report Volume 5 – Cape Flats Aquifer Model",* of the Berg WAAS series of Study Reports.

18. LANGEBAAN ROAD AND ELANDSFONTEIN AQUIFER SYSTEM MODEL

18.1 THE LANGEBAAN ROAD AND ELANDSFONTEIN STUDY AREA

Wave-cut terraces overlain by aeolian dunes dominate the topography of the Langebaan area, with sand covered plains, fixed dunes and surface limestone ridges forming the visible landscape. Intrusive granitic plutons are responsible for raised highlands and koppies, which reach up to heights of 450 mamsl.

The perennial Berg River is the most significant river in the region, and is located along the north-eastern boundary of the study area. The Berg River drains north-westwards into the Atlantic Ocean near Velddrif, with its lower courses subjected to tidal influence (Timmerman, 1985b). The model domain is indicated in Figure 18-1.

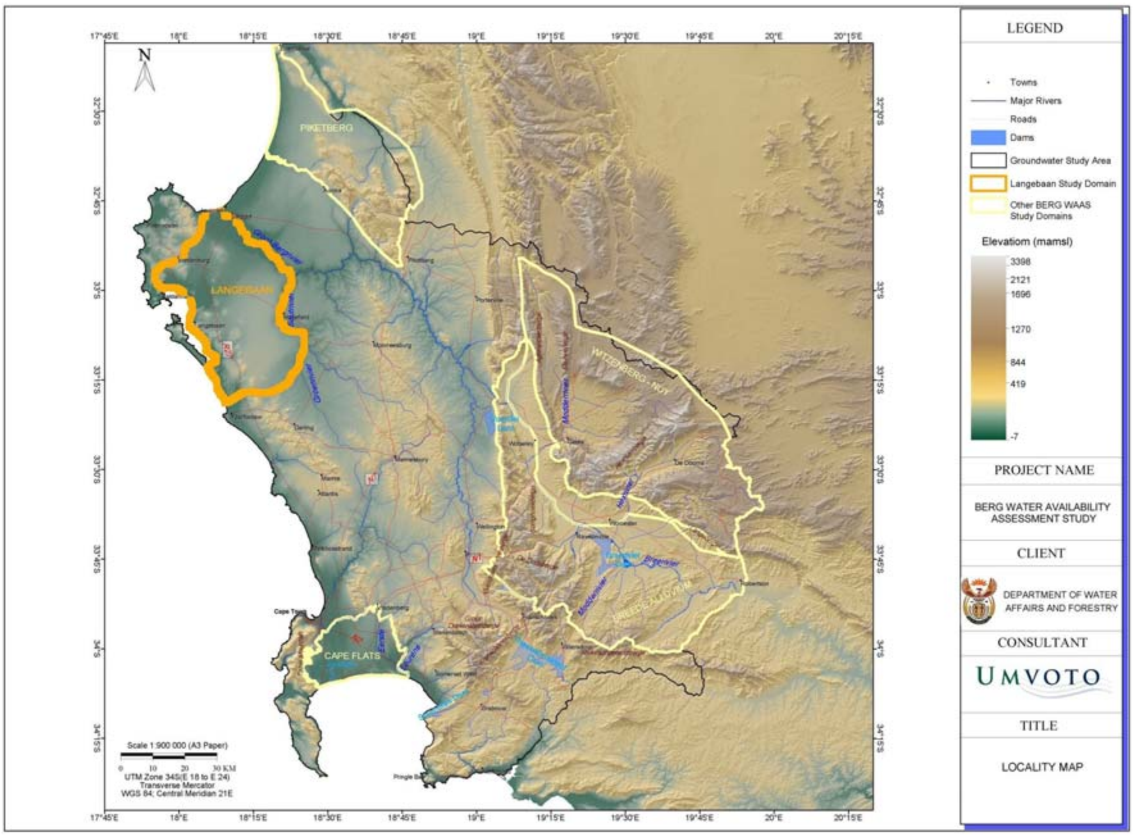

Figure 18-1 Location of the Langebaan Road and Elandsfontein Aquifer Study Area

Langebaan and its environs have a Mediterranean climate, with evaporation exceeding rainfall, and most of the rainfall occurring between the months of May to August. Average annual rainfall for the study area ranges between < 100 mm to ~ 500 mm, with most of the region having an annual rainfall of less than 280 mm.

Focussing on geological features salient to the hydrogeology, the Langebaan region is dominated by semi- to unconsolidated Cenozoic sediments that unconformably overlie basement rocks. The oldest Cenozoic deposits, the fluvial lower Elandsfontyn gravels, occur within the deeper basement areas of the palaeochannels. (Note: the Elandsfontyn gravel unit is not to be confused with the Elandsfontein Aquifer System, which is named after a farm in the area.) The lower Elandsfontyn gravel deposits were subsequently covered with clays and peats. Overlying the Elandsfontyn gravels, the aeolian sands of the Bredasdorp Group form the palaeo- and currently active dunes.

The palaeotopography reflects the palaeoclimatological interpretation that a marine transgression dammed up Proto-Berg Rivers, which previously exited to the southwest coastline. Two clear palaeochannel systems are evident in the basement. Previous workers have published basement elevation maps of the area which show these palaeochannels as enclosed basins rather than continuous channels. The interpretation suggested here is that the palaeochannels are continuous to the southwest coast.

Each of these palaeochannels comprise (semi-) separate aquifer systems. The southern palaeochannel in the area encompasses the Elandsfontein Aquifer system (EAS) and the northern palaeochannel, the Langebaan Road Aquifer System (LRAS). The sedimentary succession can be separated into three significant hydrogeological units:

- the basal gravels of the Elandsfontyn, forming the lower aquifer unit, LAU,
- the clay layer of the upper Elandsfontyn, which acts to (semi) confine the basal aquifer,
- the variably consolidated sands and calcretes, with interbedded peat clay of the Bredasdorp, the upper unconfined aquifer unit, UAU.

These three units are present in each aquifer system. The basal unit is separate between systems, and the UAU is continuous. Flow in the LAU is controlled by topography of the basement, flowing southwest towards the coast. Flow in the UAU is more controlled by surface topography and flows from a recharge high in the south, semi radially, towards the Berg River northeast, towards the LRAS to the north, and into the EAS to the south-west. The LAU is recharged in areas where the head difference between upper and lower aquifer is large enough to drive vertical recharge downwards (via leakage through clay if clay layer is present).

There is a direct interaction between the UAU and the Berg River. The regional gradient is towards the Berg River and hence on average the Berg River gains from groundwater. However during winder flood events, this gradient is likely to reverse and flood waters recharge the aquifer.

18.2 CONCEPTUAL MODEL

The conceptual model assumes that:

- The palaeotopography is representative of ancient fluvial systems and continuous palaeochannels are inferred.
- The geology can be interpreted as 3 distinct hydrostratigraphical units:
  - The upper unconfined aquifer unit comprising the Bredasdorp formation sediments and Varswater sediments, if present;
  - The confining layer (Upper Elandsfontyn clay)
  - The lower (semi-) confined aquifer unit (Elandsfontyn sediments)
- The aquifer is underlain by impermeable basement.
- The UAU is recharged directly from rainfall.
- The LAU is recharged via leakage through the clay unit.
- The UAU discharges to the Berg River, to the coastline at Saldanha Bay and the coastline at Langebaan Lagoon and south of the lagoon.
- The Berg River acts as a recharge source to the aquifer during flood events.
- Flow in the LAU is basement controlled and occurs along the axes of the palaeochannels.
- The LAU discharges to the coastline at Saldanha Bay and the coastline at Langebaan Lagoon and south of the lagoon.
- The Berg River is in direct hydraulic connectivity with the UAU only.

18.3 NUMERICAL MODEL

A fully 3-dimensional finite element model is developed of an ~2 000 km^2 area with ~7 135 triangular prismatic elements. The elements are 500–1200 m in length. The landward boundaries of the numerical model lie along topographical divides or across observed groundwater contours, and are no-flow boundary conditions. The ocean acts as a constant head in the southeast and northwest. The model is 5-layered.

The following data sets were used to construct the bedrock topography:

- Borehole depths from the NGDB data set, using records of shale and granite as indications of basement rocks.
- Offshore basement data of De la Cruz (1978).
- Spot heights on bedrock outcrops as shown in the 1:250 000 geological maps.

The recharge data used in the model is generated through a modified version of the Breede River Basin Study (BRBS) method (DWAF, 2002). Recharge over the modelled area is ~!22 million m^3/a. Water-use Authorisation and Management System data was used for abstractions. The total abstraction over the modelled area is 3.6 million m^3/a.

As per the model assumptions that the rivers act as a sink to the aquifer and the river, stages were set below the groundwater level. As an initial estimate of the modelled groundwater levels the topography and the measured water level distribution was used and river stages were input relative to this water level distribution, between 1-3 m below it.

A calibration standard of modelled water levels within 10% average error to observed point data is set. The model is calibrated to this standard with the use of groundwater fluxes and groundwater as compared to topography as an additional guide.

The numerical model was considered calibrated with the following parameter set; the model basal layer within the palaeochannels calibrated with Kx=Ky of ~10 m/d. a discontinuous low K layer overlies the basal later, at Kx=Ky of 0.01 m/d. The upper layer dominantly has a K of 10 m/d, with some area in the south at ~1 m/d. The model calibrated with vertical K an order of magnitude less than horizontal K.

18.4 MODEL RESULTS

The results show the ocean as a dominant sink to the aquifer, and that on average (i.e. the steady-state model) the Berg River behaves as a sink. The modelled groundwater fluxes are shown in Table 18-1. There is an imbalance of 100 m^3/d between the flux in and out of the model.

Table 18-1 Modelled Groundwater Fluxes

Flux into Model (m^3/d)	Flux out of Model (m^3/d)	
Recharge	Ocean	Rivers
59,800	-32,800	-27,100

The effect of abstraction is shown in Table 18-2.

Table 18-2 The effect of Abstraction

Abstraction	Flux into Model (m^3/d)		Flux out of Model (m^3/d)			Balance (m^3/d)
	Recharge	Rivers	Ocean	Rivers	Abstraction	
Abstraction (i.e. standard model case)	59 800	0	-29 500	-21200	-10 100	-1000
Zero Abstraction	59 800	0	-32 800	-27 00	0	-100
Difference caused by abstraction	-	-	Decrease of 10%	Decrease of 22%	-	Increase of 900%

The seasonal variation of the aquifer was simulated in transient modelling. The best fit was achieved using a specific yield of 2%. Scenario testing on the transient model suggests that there is a resource available for additional abstraction in the EAS, and that it is possible to abstract small quantities without affecting the water levels at potentially sensitive receptors such as the Langebaan Lagoon. An ASR scenario suggests that it is possible to site injection boreholes within the cone of depression and raise water levels, reversing some of the depression.

Recommendations regarding the future upgrading of the Langebaan Road and Elandsfontein Aquifer System Models are presented in **Section 24.**

The detailed technical report describing the full extent of the work can be found in "*Groundwater Model Report Volume 6 – Langebaan Road and Elandsfontein Aquifer System Model",* of the Berg WAAS series of Study Reports.

19. TABLE MOUNTAIN GROUP AQUIFER (PIKETBERG MODEL)

19.1 THE TMG PIKETBERG STUDY AREA

The Piketberg model domain extends from Elands Bay at the Atlantic coast along the Verloren Vlei valley towards the north eastern part of the Piketberg mountain range, from where it follows the Peninsula – Basement contact to the southern corner of the Piketberg mountain range, west of the town of Piketberg. The southern boundary follows the Peninsula – basement contact towards Aurora and extends westwards to the coast along the surface water divide. The model domain is indicated in Figure 19-1.

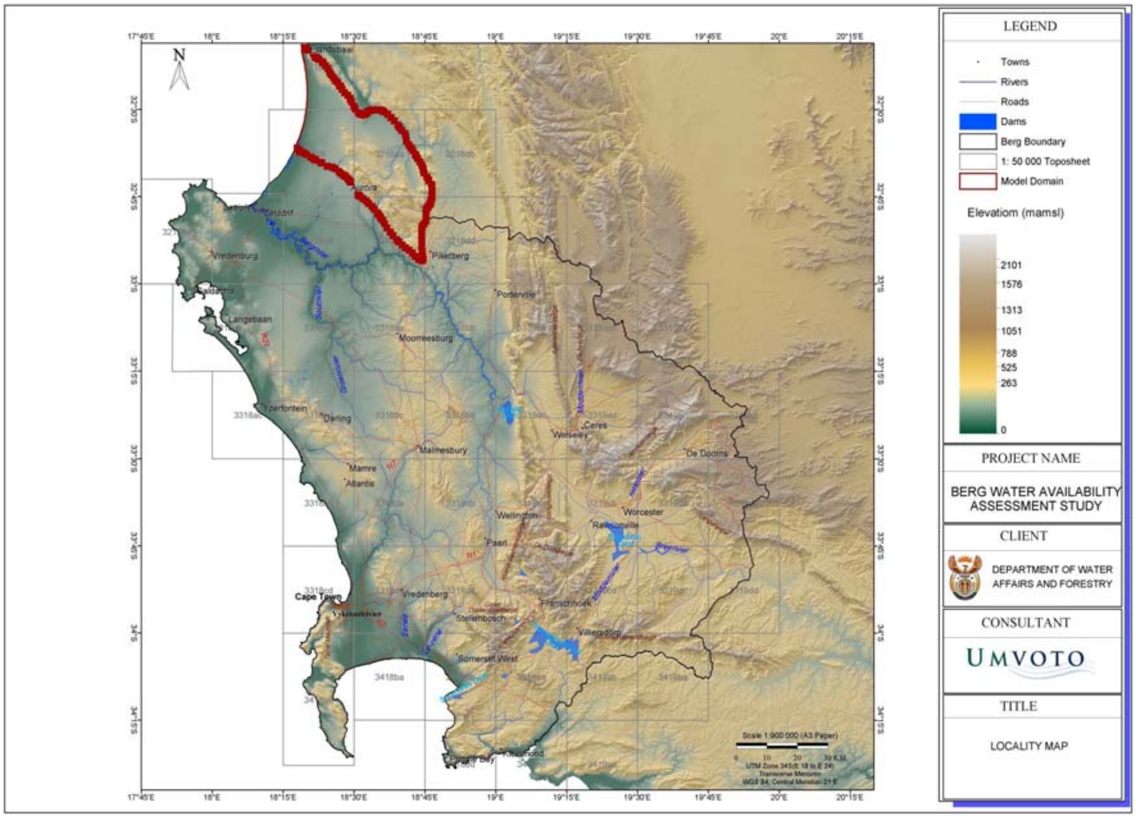

Figure 19-1 Location of the TMG Piketberg Study Area

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 model domain is host to predominantly rocks of the **Table Mountain Group** (TMG) and the overlying quaternary sediments of the **Sandveld Formation**.

The aquifers considered here include the Table Mountain Group (TMG) aquifers viz. the Piekenierskloof, the Skurweberg and the Peninsula aquifers ("Fractured rock aquifers"), as well as the primary aquifer between the Piketberg mountain range and the coast. The "fractured-and-weathered" or regolith zones are disregarded in this study.

19.2 PIKETBERG 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.

19.2.1 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 8 million m^3 (see Table **19-1**)

Table 19-1 Rock Volume vs Pore Volume for Peninsula Aquifer, given a porosity of 0.05 (5%)

Peninsula Aquifer	Area (km^2)	Rock Volume ($10^6 m^3$)	Pore Volume ($10^6 m^3$)
Unconfined portion	236.66	93,974	4,699
Confined portion	53.64	67,202	3,360
Whole Peninsula Aquifer	**290.30**	**161,176**	**8,059**

19.2.2 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 Saturated Volume Fluctuation method, are applied to compare with the regional estimation.

From the comparison in Table 19-2 it is evident that the map-centric simulation results in reasonable 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 higher recharge to the TMG aquifers and lower recharge to the intergranular and intergranular-fractured aquifers. The GRA II method yields the lowest estimates. The averaged recharge from all four methods is used for estimation of the groundwater potential.

Table 19-2 Comparison of recharge estimations

Aquifer type	Recharge [million m³/a]					
	BRBS	ISP	GRA II	Map-centric	Average	SVF confined
Peninsula	10.9	15.0	7.8	13.3	11.8	12.2
Nardouw	1.5	2.2	1.0	2.2	1.8	N/a
Fractured	3.0	2.9	2.4	3.9	3.1	N/a
Intergranular-fractured	2.8	1.7	2.6	4.2	2.8	N/a
Intergranular	18.5	12.0	13.2	26.5	17.6	N/a
Total aquifer specific	**36.8**	**33.9**	**27.1**	**50.1**	**37.0**	**N/a**

19.2.3 Discharge

Discharge from the aquifer systems is 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. The groundwater contribution to baseflow is set to zero as the rivers in the model domain are classified as ephemeral. However, there are known perennial springs along the TMG outcrop on the southern and eastern side of the model domain.

A comparison between the GRA II data sets on groundwater use and the WARMS database shows significant differences in the total volume of abstraction. The data from the GRA II are considered conservative and will be used in determining the groundwater potential (see **Table 19-3**).

Table 19-3 Estimated groundwater use per aquifer (after GRA II)

Quaternary catcment	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	Total Groundwater use
	million m³/a					
G10K	0.45	0.10	0.06	0.06	0.02	0.69
G30A	0.06		0.11	0.02	1.86	2.05
G30D	0.19		0.21	0.37	1.80	2.57
Total	**0.69**	**0.10**	**0.38**	**0.44**	**3.69**	**5.30**

19.2.4 Yield Model

The water balance and yield model suggests a total remaining long-term averaged groundwater potential of 33 million m^3/a within the study area, based on a comparison of the average recharge estimation, baseflow and current groundwater use (see Table **19-4**).

Table 19-4 Summary results of groundwater potential per aquifer (all values are $10^6 m^3/a$)

Aquifer	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
	million m^3/a				
Peninsula	11.8	0.4	11.4	0.69	10.69
Nardouw	1.7	0	1.7	0.10	1.65
Fractured	3.1	0	3.1	0.38	2.67
Intergranular-fractured	2.8	0	2.8	0.44	2.39
Intergranular	17.6	0	17.6	3.69	13.87
Total	**37.0**	**0.4**	**36.6**	**5.30**	**31.27**

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 2 and 8 million m^3, depending upon the acceptable average drawdown of between 5 m and 20 m respectively.

The results of the water balance and yield model will be used as input to the WRSM and WRYM.

19.3 CONCLUSIONS

A robust water balance and yield model was applied 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 3-d 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 regarding the future upgrading of the TMG Piketberg Aquifer System Model are presented in **Section 24.**

The detailed technical report describing the full extent of the work can be found in "*Groundwater Model Report Volume 7 – TMG Aquifer, Piketberg Model",* of the Berg WAAS series of Study Reports.

20. TABLE MOUNTAIN GROUP AQUIFER (WITZENBERG – NUY MODEL)

20.1 THE TMG WITZENBERG-NUY STUDY AREA

The Witzenberg-Nuy Domain is a combination of three subdomains, which include the Agter Witzenberg and the Tulbagh-Ceres Valley in the west, the Hex River area in the center and the Koo Valley east of De Doorns in the east. The Tulbagh-Ceres area and the Hex River area were previously considered separate model areas. However, conceptually, the groundwater flow in the various aquifers is not isolated to the originally defined domains and interbasin transfers are expected. For this reason it was decided to join the Tulbagh-Ceres and Hex River model domains as well as include the area east of De Doorns. The model domain is indicated in Figure 20-1.

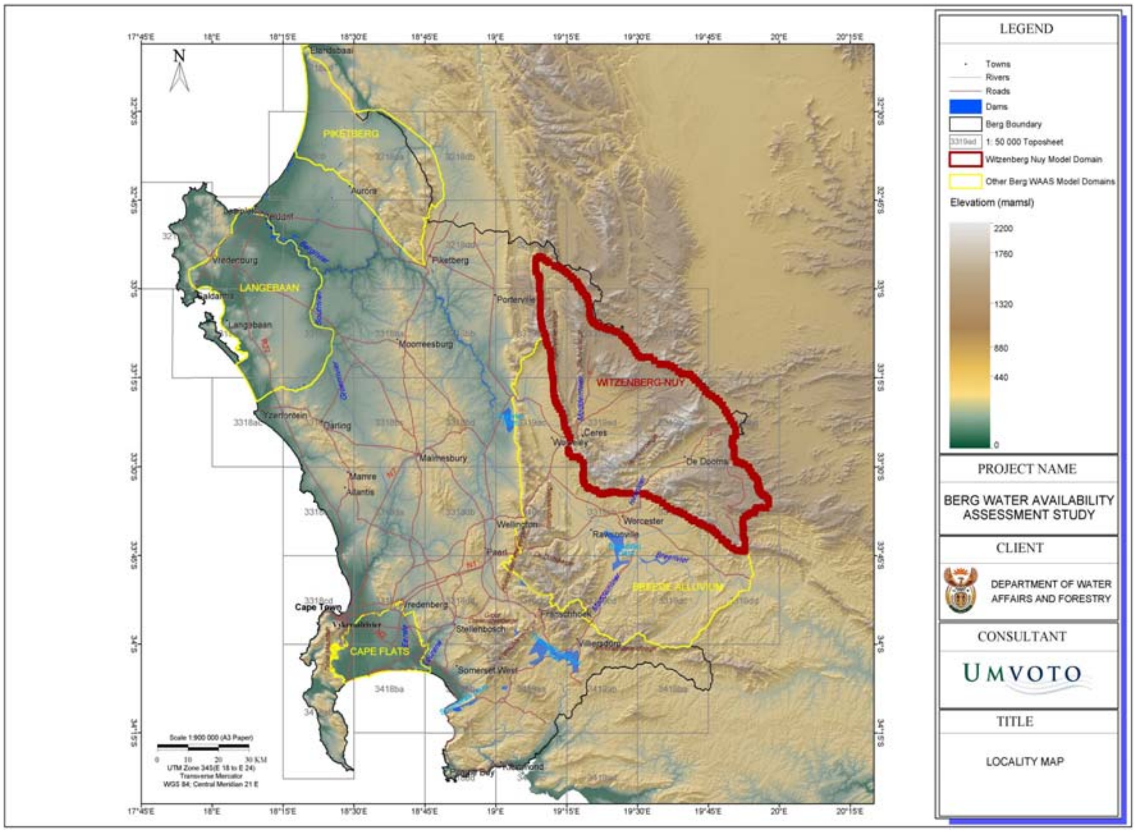

Figure 20-1 Location of the TMG Witzenberg-Nuy Study Area

20.2 WITZENBERG-NUY 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, abstraction 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.

20.2.1 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.

Table 20-1 Rock Volume vs Pore Volume for the Peninsula Aquifer, given a porosity of 5%

Model Subdomains	Peninsula Aquifer	Area	Rock Volume	Pore Volume
		(km^2)	**($10^6 m^3$)**	**($10^6 m^3$)**
Witzenberg-Nuy 1	Unconfined portion	140.53	153 793	7 690
	Confined portion	365.54	510 177	25 509
Witzenberg-Nuy 2	Unconfined portion	175.77	192 331	9 617
	Confined portion	1 131.65	1 584 132	79 207
Witzenberg-Nuy 3	Unconfined portion	260.39	256 445	12 822
	Confined portion	935.24	1 300 645	65 032
Witzenberg-Nuy Model Domain	Total Unconfined portion	576.69	602 569	30 128
	Total Confined portion	2 432.43	3 394 954	169 748
Total Aquifer		**3 009.12**	**3 997 523**	**199 876**

The results indicate a storage capacity within the Peninsula Aquifer of 200 x 10^9 m^3 (see Table 20-1), and a storage capacity of 25 x 10^9 m^3 within the Skurweberg Aquifer (see Table 20-2).

Table 20-2 Rock Volume vs Pore Volume for Skurweberg Aquifer, given a porosity of 5%

Model Subdomains	Skurweberg Aquifer	Area	Rock Volume	Pore Volume
		(km^2)	**($10^6 m^3$)**	**($10^6 m^3$)**
Witzenberg-Nuy 1	Unconfined portion	177.97	36 207	1 810
	Confined portion	101.17	25 705	1 285
Witzenberg-Nuy 2	Unconfined portion	174.35	31 299	1 565
	Confined portion	877.49	218 061	10 903
Witzenberg-Nuy 3	Unconfined portion	201.81	47 581	2 379
	Confined portion	609.60	146 046	7 302
Witzenberg-Nuy Model Domain	Total Unconfined portion	554.13	115 087	5 754
	Total Confined portion	1 588.26	389 811	19 491
Total Aquifer		**2 142.39**	**504 898**	**25 245**

20.2.2 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 Saturated Volume Fluctuation method, are applied to compare with the regional estimation.

From the comparison in Table **20-3** it is evident that the map-centric simulation results in 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 ISP method results in higher recharge to the TMG aquifers and lower recharge to the intergranular and intergranular-fractured aquifers. The averaged recharge from all four methods is used for estimation of the groundwater potential.

Table 20-3 Comparison of recharge estimations

Aquifer type	Recharge [million m^3/a]					
	BRBS	**ISP**	**GRA II**	**Map-centric**	**Average**	**SVF confined**
Peninsula	78	111	82	51	81	98
Nardouw	82	114	88	86	93	60
Fractured	1	2	2	1	1	N/a
Intergranular-fractured	39	36	57	67	50	N/a
Intergranular	12	10	11	14	12	N/a
Total aquifer specific	**212**	**272**	**241**	**220**	**236**	**N/a**

20.2.3 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. Other discharge pathways, e.g. discharge across catchment boundaries or along hydrotects towards the sea, are not estimated, as the available data are not sufficient to do so.

Table 20-4 Aquifer-specific discharge estimation per subdomain, groundwater contribution to baseflow disaggregated according to average recharge

Model Subdomain	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	Total GW contribution to baseflow	
	million m^3						*mm*
Witzenberg-Nuy1	3.96	7.71	0.04	1.16	0.12	13.00	25
Witzenberg-Nuy2	4.12	5.98	0.20	5.03	1.10	16.42	13
Witzenbrg-Nuy3	3.67	2.43	0.00	0.48	0.29	6.87	6
Total	**11.7**	**16.1**	**0.2**	**6.7**	**1.5**	**36.3**	**12**

A comparison between the GRA II data sets on groundwater use and the WARMS database shows significant differences in the total volume of abstraction. The data from the WARMS are considered reliable and will be used in determining the groundwater potential (see Table **20-5**).

Table 20-5 Estimated groundwater use per aquifer (after WARMS and NGDB)

Model Subdomain	Peninsula Aquifer	Nardouw Aquifer	Other Fractured Aquifers	Intergranular fractured Aquifers	Intergranular Aquifers	Total Groundwater use
	million m^3/a					
Witzenberg-Nuy1	0.14	1.58	0.01	4.22	0.00	5.96
Witzenberg-Nuy2	0.49	5.63	0.00	14.64	2.86	23.62
Witzenberg-Nuy3	1.15	8.22	0.00	4.67	12.27	26.31
Total	**1.78**	**15.44**	**0.01**	**23.53**	**15.13**	**55.89**

20.3 YIELD MODEL

The water balance and yield model suggests a total remaining long-term averaged groundwater potential of 144 million m^3/a within the study area, based on a comparison of the average recharge estimation, baseflow and current groundwater use (see Table **20-6**).

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 102 and 407 million m^3, depending upon the acceptable average drawdown of between 5 m and 20 m respectively. Furthermore, the long-term averaged groundwater potential does not take into account the possibility of increasing recharge due to groundwater abstraction. The results of the water balance and yield model will be used as input to the WRSM and WRYM.

Table 20-6 Summary results of groundwater potential per aquifer (million m^3/a)

Aquifer	Recharge	Baseflow	Recharge - Baseflow	Groundwater Use	Groundwater Potential (Re – BF - Use)
Peninsula	80.6	11.7	68.9	1.8	67.2
Nardouw	92.5	16.1	76.4	15.4	61.0
Fractured	1.4	0.2	1.1	0.0	1.1
Intergranular-fractured	49.9	6.6	43.2	23.5	19.7
Intergranular	11.8	1.5	10.3	15.1	-4.8
Total	**236.2**	**36.2**	**200.0**	**55.9**	**144.1**

20.4 CONCLUSIONS

A robust water balance and yield model was applied 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 3 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 regarding the future upgrading of the TMG Witzenberg-Nuy Aquifer System Model are presented in **Section 24.**

The detailed technical report describing the full extent of the work can be found in "*Groundwater Model Report Volume 8 – TMG Aquifer, Witzenberg-Nuy Model",* of the Berg WAAS series of Study Reports.

21. BREEDE RIVER ALLUVIUM AQUIFER MODEL

21.1 BREEDE RIVER ALLUVIUM STUDY AREA

The Breede River Alluvium is located in the valley south of Worcester, adjacent to Greater Brandvlei Dam. The upper Breede River valley between Wolseley and Nuy is filled with sand and gravel deposits, which constitute an extensive aquifer (Van Zijl et al, 1981). The agricultural community in the valley utilises groundwater from this aquifer for irrigation as well as for domestic use in some of the towns. The upper Breede River and the existing dams (e.g. Greater Brandvlei Dam) are considered for further augmentation towards the Berg River Water Management Area. Since the aquifer is already utilised, the water balance in this area and its split between surface water and groundwater needs to be reconciled. Additionally, the impact of further groundwater development on stream flow, the impact of river diversion on the groundwater level and quality, and the cumulative impact of both activities need to be simulated prior to decisions about upgrading of schemes. This model is seen as a first step towards quantifying the water balance in the valley and understanding the various aquifer interactions which are present.

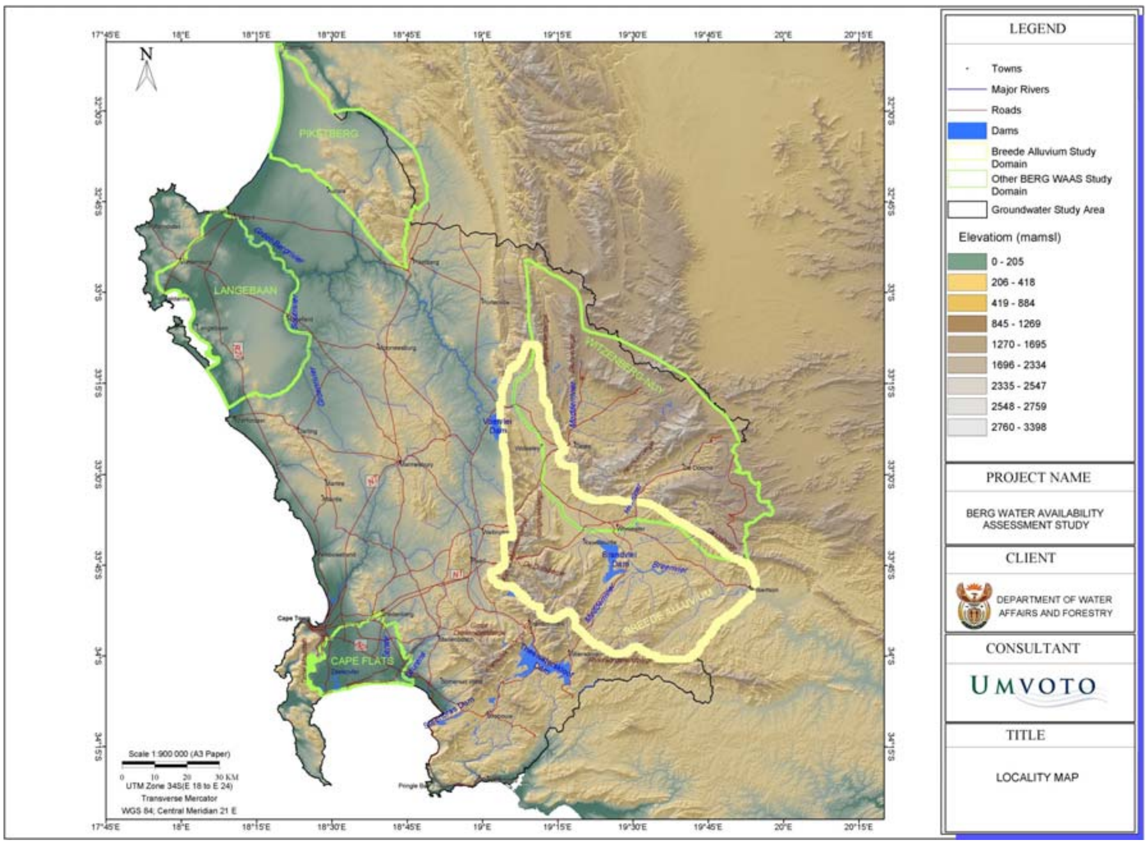

Figure 21-1 Location of the Breede River Alluvium Study Area

The main aims in development of the model are:

- Model different scenarios under different hydrological conditions (e.g. flood, drought, surface water abstraction)
- Establish at least first order estimates of the rate and volume of exchange between the water in the alluvium and that in the river, and between groundwater in various aquifers
- Test the possibility for an aquifer storage and recovery scheme to store surplus flood water.

21.2 CONCEPTUAL MODEL

The Table Mountain Group (TMG) discharges to springs and perennial rivers, which flow from the steep mountain sides into alluvial fans within the Breede valley. The alluvial fans and the alluvium which underlies the central Breede River, together make up the heterogeneous Breede River Alluvial Aquifer. The alluvial fans are coarsest at the fan heads and act as sponges to the perennial surface waters. The surface waters recharge the aquifer on entrance to the valley, and then these alluvial fans discharge to the Breede River in the centre of the valley. At the regional scale the groundwater movement is towards the centre of the valley, discharging at the Breede River, and also along the valley southwards. The alluvium overlies TMG aquifers and the aquitards of the Malmesbury and Cape Granite Suite. Lateral recharge from the TMG to the alluvium occurs where these units are juxtaposed. The third form of recharge to the alluvium is from rainfall.

The aquifer discharges to the Breede River along its length and groundwater also flows southwards through the valley, though ultimately discharging to the Breede as the alluvium reduces in volume and therefore capacity to carry the water south of Greater Brandvlei Dam and west of Robertson.

21.3 NUMERICAL MODEL

The mountains bounding the Breede valley are comprised of TMG rocks which also underlie the valley. The deep flows in the TMG are investigated in the Brandvlei hot spring numerical model. The model shows that discharge from the TMG aquifer into the alluvium and into the TMG-fed surface waters, is relatively constant. Therefore the Breede Alluvium model can be simplified to represent the Alluvium only, with the TMG-derived fluxes incorporated as constant fluxes.

Based on the conceptual model a 3-dimensional finite difference model is developed for the Breede River Alluvium Aquifer. The modelled area covers 486 km^2. The Modflow software functions on a square grid and the model contains 7 778 grid squares or cells in each layer, 23 334 grid squares in total.

21.4 MODEL RESULTS

The modelled water levels are compared to the observed water levels based on a comparison with mapped data. The major features of the flow regime are replicated in the model. Groundwater flows from the valley sides towards the Breede River, and also through the valley towards the southeast. The observed groundwater gradients are also broadly replicated. The model replicates the flow regime at a regional scale and gives expected mass balance numbers.

Model runs showed that the equivalent hydraulic conductivity in the valley must be in the range of 10-100 m/d. The seasonal variation of the aquifer was simulated in transient modelling. The modelled groundwater fluxes are shown in Table 21-1.

Table 21-1 Modelled groundwater fluxes

Units	Influx		Discharge	Balance
	Recharge	Constant heads	Rivers	
m^3/day	62 982	8 144	-71 062	64
$10^6 m^3$/a	23	3	-25	0

Scenario testing on the transient model suggests that the aquifer is relatively fast to respond to major changes in the influxes or outfluxes applied to the aquifer. Inputting the assumed current abstraction to the transient model shows that the system re-adjusts to the lower net recharge conditions and achieves stability after 10 years of this continued abstraction.

The modelled system responds within 1 year to maximum and minimum surface water levels taken from flood and low flow records, suggesting a short time lag between groundwater storage and surface water. The relationship does suggest that the alluvium can readily take up excess surface water, and that this time lag could be optimised to store winter flood water for use within the following summer dry period. The ASR scenario showed that there is a potential for significant storage within the aquifer, away from the centre of the valley. Local-scale mapping of water levels as depth to water is required to quantify such available storage.

Recommendations regarding the future upgrading of the Breede River Alluvium Aquifer Model are presented in **Section 24.**

The detailed technical report describing the full extent of the work can be found in "*Groundwater Model Report Volume 9 – Breede River Alluvium Aquifer Model",* of the Berg WAAS series of Study Reports.

22. OVERVIEW OF BERG AND MHLATUZE WAAS

22.1 CONTEXT

The quantification of water availability in South African catchments is generally burdened by variable confidence levels that are the result of *historically uneven spatial distributions of observation sites* of rainfall, evaporation, streamflow, groundwater-levels and -abstractions, inter-catchment transfers, reservoir releases, river-diversions/-abstractions and water use. Further challenges to the quantification of water availability arise from the variable consistency, continuity, reliability and accuracy of the *historical observation values and sequences, at any particular site*, of any of the above components of any specific catchment's water cycle. In this context, it follows that close attention to the implementation of credible, verified and established procedures and conventions for the scientific remediation of any of the above challenges should be a primary requirement for any new quantification of water availability.

Consequently, to ensure the implementation of credible, verified and established procedures and conventions in the various overlapping Water Availability Assessment Studies, DWAF instituted, among pairs of the relevant individual WAAS Professional Service Providers (PSPs), a systematic and cross-project process of independent peer reviews of the catchment hydrology components of the various Studies. This document presents an outline of these independent hydrological reviews performed by Mr Craig Schultz (Company: Arcus Gibb) and Dr Ingrid Dennis (Institute of Groundwater Studies, University of the Free State) regarding the Berg WAAS and by Prof André Görgens (Company: Aurecon) regarding the Mhlatuze WAAS.

22.2 BERG WAAS REVIEW

22.2.1 Scope

The review of the Berg WAAS by Mr Schultz covered all the components of the surface water hydrology, the associated catchment model calibrations and the associated data processing and preparations, but did not cover the groundwater component of the study, nor the WRYM system model configuration. The review by Dr Dennis covered all the groundwater components of the Berg WAAS, with a particular focus on the various groundwater modelling approaches.

22.2.2 Approach: Surface Water Studies Review

Mr Schultz had two working meetings with the surface water hydrology team. The first meeting took place on 27 June 2007, after completion of the new mean annual precipitation (MAP) surface for the Berg WAAS study area and surrounds, as well as of the pilot modelling studies in selected sub-catchments devised to help formulate an appropriate way to model the groundwater-surface water interaction in the catchment model. The second meeting took place on 22 February 2008, after completion of the majority of the catchment model calibrations. Draft reports on the completed work were sent to Mr Schultz prior to both meetings. During each meeting detailed presentations were made by the team members, who also responded in detail to both verbal comments and questions by Mr Schultz and to his annotations in the draft reports. No written reports on the review process were received from Mr Schultz.

22.2.3 Approach: Groundwater Studies Review

Dr Dennis had various working meetings and numerous technical discussions and written communications with the groundwater team between June 2006 and December 2007. Her interactions focused initially on the credibility and suitability of the groundwater modelling approaches being proposed for the Berg WAAS and, later, she commented in detail on the various draft reports available at that stage. During each meeting detailed presentations were made by the team members, who also responded in detail to both verbal and written comments and questions by Dr Dennis and to her annotations in the draft reports. DWAF groundwater specialists, Dr Fanie Botha, Paul Seward and Mike Smart participated in some of the interactions between Dr Dennis and the WAAS team. It should be noted that during 2007 the groundwater team, in a separate external review process, commissioned Dr Ray Mackay at Birmingham University in the UK to do a critical review of the modelling approach that had been devised for the Berg WAAS.

22.3 MHLATUZE WAAS REVIEW

22.3.1 Scope

The review of the Mhlatuze WAAS by Prof Görgens covered all the components of the surface water hydrology, the associated catchment model calibrations and the associated data processing and preparations, but it did not cover the WRYM system model configuration. Only the approach to the groundwater component of the study was included in this review, but not its final outcome.

22.3.2 Approach: Surface Water Studies Review

Prof Görgens had two working meetings as well as various verbal and e-mail technical communications with the Mhlatuze WAAS surface water hydrology team. The first meeting took place on 24 October 2006, after the provisional completion of the rainfall data processing and the initial catchment discretisation and early model calibrations. The second meeting took place on 04 June 2007, after completion of the rest of the catchment model calibrations, on the basis of a new mean annual precipitation (MAP) surface for the Mhlatuze WAAS study area and surrounds. Draft reports on the completed work were sent to Prof Görgens prior to both meetings. During each meeting detailed presentations were made by the team members, who also responded in detail to both verbal comments and questions by Prof Görgens and to his annotations in the draft reports. An in-house report on the Mhlatuze WAAS hydrology review was prepared and presented to the Client and to the Mhlatuze surface water team.

22.4 CLOSING REMARKS

The two independent external review processes outlined above produced an extensive collection of conceptual, scientific and technical comments and questions which were responded to very seriously by the respective recipients. These comments and questions were accommodated responsibly through modifications in physical process interpretations or underlying assumptions, or in the relevant team members' approach to the individual tasks under consideration, or in particular model configurations, or in the finalisation of the project deliverables. The external review processes sharpened the quality of the conceptual, scientific and technical work executed during these two WAAS studies and heightened the credibility of their outputs.

23. APPLICABILITY OF THE SAMI GROUNDWATER MODEL TO THE BERG WAAS AREA

23.1 BACKGROUND

At the groundwater technical committee meeting of 30 May 2007 it was requested of the Berg WAAS project team to evaluate the applicability of the GRAII / Sami Groundwater model to the Berg WAAS area. The purpose of the Sami model, which has been incorporated into the later versions of the WRSM2000 (Pitman) model, is to model surface water-groundwater interaction in monthly time steps at a quaternary or sub-quaternary catchment scale. The WRSM2000 model can be run with this model enabled or disabled. The primary purpose of this task is to describe the applicability of the Sami model in the Berg WAAS domain by evaluating where, how and why, or why not, physical reality can be simplified to model definition or concept in the different quaternary catchments.

23.2 PRACTICAL EVALUATION

Based on a practical evaluation and a conceptual analysis of whether and how different aquifers exchange water with the tributaries and main stem of the river in each catchment in the study domain, it was concluded that the Sami model is not appropriate to use in 84% of the quaternary catchments in the Berg WAAS area. In all of these catchments the groundwater flow regime is truly 3D and cannot in any meaningful way be simplified to 1D, as is the case in the Sami model. In the remainder of the quaternary catchments, the Sami model can possibly be applied, although it is also not recommended. On the basis of the above assessment, two catchments representing each of the above categories were selected in which to test the Sami model by running the WRSM2000 model with the Sami model enabled and disabled and by using both the default as well as derived input parameters for the Sami model.

23.3 FINDINGS

The results of this assessment showed that, in both catchments, the default Sami parameters generally result in a slight decrease in simulated runoff - even when no groundwater abstractions are modelled, while the improved Sami parameters result in a fairly significant increase in simulated runoff. The results also showed that the introduction of groundwater abstractions, with the improved Sami parameters, reduces the long-term mean annual runoff (MAR) by about 25% of the actual annual volume that is abstracted. Furthermore, the investigation confirmed that re-calibration of the Pitman model, once the Sami model (with groundwater abstraction) is enabled, may be achieved by means of adjustments to ST, FT, ZMIN and ZMAX.

A more drastic re-calibration is required for those catchments that are classified as “inappropriate” as opposed to catchments in which the Sami model was deemed to be “possibly appropriate”. This was necessitated by a significant increase in simulated flow during the wet season in the “inappropriate” catchment.

23.4 POSSIBLE APPROACHES TO SURFACE WATER-GROUNDWATER INTERACTION MODELLING

In light of the findings of this evaluation, three possible approaches to facilitate the modelling of surface water-groundwater interaction in both the catchment and system models were considered, *viz.*:

- Conventional Pitman modelling (Sami groundwater model disabled)
- Pitman modelling with Sami model enabled

- Pitman model with external source representing groundwater contribution to discharge and "dummy" groundwater reservoir representing aquifer storage in the system model.

23.4.1 Pitman modelling with Sami model enabled

The first approach takes into consideration the serious concerns which have been raised with regard to the applicability of the Sami model and therefore proposes the use of conventional Pitman modelling, i.e. with the Sami model not enabled, as an option for the Berg WAAS. Such an approach assumes that the Pitman model implicitly accommodates the groundwater contribution to baseflow and that this is reflected in the calibrated Pitman parameters. The shortcoming of this approach however, relates to the most appropriate way in which to accommodate groundwater abstraction in the WRYM system model, taking into account that the naturalised flows, which will be produced by the calibrated Pitman model and which will be used as input to the system model, already reflect the impact of any groundwater abstractions as well as the groundwater contribution to baseflow.

23.4.2 Conventional Pitman modelling (Sami groundwater model disabled)

The second approach is based on the fact that, in spite of the findings of this report that the Sami model assumptions and implications for the hydrological process are not appropriate for the majority of the subcatchments in the study area, DWAF did put the Sami model forward for undertaking groundwater resource assessments in the WAA studies. It could therefore be considered appropriate for application in the Berg WAAS, as long as its limitations and the level of confidence in the results are clearly stated. Furthermore, as the Sami algorithms have been integrated into the system model, the effect of groundwater abstractions on baseflow and system yield can be assessed. However, it is the opinion of the study team that this approach will result in low levels of confidence in the modelling results due to the Sami model being considered "inappropriate" for 84% of the Berg WAAS quaternary catchments.

23.4.3 Pitman Modelling with "Dummy" Groundwater Reservoir

The third option aims to avoid the issues surrounding the application of the Sami model and promotes a simple, transparent conceptual model for accommodating surface water-groundwater interaction in both the catchment modelling and system modelling phases of the Berg WAAS. During the catchment modelling phase, it is envisaged that estimates of groundwater contribution to baseflow, as available on a quaternary catchment basis from the GRDM data (DWAF, 2006b), will be introduced into the Pitman network configuration as an external water source. This, in conjunction with the existing technique whereby the areas that are irrigated from groundwater sources are excluded from the total irrigated area, will ensure that the calibrated Pitman parameters reflect the net cumulative impact of groundwater use and groundwater baseflow on simulated river flow.

During the system modelling phase, the effect of groundwater use on baseflow (and system yield) will be simulated by introducing a "dummy" groundwater reservoir to represent the aquifer from which groundwater is abstracted. Estimates of aquifer capacity (size of the reservoir), recharge (inflow into the reservoir) and groundwater baseflow (outflow from the reservoir), will be based on best available knowledge. It is important to note that the GRDM estimates of groundwater contribution will be refined in those areas where the detailed numerical groundwater modelling which is currently underway, leads to an improved understanding of the surface water-groundwater interaction. During this refinement, which will take place before system modelling commences, the necessity for the reconfiguration of the catchment at a finer spatial resolution in order to accommodate aquifer specific groundwater discharge will also be considered.

Although the conceptual approach does not attempt to simulate all the groundwater processes that are treated as standard in conventional groundwater models, it is considered to be the most appropriate methodology within the context of the Berg WAAS and it is recommended that this approach be implemented.

24. SUMMARY OF OVERALL RECOMMENDATIONS

The following recommendations are summarised from the findings of the Berg WAAS.

24.1 RAINFALL MODELLING

The rainfall data analysis undertaken for the Berg WAAS and the development of a revised rainfall surface provides a better representation of Mean Annual Precipitation in the high mountain regions and these rainfall sequences should be regularly updated and used to generate catchment rainfall files for the purposes of future hydrological modelling.

24.2 STREAMFLOW GAUGING

The assessment of the streamflow gauging revealed several stations that are suitable for providing data for monitoring surface water-groundwater interaction. In some cases, these stations are no longer active and need to be reinstated in order to collect data suitable for future studies. In addition, some of the existing streamflow stations need to be upgraded and calibrated for accurate “low flow” measurements. The measurement of flow from springs and seeps also requires attention.

24.2.1 Enhancement of Existing Streamflow Gauging Stations

Table 24-1 shows a list of 31 existing streamflow gauging stations that are well suited for surface water / groundwater interaction modelling purposes.

Table 24-1 Existing Streamflow Gauging Stations Recommended for Reinstatement and Low Flow Measurement Enhancement

Gauge No.	River	Gauge No.	River
G1H002	Vier en Twintig	H1H003	Upper Breede
G1H008	Klein Berg	H1H006	Klein Berg
G1H011	Watervals	H1H007	Wit River
G1H012	Waterval River	H1H013	Koekedouw
G1H014	Wemmershoek	H1H018	Molenaars
G1H015	Wemmershoek	H2H004	Sanddrif River
G1H016	Wemmershoek	H6H007	Du Toits
G1H017	Wemmershoek	H1H003	Riviersonderend
G1H018	Wemmershoek	H1H006	Klein Berg
G1H019	Banhoek	H1H007	Wit River
G1H021	Klein Berg	H1H013	Koekedouw
G1H035	Matjies	H1H018	Molenaars
G1H066	Klein Berg	H2H004	Sanddrif River
G2H005	Jonkershoek	H6H007	Du Toits
G2H008	Jonkershoek	H6H008	Riviersonderend
G4H030	Palmiet		

24.2.2 Recommended Additional Streamflow Gauging

Table 24-2 shows a list of 11 proposed streamflow gauging stations for enhancing the monitoring of surface water-groundwater interaction, as well as 13 recommended locations for monitoring of springs.

Table 24-2 Additional Flow Gauging Required

Latitude	Longitude	River
GROUNDWATER – SURFACE WATER INTERACTION		
33.84751	19.01585	Berg
33.477300	19.175670	Breede
33.552490	19.220890	Breede
33.589240	19.263540	Breede
33.318630	19.098090	Klein-Berg
33.397410	19.290110	Breede
33.314790	19.298780	Skaap
33.409070	19.443540	Titus
33.506490	19.493220	Amandel
33.495940	19.530250	Sanddrif
33.512220	19.534970	Amandel
MONITORING OF SPRINGS		
33.74694	19.06834	Hugos
33.73220	19.41360	Brandvlei
33.66500	19.26639	Klip
33.73000	19.41556	Brandvlei
34.21200	18.83580	Boskloof
34.22700	18.84290	Dappas se gat
34.25650	18.85450	Rooiels
34.05000	18.88480	Lourens
34.23888	19.16861	Bot
34.22722	19.18055	Bot
34.09190	19.04900	Palmiet
34.22167	19.43805	Swart
34.25230	19.09780	Palmiet

24.3 CATCHMENT HYDROLOGY

Most subcatchments in the Berg WAAS area are adequately represented by suitable active rainfall stations except for those located in mountainous catchments. The MAPs generated from the new rainfall surface generally show an increase in both the CCWR and DWAF MAPs used previously. Some subcatchments in the mountainous regions are still under-represented in terms of their MAP due to the paucity of adequate rainfall stations in these regions. Thus, it is very important that the existing station network be well maintained and wherever possible, be enlarged to allow for better representation of observed records across the catchments.

24.4 BERG RIVER WATER QUALITY

The following are recommendations in relation to water quality issues impacting the Berg River:

- There is a need for careful and proactive management of all water resources within the Berg WMA to ensure that development and water requirement does not outstrip the available resources.
- Appropriate design and management of inter-catchment transfer schemes is necessary to mitigate the impacts on water quality and flow reduction in the rivers and the estuary. Management plans should be developed to schedule transfers.
- Site-specific receiving water quality objectives must be set to protect the headwaters of the rivers from the influence of increased volumes of wastewater being discharged.
- Measures to investigate and address increases in salinity in the Berg River downstream of Hermon and of Misverstand Dam should be developed.
- The effects of increased irrigation return flows need to be quantified and monitored in future. Effort should be made to ensure that the salts loads from all return flows are effectively managed.
- The influence of point and non-point source discharges on the receiving water quality must be determined, with particular reference to the aquatic ecology.
- There is an urgent need to integrate the various water quality data sets into a centralised and regularly updated and maintained database. The results of such an exercise would have numerous benefits for the water quality status in the WMA such as:
  - The ability to prioritize areas for improvement.
  - The water quality responses to sources of pollution may be used to prioritise source reduction efforts to pollutants with the greatest impacts or greatest worsening trends.
  - The results may be used to identify regional and local impacts on freshwater inflows and salinity regimes of the estuarine portions of the river systems.
  - The results may provide background scientific results for incorporation into public education material.
  - The results may provide a statistical framework for future monitoring of the effectiveness of management actions.
- An integrated water quality monitoring network is also essential to support the move toward an ecosystem-based management.
- The overall monitoring system design should determine what and where to monitor, including the definition of a set of core variables. Technical expertise is needed to standardise procedures and establish quality control, data management, and reporting protocols.
- The national monitoring network should include the following elements:
  - a core set of variables to be measured at all sites, with regional flexibility to measure additional variables where needed.
  - an overall system design that determines where, how, and when to monitor and includes a mix of time and space scales, probabilistic and fixed stations, and stressor- and effects-oriented measurements.
  - technical coordination that establishes standard procedures and techniques.
  - periodic review of the monitoring network, with modifications as necessary to ensure that useful goals are being met in a cost-effective way.
- Reforms to ensure that in the Berg River catchment, all environmentally significant activities (including significant new agricultural activities or the significant intensification of existing activities) are subject to a proper environmental impact assessment and approval process.
- Environmental management plans should be promoted for agricultural activities to promote farming practices that minimise downstream impacts.
- Ensure the Berg WMA water quality targets are reflected in the relevant provincial and local government legislations plans. Set up a catchment-scale water quality model for the Western Cape/ Berg WMA.

24.5 GROUNDWATER DATA

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

- Undertake a comprehensive spring hydrocensus
- Undertake a borehole hydrocensus
- Investigate and develop fracture mapping in TMG terrain
- Implement hydraulic testing in selected boreholes in both the Peninsula and Skurweberg aquifers
- Map the paleochannels and bedrock topography in West Coast and alluvium aquifers
- Undertake hydrochemical sampling at specific river reaches
- Review and revise monitoring network
- Review and revise geological mapping in selected areas.

24.6 GROUNDWATER MODELLING

24.6.1 Water Balance Model

The results of the Water Balance Model show that the uncertainty of the data input as well as the applied method has a significant impact on the reliability of the output, as well as on 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.

- Rainfall sampling and chemical / isotope analysis in selected recharge areas for calibration of the recharge model with a 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 to determine 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.

The development of a comprehensive monitoring programme for the Berg WAAS area is further suggested so as to comprise all relevant aspects in an integrated and optimised manner.

24.6.2 Cape Flats Aquifer Model

Table 24-3 presents the suggested recommendations for upgrading the Cape Flats Aquifer Model in the future.

Table 24-3 Recommended Upgrades to the Cape Flats Aquifer Model

Purpose	Aspect	Information required	Source of information
Boundary Conditions and Conceptual model refinement	Investigate whether significant groundwater flow occurs to the northwest discharging to Table Bay.	Basement elevation data, especially in the northwest	Geophysical investigation Borehole logs New boreholes
		Water table surface map	Additional water level point data, especially in northwest
	Investigate whether groundwater mounds exist across the water level surface or whether these are topographic imprints.	Water table surface map More data	Additional and more reliable water level point data across the Cape Flats
	Detail the hydraulic nature of the aquifer and the nature of confinement or not	Pump test results; Downhole geophysics; Estimates of porosity to refine model layers; Field estimates for different layers.	Pump test conducted in the central palaeochannel; Layer specific monitoring
Improve confidence in numerical model	Test reliability of numerical model boundary conditions and uniqueness of model solution for SW-GW interactions; Run model scenario with rivers as internal boundaries, and no flow boundaries at the aerial limit of the aquifer	Information above required to populate the larger model domain (especially to the northwest)	As above.
	More accurate representation of rivers	Actual data on river stages, and river widths, thus reducing the potential range of transfer rate parameter and improving confidence in the SW-GW interaction numbers	Field measurements of actual river widths; River stage data

24.6.3 Langebaan Road and Elandsfontein Aquifer Model

The following recommendations are made in respect of the Langebaan Road and Elandsfontein Aquifer Model:

- Implement a hydrocensus and data collection exercise across the Langebaan area, including information on water levels, borehole use, accurate GPS locations (X,Y,Z coordinates) of boreholes.
- Make surface water data available to all disciplines by allowing it to be converted to a universal datum. All gauging stations are required to be surveyed at the point at which the measurements are taken.
- Undertake
    - additional modelling at a smaller scale in order to understand the hydraulic nature of the aquifers and replicate differing flow directions at different depths. In the vicinity of the Berg River this will generate a better understanding of the nature of the surface water-groundwater interaction.
    - additional modelling at a smaller wellfield scale in order to manage the current situation of abstraction from storage.

- o smaller-scale modelling for the purpose of optimisation of abstraction volume and rate, and positions, for additional potential wellfields and licensing thereof.
- o smaller-scale model to be constructed for the purpose of optimisation of Artificial Storage Recovery injection volume and rate, and borehole positions.

24.6.4 TMG Aquifer Models

It is strongly recommended that a data collection and monitoring programme be initiated. The following activities are required for increasing the confidence in the model outputs of any model updates or refinements:

- Conduct a spring hydrocensus including diverse hydrochemical sampling to verify discharge rates;
- Implement continuous flow monitoring of selected springs, e.g. Aurora spring;
- Conduct a borehole hydrocensus to verify groundwater abstraction;
- Hydraulic test selected boreholes in both the Peninsula and Skurweberg aquifers to improve the estimate for the specific storage;
- Undertake hydrochemical sampling at specific river reaches to be used in mixing models for baseflow estimation.

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 respect to refining unused potential estimates;
- Monitoring of ambient boreholes in different aquifers to establish seasonal fluctuation of water levels for calibration of recharge estimation.

If further exploitation of the aquifers in the Piketberg area is considered, a feasibility study is recommended that comprises the development of a flow model on the wellfield scale, based on long-term monitoring data, as described above.

Due to the over-utilisation of the aquifers in the Hex River Valley, compulsory licensing of groundwater use is strongly advised. This should be based on a detailed flow model for the valley, using the regional pattern as described and quantified in this report and on long-term monitoring data.

24.6.5 Breede River Alluvium Model

It is recommended that priority be given to the acquisition of monitoring data (including surface water data, hydrogeological data, and hydroclimatic monitoring), to address model uncertainty, and for further scenario testing. These recommendations can be summarised as discrete projects, namely:

- Design and establish a dedicated groundwater/surface water monitoring network (water levels, abstractions, hydroclimatology and hydrochemistry) in the Upper and Middle Breede to obtain time-series data on fluvial aquifer response to vertical and lateral recharge (short-term priority).
- Map and understand the time lag between surface water and groundwater in the Breede to identify preferred sites for establishing a pilot ASR scheme as well as to upgrade the hydrological models that are input to the WRYM (medium-term priority).

- Hydraulic testing of the aquifer at selected sites to determine aquifer properties including storage potential and quantification of preliminary design of an ASR scheme (medium to long-term priority).
- Undertake model upgrade based on extensive testing and field confirmation of selected assumptions in the formal model test process, such that it can be used predicatively and thereby realise medium to long-term upgrade of the hydrological data and WRYM (short-term priority and ongoing).
- Evaluate use of heat flow modelling of TMG aquifers (short-term priority).

24.7 THE SAMI GROUNDWATER MODEL

Recommendations regarding the suitability of the use of the Sami Model in the Berg WAAS Area are as follows:

24.7.1 Conventional Pitman modelling (Sami groundwater model disabled)

This approach takes into consideration the serious concerns which have been raised with regard to the applicability of the Sami model and therefore proposes the use of conventional Pitman modelling, i.e. with the Sami model not enabled, as an option for the Berg WAAS. Such an approach assumes that the Pitman model implicitly accommodates the groundwater contribution to baseflow and that this is reflected in the calibrated Pitman parameters.

The catchment modelling will be relatively simple and there will be no need for recalibration once the Sami model has been enabled. The shortcoming of this approach however, relates to the most appropriate way in which to accommodate groundwater abstraction in the WRYM system model, taking into account that the naturalised flows, which will be produced by the calibrated Pitman model and which will be used as input to the system model, already reflect the impact of any groundwater abstractions as well as the groundwater contribution to baseflow.

24.7.2 Pitman modelling with Sami model enabled

This approach is based on the fact that, in spite of the findings of this report that the Sami model assumptions and implications for the hydrological process are not appropriate for the majority of the subcatchments in the study area, DWA did put the Sami model forward for undertaking groundwater resource assessments in the WAA studies. It could therefore be considered appropriate for application in the Berg WAAS, as long as its limitations and the level of confidence in the results are clearly stated. The Sami model does add enhanced groundwater simulation capabilities to the Pitman model and provides a generic algorithm that can be applied on a quaternary catchment scale to simulate groundwater-surface water interactions. Furthermore, as the Sami algorithms have been integrated into the system model, the effect of groundwater abstractions on baseflow and system yield can be assessed. It has also been demonstrated that the default Sami parameters may be replaced with improved estimates thereof by groundwater specialists with an intimate knowledge of the groundwater dynamics in the study area in order to improve confidence in the modelling results.

24.7.3 Pitman model with external source representing groundwater contribution to discharge and "dummy" groundwater reservoir representing aquifer storage

This option aims to avoid the issues surrounding the application of the Sami model and promotes a simple, transparent conceptual model for accommodating surface water-groundwater interaction in both the catchment modelling and system modelling phases of the Berg WAAS. During the catchment modelling phase, estimates of groundwater contribution to baseflow, as available on a quaternary catchment basis from the GRDM data (DWAF, 2006b), will be introduced into the Pitman network configuration as an external water source. This, in conjunction with the existing technique whereby the areas that are irrigated from groundwater sources are excluded from the total irrigated area, will ensure that the calibrated Pitman parameters reflect the net cumulative impact of groundwater use and groundwater baseflow on simulated river flow.

During the system modelling phase, the effect of groundwater use on baseflow (and system yield) will be simulated by introducing a "dummy" groundwater reservoir to represent the aquifer from which groundwater is abstracted. Estimates of aquifer capacity (size of the reservoir), recharge (inflow into the reservoir) and groundwater baseflow (outflow from the reservoir), will be based on best available knowledge.

24.7.4 Overall Comment

It is the opinion of the study team that the conventional Pitman approach should not be used in the Berg WAAS due to its limitations with regard to accommodating groundwater use in the system model. Similarly, although the Sami model approach is the preferred methodology for WAA studies, in the case of the Berg WAAS this approach will result in low levels of confidence in the modelling results due to the Sami model being considered "inappropriate" for 84% of the Berg WAAS quaternary catchments.

It is consequently proposed that the conceptual groundwater model be used for modelling surface-water groundwater interaction in Berg WAAS. Although the proposed conceptual model is a very simple model, which does not attempt to simulate all the groundwater processes that are treated as standard in conventional groundwater models, it is considered to be the most appropriate methodology within the context of the Berg WAAS. It is also proposed that the original GRDM estimates of groundwater contribution to baseflow are refined in those areas where the detailed numerical groundwater modelling which is currently underway, leads to an improved understanding of the surface water-groundwater interaction. During this refinement, which should take place before system modelling commences, the necessity for the reconfiguration of the catchment at a finer spatial resolution in order to accommodate aquifer specific groundwater discharge will also be considered.