UMVOTO AFRICA (PTY) LTD

Consultants for Water Resource Development and Management

Project No. WP10261 Groundwater Reserve Determination Study in the Mzimvubu to Keiskamma WMA – Western Portion

Intermediate GRDM Assessment

Draft

February 2012

Umvoto Africa (Pty) Ltd. Earth . Water . Science . Life
P.O. Box 61 Muizenberg 7950. Telephone: (021) 788 8031. Fax: (086) 524 0001.
E-mail: amanzi@umvoto.com Internet: www.umvoto.com
Reg. No.: 2001\013609\07
Directors: E R Hay CJH Hartnady A Mlisa Associate: K Riemann

Department of Water Affairs
Directorate: Reserve Requirements

GROUNDWATER RESERVE DETERMINATION IN THE MZIMVUBU TO KEISKAMMA WMA – WESTERN PORTION

INTERMEDIATE GRDM ASSESSMENT

APPROVAL

TITLE	:	**Groundwater Reserve Determination in the Mzimvubu to Keiskamma WMA – Western Portion:** **Intermediate GRDM Assessment**
DWAF REPORT NO.	:	
CONSULTANTS	:	**Umvoto Africa (Pty) Ltd**
AUTHORS	:	**Kornelius Riemann** **Len von Scherenberg** **Masibulele Fubesi** **Sinawo Oscar Jack**
REPORT STATUS	:	**Draft**
DATE	:	**February 2012**

STUDY TEAM: Approved for Umvoto

…………………………………………….	…………………………………………
E.R HAY	**K RIEMANN**
Project Director	**Project Leader**

DEPARTMENT OF WATER AFFAIRS
Directorate: Reserve Requirements
Approved for Department of Water Affairs

…………………………………………	…………………………………………
N MOTEBE	**Y ATWARU**
Groundwater RR	**D: RR**

REFERENCE

This report is to be referred to in bibliographies as :

Department of Water Affairs, South Africa. 2011. *Groundwater Reserve Determination in the Mzimvubu to Keiskamma WMA – Western Portion: Intermediate GRDM Assessment*. Prepared by Umvoto Africa (Pty) Ltd (Authors: K Riemann. L von Scherenberg, M Fubesi, S O Jack) on behalf of the Directorate : Reserve Requirements. DWA Report No.

Authors' Contributions

Dr Kornelius Riemann	Project Leader, supervision of staff
Mr Len von Scherenberg	Task leader for fieldwork, data analysis, and reporting
Mr Masibulele Fubesi	Fieldwork, data analysis, map production
Mr Sinawo Jack	Fieldwork and data analysis, Honours thesis on water quality
Mr Two Kufahakurambwi	Initial analysis on water level data and conceptual model
Mr Nisbert Chimboza	GIS data analysis, map production
Mr Alex Kuhudzai	GIS database, data management
Ms Andiswa Mlisa	Supervision of GIS staff
Dr Chris Hartnady	Technical review and geological overview
Mr Lawrence Maluleke	DWA secondment, fieldwork and initial data analysis
Mr Philani Khoza	DWA secondment, analysis of groundwater use data

TABLE OF CONTENTS

Chapter	Description	Page

List of Tables

List of Figures

List of Abbreviations

a	-	annum
cf	-	Compared with
e.g.	-	For example
ha	-	Hectare
km	-	Kilometre
m	-	Meter
mm	-	Millimetre
m^3	-	meter cubed
mS/m	-	milli Siemens per meter
op.cit.	-	Work previously cited
p.	-	Page
BHN	-	Basic Human Needs
DWAF	-	Department of Water Affairs and Forestry
EIS	-	Ecological Importance and Sensitivity
EISC	-	Ecological Importance and Sensitivity Class
ER	-	Ecological Reserve
EWR	-	Ecological Water Requirements
GIS	-	Geographic Information System
GRA II	-	Groundwater Resource Assessment, Phase II
GRDM	-	Groundwater Resource Directed Measures
IUA	-	Integrated Unit of Assessment
IWRM	-	Integrated Water Resource Management
K	-	Hydraulic Conductivity
MAP	-	Mean Annual Precipitation
MAR	-	Mean Annual Runoff
NGDB	-	National Groundwater Data Base
NW	-	Northwest
NWA	-	National Water Act (Act 36 of 1998)
NWRS	-	National Water Resource Strategy
PES	-	Present Ecological State
PESC	-	Present Ecological State Category
REC	-	Recommended Ecological Class
RDM	-	Resource Directed Measures
RDP	-	Reconstruction and Development Programme
RQO	-	Resource Quality Objectives
RU	-	Resource Unit
T	-	Transmissivity
WARMS	-	Water Use Authorisation and Registration Management System
WMA	-	Water Management Area
WRC	-	Water Research Commission

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES OF STUDY

The-Chief Directorate: Resource Directed Measures (CD:RDM) is tasked with the responsibility of ensuring that the Reserve requirements, which have priority over other uses in terms of the National Water Act (Act No. 36 of 1998), are determined before license applications are to be processed, particularly in stressed catchments or water management areas (WMA's).

In order to support the process of water use licensing while at the same time giving effect to the Reserve, the DWA appointed Umvoto Africa (Pty) Ltd and TG Bay Technologies (Pty) Ltd. for a determination of the groundwater component of the Reserve and development of Groundwater Resource Directed Measures (GRDM) in the Mzimvubu to Keiskamma WMA. There are generally differing levels of groundwater importance and sensitivity (per groundwater resource unit) within the Mzimvubu to Keiskamma WMA, especially in areas where groundwater has been severely impacted. Based on the variability with respect to the importance, sensitivity as well as the demand and the current use of groundwater, the confidence levels required in the results will vary with resultant differing levels of GRDM determinations required.

The objectives of conducting the Mzimvubu to Keiskamma GRDM determination are to:

- Undertake GRDM determinations for identified groundwater resource units and/or groundwater dependent ecosystems.
- Prioritising the groundwater resource units and/or groundwater dependent ecosystems- in terms of the following criteria
  - Current use
  - Future potential use
  - Level of stress (contamination, depletion etc.)
- Liaise and integrate results from the GRDM determination studies with available surface water resource studies, which should include the identification of groundwater dependant ecosystems (rivers, wetlands).
- Address both the quantity and quality of the groundwater resource. Groundwater quality aspects may be addressed as part of the Description of the Study Area, Water Resource Classification and Resource Quality Objectives.
- Address the use and protection of the entire water resource, including dependent ecosystems, in a holistic manner.
- Ensure the proactive protection of water resources, including groundwater resources, according to equity and sustainability principles for current and future use.
- Report results according to the geographical units relevant for the management and administrative processes of the DWA.

The appointment is for the technical component of the Mzimvubu to Keiskamma WMA GRDM study only. It excludes the setting of the 'Desired Status Category' and 'Management Class' for the delineated resource units that is achieved through a public participation process involving all stakeholders, especially DWA.

1.2 STUDY AREA

1.2.1 Delineation of study area

The study area of the overall project comprises the whole of the Mzimvubu to Keiskamma Water Management Area which is shown on **Figure 1-1**. It consists of three large drainage basins and the catchments of a number of smaller rivers that lie between the major drainage basins and the Indian Ocean. The major drainage basins are the Great Kei (Drainage Region S), the Mbashe (part of Drainage Region T), and the Mzimvubu (part of Drainage Region T).

It was agreed in discussions with the DWA to split the WMA into two parts that are investigated by two separate teams; viz. Umvoto Africa for the western part and TG Bay Technologies for the eastern part. The following split was defined in the Memorandum of Understanding between the two parties:

> **Umvoto**: Perform groundwater reserve determination study in the Mzimvubu to Keiskamma water management area focusing on primary drainage regions R and S, and secondary drainage region T9 incorporating the following towns: Cala, Idutywa, Willowvale, East London, Hamburg, King Williams Town, Alice, Queenstown, Sterkstroom, Indwe, inter alia.
>
> **TG Bay**: Perform groundwater reserve determination study in the Mzimvubu to Keiskamma water management area focusing on secondary drainage regions T1, T2, T3, T6, T7 and T8 incorporating the following towns: Matatiele, Kokstad, Mt. Ayliff, Flagstaff, Port St Johns, Coffee Bay, Elliotdale, Umtata, Engcobo, Elliot, Maclear, Mount Fletcher, inter alia.

1.2.2 Groundwater and domestic water supply

Groundwater has played a significant role in bringing safe water supply to the rural areas of the former Transkei and Ciskei. Water supply systems within the rural areas are often based upon rudimentary wellfields, with windpumps linked to a central reservoir tank. This approach was necessitated in areas where there is limited electricity supply, as well as the need to provide basic water supply to geographically dispersed villages and homesteads. Many rural schools and clinics also rely upon boreholes, where there may be access to electricity. The spring protection programme has contributed towards safeguarding the water quality of groundwater and has assisted Water Services Authorities to limit the risk of disease during times of cholera outbreak.

However, due to the inaccessibility of the areas and lack of infrastructure support, these rudimentary schemes are not always well maintained and groundwater is generally regarded as unreliable by the communities in the rural Eastern Cape.

Good results have been achieved such as within the Chris Hani District Municipality where technical support for groundwater supply systems has shown that groundwater can provide a safe, reliable source of water at an appropriate level of affordability. These small scale on-site systems are ideally suited to address the needs of dispersed communities in the rural areas and demonstrate that large surface water engineering solutions can be complemented by groundwater to achieve sustainable services in the Eastern Cape.

Figure 1-1 Umvoto study area as part of the Mzimvubu to Keiskamma WMA

1.3 REPORT STRUCTURE

Section 1 of this report provides the background to the study and project requirements.

Section 2 describes the main methodology for the Reserve determination and the available information and data sources.

The additional data collection and verification of information during the field work is described in **Section 3**.

Section 4 gives an overview of the study area and provides a detailed description in terms of topography, climate and aquifers.

The delineation of the Resource Units and a detailed description of each RU including their current status are provided in **Section 5**.

The results of the intermediate Reserve determination and the determination of the Resource Quality Objectives are summarised in **Section 6**.

Section 7 details the Monitoring Programme necessary to measure compliance with the RQOs.

Recommendations for the implementation of the study results and further work are given in **Section 8**.

The chemical analysis results of the groundwater samples taken during the field work are documented in **Appendix A**.

The Honours Thesis by Sinawo Oscar Jack, entitled "Groundwater Quality Analysis for Mzimvubu-Keiskamma Water Management Area (WMA) – Western Portion", which forms part the study and informed the groundwater quality aspect of the Reserve and RQOs, is attached as Annexure.

2. METHODOLOGY AND AVAILABLE DATA

2.1 STANDARD GRDM ASSESSMENT METHODOLOGY

The general methodology to follow for the Reserve Determination Study is outlined in the Terms of Reference and described in the Training Manual (Parsons, 2004). Further details regarding the methodology for setting Resource Directed Measures (RDM) and Resource Quality Objectives (RQOs) can be found in Xu et al (2002) and Colvin et al. (2003).

The National Water Act (NWA) recognises the need to develop and use the country's water resources to grow. However, the Act also recognises that our water resources must not be used to the detriment of future users. RDM hence strives to ensure that the water resources are afforded a level of protection that will assure a sustainable level of development for the future. To this end, RDM comprises three main interrelated components, namely:

- Classification
- Reserve
- Resource quality objectives.

Sequential steps to be followed when assessing these three components are briefly described in the following chapter.

2.1.1 Classification

An integral part of the GRDM process is the classification of each quaternary catchment or the identified single water resource units. The main objective of the Classification process is to ensure that the resource can be utilised sustainably in the long term if the proposed class is adhered. In general during the classification process one has to distinguish between classes and categories of the resource units. While the identification of resource classes is done including a public participation process, the categories are solely based on technical input by the assigned expert.

The identification of present status categories can generally be done on the basis of different criteria, such as:

- Observed environmental impact indicators
- Groundwater stress
- Groundwater quality and contamination

The final identification of the classes/categories should include both water quantity and quality considerations. Groundwater quantity is addressed by the stress index which is introduced further on in this report. An overview of the classes as introduced by Dennis et al is given in **Table 2-1**.

The water resource classification process is not part of this technical study and will need to be addressed in follow-up studies. The present status of the resource units will be described in **Section 5**.

Table 2-1 Classification system (after Dennis et al, 2010)

PRESENT CLASS	GENERIC DESCRIPTION	AFFECTED ENVIRONMENT
Minimally used (I)	The water resource is minimally altered from its pre-development condition.	No sign of significant impacts observed
Moderately used (II)	Localised low level impacts, but no negative effects apparent	Temporal, but not long-term significant impact to: -spring flow - river flow - vegetation - land subsidence - sinkhole formation - groundwater quality
Heavily used (III)	The water resource is significantly altered from its pre-development condition.	Moderate to heavy impacts to: - spring flow - river flow - vegetation - land subsidence - sinkhole formation - groundwater quality

2.1.2 Reserve

The Reserve for a specific water resource is the quantity as well as the quality of water from that resource necessary to (Dennis et al, 2010)

- satisfy basic human needs by securing a basic water supply as prescribed under the Water Services Act (Act 108 of 1997), for people who are currently or who will in the reasonably near future be relying upon that resource, who will be taking water from that resource or will be supplied from that resource (known as the basic human needs Reserve); and
- protect the aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource (known as the ecological Reserve).

The ecological Reserve should be determined by surface water and ecological specialist, as the methods require quantification of flow, habitat and water quality requirements of all the ecosystems in the water resource in order for them to remain at or attain the selected level of health, and therefore classification of the ecosystem.

The groundwater component of the ecological Reserve comprises the required groundwater contribution to the relevant surface water resource to sustain the ecological Reserve in terms of quantity and quality. The approach to determining the groundwater contribution varies depending upon the flow regime in the surface water resource, the aquifer characteristics and level of the assessment.

2.1.3 Resource Quality Objectives

Resource Quality Objectives (RQOs) must set objectives for the management of water resources in a catchment or Resource Unit, and must be applicable on that scale. RQOs should spell out the principles upon which licensing conditions are based. In general terms, RQOs establish clear goals relating to the quantity and quality of a water resource. Typical characteristics of RQOs include the following (Dennis et al, 2010):

- They set limits that are simple and measurable.
- They set the limits of acceptable impact.
- They may be numeric or descriptive.

Setting RQOs requires an understanding of groundwater resources and their boundary conditions, uses of groundwater, the importance of various uses and the agreed degree of modification of the surface water resource. When setting RQOs, consideration must also be given to ecological dependencies on groundwater and the consequences of modifying the geohydrological regime (Dennis et al, 2010).

2.1.4 Steps in undertaking GRDM assessment

The following steps are the standard tasks of the GRDM process, as outlined in the Training Manual:

- Preparatory phase
- Description of study area
- Delineation of groundwater resource units
- Resource classification
- Quantification of the Reserve
- Setting resource quality objectives
- Recommending a groundwater monitoring programme

2.2 APPLIED METHODOLOGY FOR GRDM ASSESSMENT

The standard GRDM methodology is used to calculate the Basic Human Needs (BHN) and the Ecological Reserve with the following changes and considerations.

- Recharge is calculated per aquifer type to ensure aquifer specific estimates.
- The groundwater component of the Ecological Reserve is set as equal the Maintenance Low Flow (MLF) for the relevant quaternary catchments;
- Basic Human Needs is based on the current population, irrespective of whether they are currently served from surface water or groundwater;
- Current groundwater usage is determined from a variety of sources and the fieldwork verification;
- Protected areas and special ecological sensitive sites are considered as hotspots with special RQOs;
- The Present Status Category (PSC) of the groundwater resources is determined for quantity (aquifer stress) and quality (aquifer contamination).

Further details of the approach and methodology to estimate the different parameters are given below. The results of the applied methodology are discussed in Section 6.3.

2.2.1 Groundwater Recharge

The recharge values obtained from the Internal Strategic Perspective (ISP) report (DWAF, 2004) for different aquifer types are used to estimate groundwater recharge within each Resource Unit. The data compiled for the ISP study provides total recharge volumes per year for the different aquifer types in each quaternary catchment. The respective polygons are processed using GIS in order to compute the total recharge per Resource Unit. Since the Resource Unit boundaries follow the quaternary catchments and geology boundaries, the polygons can be assigned the respective Resource Unit. The sum of all values of the polygons within one Resource Unit yields the total recharge for the respective Unit.

In some instances (Resource Units 5, 8 and 22) the number obtained from the detailed ISP data does not appear realistic. The numbers for these Units seem to be faulty due to errors in the GIS processing and are therefore corrected using GRA II numbers and initial ISP estimates that were done on quaternary catchment level.

2.2.2 Maintenance Low Flow

Values for the Maintenance Low Flow (MLF) are obtained from the software Spatial and Time Series Information Modelling (SPATSIM) for all quaternary catchments in the study area. The Recommended Ecological Category (REC) for the surface water catchments is used as an input parameter to calculate the MLF for each quaternary catchment. The REC is selected based on available surface water Reserve determination for the selected catchments or desktop Reserves previously undertaken. Whenever the REC is between two categories (e.g. A/B) the higher class (e.g. A) is used in order to cater for a conservative scenario resulting in a higher MLF value.

If a Resource Unit covers more than one catchment or parts of various catchments, a spatial split is required to translate the MLF values per quaternary catchment into values per Resource Unit. The sum of the quantified MLF values of each catchment or parts thereof yields the MLF value for the Resource Unit.

2.2.3 Basic Human Needs

Numbers for Basic Human Needs (BHN) are calculated using population data obtained from the All Towns Reconciliation Strategy Study (DWA, 2011) for the Amatole and Chris Hani District Municipalities. Data from the GRDM tool is not considered because it shows a sparse population compared to the municipal data set. The population number per Resource Units is multiplied by 25 litres per day and person (BHN standard) in order to obtain the total volume per year.

This method results in effectively counting twice the population that is already supplied by bulk water supply systems or local groundwater source. However, the BHN number is not very significant compared to the other elements of the water balance and the likely double counting of the population is deemed acceptable and on the conservative side. Hence, the standard approach is followed.

2.2.4 Groundwater Reserve

The Groundwater Reserve is calculated as the sum of BHN and MLF for each Resource Unit, and given as total volume and as percentage of recharge.

2.2.5 Quantification of current Groundwater Usage

The estimation of current groundwater usage requires special attention since a number of data sources are available with sometimes very different numbers. The available data sources are summarised in **Table 2-2**.

Table 2-2 Data sources used for the estimation of current groundwater usage

Data source	Aspects considered	Shortcomings
GRA II	All water use sectors	Usage might be over-estimated
WARMS	All DWA water usage registrations	Small scale abstraction not considered Registered amount might be exceeded significantly
GRIP	Percentage of communities being supplied by groundwater	Restricted to certain parts of the study area
All Towns Reconciliation Study	Municipal demand supplied by groundwater	No agricultural usage included
Lukhanji Feasibility Study	Irrigation water requirements in Lukhanji LM area	Estimate for a certain part of the study area only
Field work	Mainly agricultural groundwater use	Focus on area around Queenstown

All available data sources are used to give an estimation of the groundwater usage per Resource Unit. The different sources all have certain shortcomings, which is why for each Resource Unit a more detailed assessment of the numbers is required in order to obtain a realistic estimation for the actual usage. A discussion of the final numbers according to the different data sources per Resource Unit is given in section 5 (Resource Units).

2.2.6 Quantification of available Groundwater Resources

After estimating groundwater recharge and the groundwater reserve, the total allocable amount is calculated. Also taking into account the current usage the additionally available amount is obtained.

The total allocable resources for each Resource Unit are obtained as:

Allocable = Recharge - Reserve

The currently additionally available resources for each Resource Unit are obtained as:

Available = Allocable - Allocated

Available = Recharge - Reserve - Allocated

2.2.7 Present Status Category

The Present Status Category of the aquifers in each resource unit is determined for quantity and for quality, using the concept of aquifer stress and aquifer vulnerability as proposed by Parsons (2005).

2.3 Methodology for Water Quality Data Analysis

The data analysis was undertaken for both the available data sets and the additional field data collected in this project, and focused on two aspects; i.e. the hydrochemical characterisation of different aquifers and the identification of areas impacted by deteriorating water quality.

The hydrochemical characterisation was based on

- Histogram analysis of selected parameters;
- Piper and Durov Diagrams for different areas;
- Scatter diagrams for selected parameters; and
- Spatial variation of hydro-chemical characteristics.

The identification of deteriorating water quality was based on a combination of the following analyses:

- Water quality trends for selected monitoring boreholes using time series graphs;
- Identification of pollution sources, based on the GRIP data sets; and
- Spatial variation of pollution based on all available data sets.

2.4 Available Data and Information

2.4.1 Groundwater monitoring programmes in the Eastern Cape

There are only 52 boreholes in the Eastern Cape Province which are currently routinely monitored as part of the DWA national groundwater monitoring programme, the majority of which are situated in WMA 15: Fish to Tsitsikamma. This means that there is a lack of data on groundwater quality in the areas where water is routinely used for drinking water supply. Effects of pollution from on-site sanitation systems, disposal of swine fever carcasses and solid waste sites on groundwater are not monitored or quantified. In combination with the logistical difficulties in providing disinfection agents to local users, it is imperative that groundwater resources are protected. Research into small water supply systems in the Alice district has shown that microbiological pollution from pit latrines can reach boreholes used for drinking water within a radius of 50 meters or less (Momba and Brouckeart, 2005). In the absence of monitoring information, the sustainability of the aquifers in the Eastern Cape can be at significant risk of pollution which poses a hazard to the natural environment as well as to any possible domestic users.

Some of the Water Services Authorities (WSA) have their own groundwater monitoring programmes, especially in areas where groundwater is utilised for domestic supply. However, these are very limited and not easily accessible.

The National Groundwater Database (NGDB) contains historic information about water level, field measurements and chemical analyses for 9014 boreholes and springs in the study area.

2.4.2 Groundwater use

Groundwater use in the Eastern Cape is generally a hidden water use activity, and it is estimated that less than 20% of all boreholes are registered with the DWA. This situation makes it difficult for the responsible authorities to regulate and control groundwater users, to ensure that the use is sustainable. In sensitive aquifers this poses the added risk of aquifer damage, such as in Alexandria where over-pumping of municipal supply boreholes resulted in incursion of marine water. The programme of the DWA Eastern Cape to identify and register all significant groundwater users, i.e. the Groundwater Resource Information Programme (GRIP), has made inroads in increasing the numbers of groundwater users who are registered with the Department. However the GRIP has not been completed yet and there are areas where no information on groundwater usage is available.

The present project will contribute towards improving the groundwater data for the Eastern Cape, as it will be necessary to source field data on existing boreholes as far as possible for determining the groundwater Reserve. All data sourced through this project will be provided to the National Groundwater Database (NGDB) and/or the National Groundwater Archive (NGA) depending upon the requirements of the DWA.

A further indication of current and future groundwater use is the borehole distribution, although not all drilled boreholes are in use. The NGDB/NGA provides detailed information about all boreholes that were drilled in the study area, while the GRIP gives an update of that information for certain areas, confirming the current status and use of the boreholes. The distribution of boreholes according to both sources is shown in **Figure 2-1.**

Figure 2-1 NGDB, GRIP and WMS boreholes

2.4.3 Groundwater Quality

The list of available und utilized data includes:

- DWA National Groundwater Database (NGDB) with information about boreholes and their positions in the study area, some of which have chemical analysis data attached.
- DWA Water Management System (WMS) with information about monitoring boreholes, their positions in the study area and chemical analysis results of groundwater from each borehole (see **Figure 2-2**).
- DWA Groundwater Resource Information Programme (GRIP) with information about boreholes, their positions and use in mainly rural areas of the Eastern Cape, as well as possible pollution sources in the vicinity of these boreholes. However the GRIP has not been completed for the whole study area and there are areas where no information is available.
- Water samples collected during the field work in July 2012 (see section 3). All collected samples were sent for chemical analysis to Talbot & Talbot Laboratories in Pietermaritzburg. The chemical analysis included the standard parameters as per SANS 241. The results are documented in Appendix B.

2.4.4 Previous Groundwater Studies

A large number of groundwater studies have already been conducted in the study area. The available groundwater studies from 2003 to date are:

- Centane District Water Supply Feasibility Study, Camdecon (2006)
- Final Feasibility Study Report for Ibika-Centane Water Supply Project, SMM (2008)
- Idutywa Groundwater Feasibility Study, Jeffares Green Parkman Consultants (2003)
- Butterworth Water Services Feasibility Study, Arcus Gibb & VSA (2005)
- Nqamakwe Water Services Feasibility Study - Hydrogeological Investigation, FST/SRK (2004)
- Tsomo Rural Water Supply - Geohydrological Exploration, TMH/VSA (2003)
- Mtshanyane Water Supply Project - Hydrogeological Investigation, Lukhozi/SRK (2007)
- Teko Springs Water Supply Project - Hydrogeological Investigation, Arcus Gibb/SRK (2006)
- Emahlaleni Water Services Feasibility Study - Hydrogeological investigation sub report, SRK (2005)
- Lukhanji Regional Water Supply Feasibility Study – Appendix 5: Groundwater Component, Umvoto (2006)
- Chaba Cwecweni Study - CHTT, Hydrogeological Investigation, Groundwater evaluation & development, AGES SA (PTY) LTD (2008)
- Sterkstroom Feasibility - CHTT , Hydrogeological Investigation, Groundwater Supply verification and design, AGES SA (PTY) LTD (2009)
- Hydrogeological feasibility study in and around the town of Kei Mouth, SRK (2009)
- Hydrogeological investigation in and around the village of Ngileni, SRK (2008)
- Groundwater Development Strategy - Chris Hani DM

- Centani Water Supply Project - Geohydrological Investigation, Khulani VSA Groundwater Consultants (2006)
- Centane Rural Water Supply Project-Geohydrological Exploration, E.R. Chipps (2003)
- Kwelera Rural Water Supply Project, A.J. van Rooyen (2004)
- Hydrogeological Investigation into the Sterkstroom Area - Phase 1 based on Tender W8783 - Chris Hani District Municipality - Eastern Cape Province, AGES (2007)
- Groundwater Reserve determination for Catchment S20B, Elitheni Coal; AGES (2011)
- Preliminary Determination of the Reserve for the Groundwater Component in Quaternary Catchment R30B; DWA (2005)
- Preliminary Determination (Desktop Level) of the Reserve for the Groundwater Component in Quaternary Catchment R40A; DWA (2006)

2.4.5 Other relevant monitoring programmes

The Water Services Authorities, i.e. Amathole and Chris Hani District Municipalities, have their own monitoring programmes, mainly with respect to the water quality of the groundwater supplied to the communities. Where available, the monitoring results have been incorporated into the database for analysis.

The DWA carries out further monitoring of the surface water resources and climate that were used where relevant for the determination of the groundwater Reserve. The following datasets have been utilised (see **Figure 2-2**):

- Monthly rainfall from selected rainfall stations across the study area;
- Daily and monthly flow records from selected flow gauging stations; and
- Water quality information from selected WMS monitoring sites.

Figure 2-2 DWA Surface Water Monitoring Sites

3. FIELDWORK

3.1 INTRODUCTION

In the beginning of July 2011 some initial field work was carried out by a team of 2 Umvoto staff members supported by Lawrence Maluleke from the DWA and University of Fort Hare student Sinawo Jack. During a period of 10 days selected sub-areas of the study area (see **Table 3-1**) were studied with regards to groundwater usage, water quality as well as general (hydro)geology and geomorphology. The principal aims of the initial fieldwork were as follows:

- Carry out a hydro-census in the near vicinity of Queenstown (quaternary catchments S31E, S31F, S31G and S32H) where the GRDM tool (GRA II data) indicates a very high groundwater stress.

- Test groundwater quality in terms of physico-chemical and microbiological parameters in selected areas of different geology with known pollution and/or a high concentration of potential contamination sources. For the analysis of groundwater quality three general target areas were identified based on existing water quality data and potential contamination sources (see Error! Reference source not found.). The analysed target areas are:

  - Nqamakwe and surrounding rural communities

  - Centane and coastal rural communities

  - King William's Town, Dimbaza, Keiskammahoek and surrounding rural communities

Table 3-1 Focus areas of the fieldwork

Area	Focus	Motivation	Boreholes tested	Interviews conducted	Geology/ Aquifer
Queenstown and surroundings	Groundwater usage	High Stress Index	9	15	Quaternary
Keiskammahoek, Dimbaza, King William's Town	Groundwater quality	Industrial contamination	3	3	Adelaide
Nqamakwe and surroundings	Groundwater quality	Microbiological contamination	7	7	Katberg/ Adelaide
Centane and surroundings	Groundwater quality	Microbiological contamination	11	11	Adelaide

Figure 3-1 Focus areas of the fieldwork

3.2 HYDRO-CENSUS AROUND QUEENSTOWN

The desktop Reserve determination of the Inception Phase (DWA 2011) has shown that according to GRA II data used in the GRDM tool a very high groundwater stress is present in some catchments around Queenstown. The WARMS database indicates that groundwater usage in the highly stressed catchments is predominantly owing to agricultural irrigation. The analysis of earth observation images as well as the Lukanji Feasibility Study (DWA 2006) have risen doubt on the accuracy of the GRA II data. Therefore some of the catchments with high stress index identified in the desktop reserve determination (section 4.10) were subject to a hydro-census. Visiting the area and assessing the degree of water usage in irrigation, an overview of the situation was obtained. During the hydro-census areas of farmland as well as areas of municipal groundwater usage were targeted for interviews with the respective person in charge of managing the borehole (farmer or municipal worker). The area of field work as well as the targeted boreholes are shown in **Figure 3-2** to **Figure 3-5**.

Figure 3-2 Focus area of field work south of Queenstown

Figure 3-3 Focus area of field work west of Queenstown

Figure 3-4 Focus area of field work north-west of Queenstown

Figure 3-5 Focus area of field work north-east of Queenstown

3.3 WATER QUALITY SAMPLING

3.3.1 Keiskammahoek, Dimbaza and King William's Town

Since the greater area of King Williams Town is to a large degree supplied by surface water from the surrounding dams (e.g. Sandile Dam), groundwater is rarely used for domestic supply. However in some rural areas that are not yet connected to the schemes communal boreholes are used.

The National Groundwater Database (NGDB) reflects numerous entries in the area but finding functional boreholes that allow water sampling has proved to be problematic. Since boreholes are no more used, maintenance is stopped and they might not be accessible any more. Although groundwater is rarely used for public supply its quality needs to be monitored and managed in order to protect its function as a natural resource. The area of field work as well as the targeted boreholes are shown in
Figure 3-6.
.

3.3.2 Centane and Coastal Rural Communities

The town of Centane is fully supplied by boreholes whereas the surrounding coastal communities are partly supplied by communal boreholes used to fill the existing reservoirs and partly connected to the Lower Qolora Scheme using water from the Qolora and Qxora Rivers. Since the area is densely populated and there is wide spread small cattle farming, there is a risk of microbiological contamination. The area of field work as well as the targeted boreholes are shown in **Figure 3-7**.
.

3.3.3 Nqamakwe and Surrounding Rural Communities

The site visit has shown that groundwater is widely used for water supply of the rural communities in the Nqamakwe area. These communities frequently depend on boreholes as their only source of supply which highlights the importance of sustainable management of the available resources in terms of quantity and quality. Since the area is densely populated and there is wide spread small cattle farming, there is a risk of microbiological contamination. The area of field work as well as the targeted boreholes are shown in **Figure 3-8**.

Figure 3-6 Focus area of field work around Keiskammahoek and King Williams Town

Figure 3-7 Focus area of field work around Centane

Figure 3-8 Focus area of field work around Nqamakwe

3.4 LABORATORY ANALYSIS

The parameters measured in the field were pH value, Electrical Conductivity (EC), temperature, odour, turbidity and colour of the samples. Groundwater samples were usually taken with a bailer and filled in 100 ml and 1000 ml bottles. All collected samples were sent for chemical analysis to Talbot & Talbot Laboratories in Pietermaritzburg. In addition, the water level in the borehole was measured using a dip meter. The chemical analysis including the standard parameters as per SANS 241 are documented in Appendix B and discussed in section 5.

Table 3-2 Parameter list of chemical and microbiological analysis with DWQ Classes

Parameter	Unit	Class 0 (Ideal)	Class I	Class II	Class III
Conductivity at 25˚	mS/m	0 – 70	70 - 150	150 – 370	>370
Total Dissolved Solids	mg/l	0 – 450	450 - 1000	1000 – 2400	>2400
pH value at 25˚	pH units	6 – 9	5 – 9.5	4 – 10	<4 or >10
Ammonia as N	mg/l	0 – 1	1 – 2	2 – 10	>10
Fluoride as F	mg/l	0 – 1	1 – 1.5	1.5 – 3.5	>3.5
Sulphate as SO_4-	mg/l	0 – 200	200 - 400	400 – 600	>600
(Nitrate and Nitrite) as N	mg/l	0 – 6	6 – 10	10 – 20	>20
Sodium	mg/l	0 – 100	100 – 200	200 - 400	>400
Chloride	mg/l	0 – 100	100 – 200	200 - 600	>600
Colour	mg/l Pt	0 - 15	15 - 20	20 – 50	>50
Dissolved calcium	mg/l	0 – 80	80 – 150	150 – 300	>300
Dissolved magnesium	mg/l	0 – 30	30 – 70	70 - 100	>100
Faecal coliforms	Count per 100 ml	0	0	1 - 10	>10
Odour	TON	0 – 1	1-5	5 – 10	>10
Potassium	mg/l	0 – 25	25 – 50	50 – 100	>100
Soluble organic carbon	mg/l	0 - 5	5 – 10	10 – 20	>20
Total iron	µg/l	0 – 10	10 – 200	200 - 2000	>2000
Total alkalinity	mg $CaCO_3$/l	0 – 50	50 – 120	120 – 300	>300
Total coliforms	Counts per 100 ml	0 - 5	5 – 10	10 – 100	>100
Total hardness	mg CaCO3/l	0 – 100	100 – 200	200 – 300	>300
Total manganese	µg/l	0 – 50	50 – 100	100 – 1000	>1000
Turbidity	NTU	0 – 0.1	0.1 – 1	1 - 5	>5

Class I Recommended optional limit
Class II Maximum allowable for limited duration
Class III Not suitable for human consumption

4. STUDY AREA DESCRIPTION

4.1 INTRODUCTION

The study area considered in this report comprises the western portions of the Mzimvubu to Keiskamma Water Management Area and lies within the borders of the District Municipalities of Chris Hani and Amathole. It consists of the whole drainage basin of the Great Kei (Drainage Region S), a smaller portion of the drainage basin of the Mbashe (part of Drainage Region T) and the catchments of a number of smaller rivers (Drainage Region R) located in the south-west of the study area between the major drainage basins and the Indian Ocean. The study area as part of the Mzimvubu to Keiskamma WMA with the respective primary and quaternary surface water catchments as shown in **Figure 1-1**. The detailed topography of the study area is shown in **Figure 4-1**.

4.2 DRAINAGE AND TOPOGRAPHY

The study area is bounded by the Fish to Tsitsikamma WMA in the west, the Upper Orange WMA in the north, the remaining part of the Mbashe drainage basin in the east and the Indian Ocean in the south-east.

The topography is hilly to mountainous throughout the study area with the high mountains of the Amatola Mountain Range with an elevation of up to 1400 mamsl. The rivers are usually deeply incised in the area of the coastal strip.

For purposes of assessing water requirements and the available water resources, the water management is divided into quaternary catchments which are the basic unit of area used in assessment of the surface water resources of South Africa and also used as primary unit for groundwater assessment.

The study area consists of Drainage Regions S, R and a smaller portion of Drainage Region T. It contains a total of 95 quaternary catchments from these drainage regions.

- Drainage Region R, known as the Amatole Region, consists of the catchments of the Keiskamma River (R10A to R10M), the Buffalo River (R20A to R20G), the Nahoon (R30E, R30F) and the Gqunube (R30C, R30D) Rivers, and several smaller rivers along the coast from the western boundary of the WMA to the catchment of the Great Kei River to the north-east. The area is generally mountainous, with the rivers flowing in deeply incised valleys. Most rivers are perennial (see **Figure 4-2**).
- The catchment of the Great Kei River is designated Drainage Region S. It extends from the northern and north-western edges of the WMA to the coast. The main tributaries of the Great Kei River are the Black Kei River (S31, S32), the White Kei River (S10A to S10J), with its tributary, the Indwe River (S20A to S20D), the Tsomo River (S50A to S50H), and the Thomas (S40A to S40E), Kubusi (S60A to S60E) and Zilinxa (S70C to S70E) Rivers. The upper reaches of the Black Kei, Klaas Smits and White Kei are ephemeral, while the rivers in the lower parts are mostly perennial (see **Figure 4-3**).
- A smaller portion in the south-east of the study area lies within Drainage Region T, which extends into the District Municipality of O.R. Tambo and further east into the Mvoti to Mzimkulu WMA. The quaternary catchments of some smaller coastal rivers (T90A to T90G) between the main catchments of the Kei River and the Mbhashe River form part of the study area, while the majority of Drainage Region T is located within the remaining part of the Mzimvubu to Keiskamma WMA which is not part of this study.

Figure 4-1 Topography of the study area

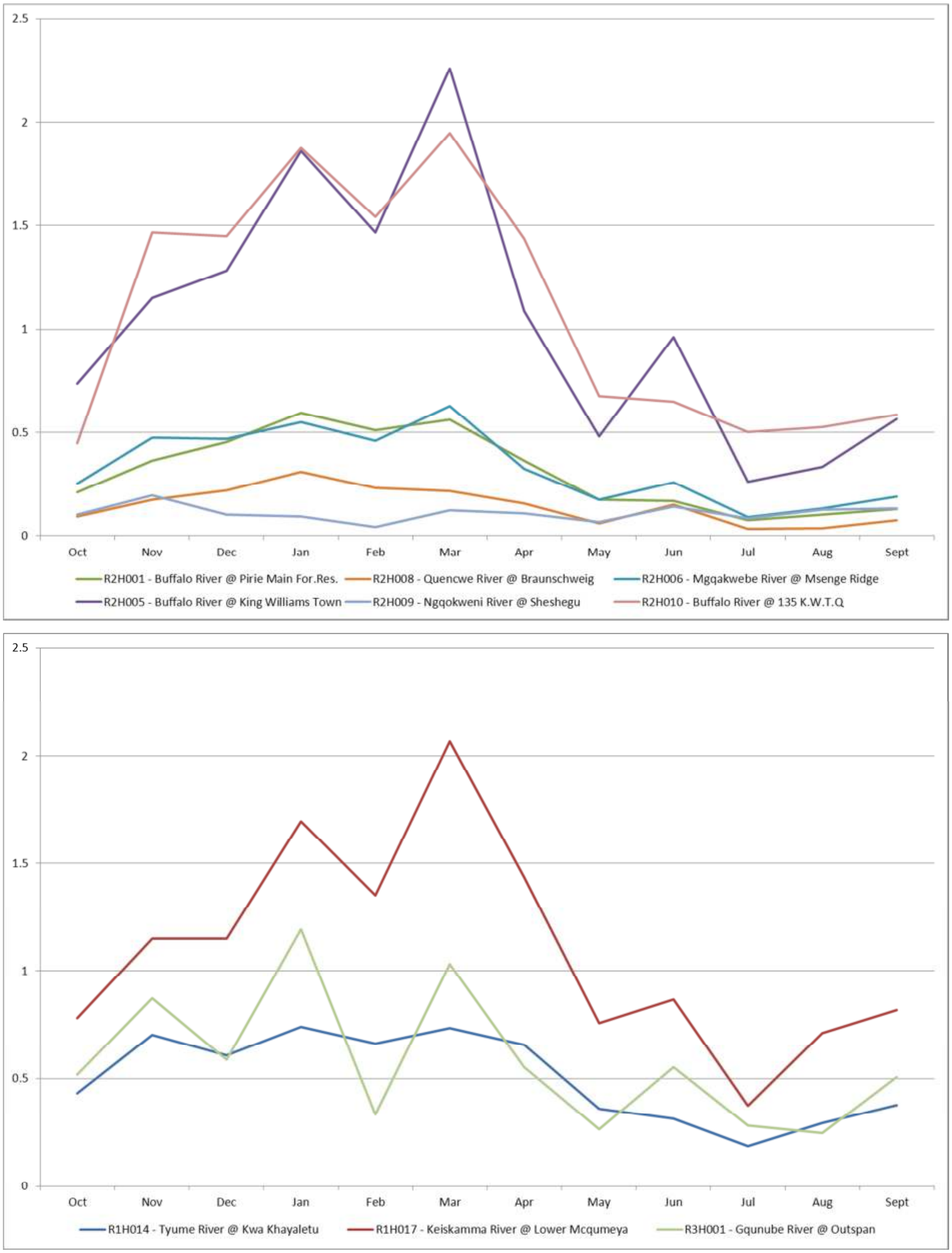


Figure 4-2 **Average seasonal stream flow (m^3/s) in Drainage Region R; a) Buffalo River, b) Tyume, Keiskamma and Gqunube rivers**

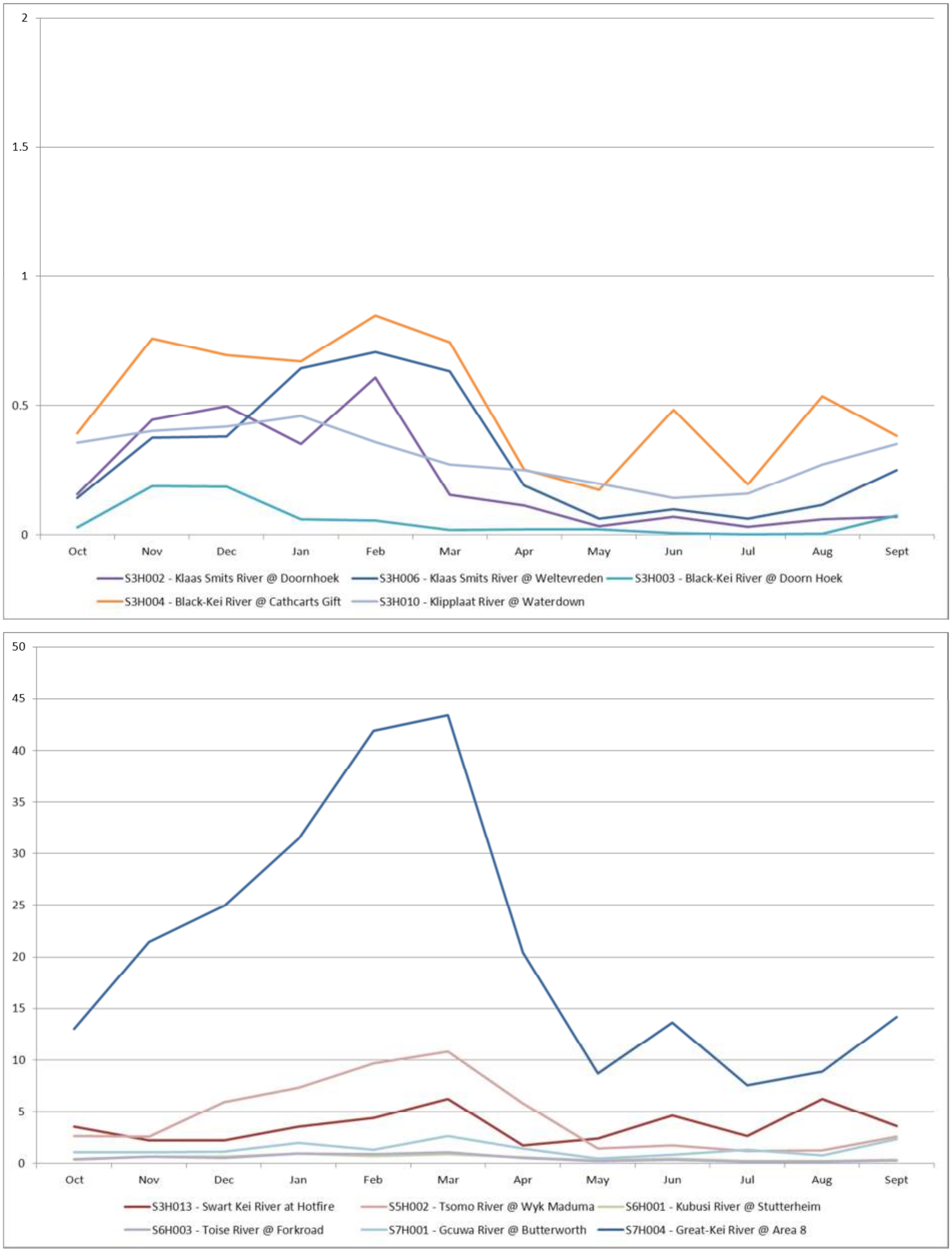


Figure 4-3 **Average seasonal stream flow (m^3/s) in Drainage Region S; a) Black Kei River and tributaries, b) Great Kei River and major tributaries**

4.3 CLIMATE

The climate and temperature variations of the study area are closely related to elevation and proximity to the coast. The area experiences a temperate climate along the coast to more extreme conditions inland. Most rainfall occurs during the summer months. Temperature variations along the coast are less pronounced than inland where frost (and sometimes snow) is regularly experienced during the winter months while temperatures regularly exceed 40°C during the summer months.

Rainfall increases from the west to the east and from inland to the coast with a local high along the Amatola mountain range. Annual rainfall along the coastline varies from approximately 500 mm in the West to approximately 800 mm in the East, and over 1200 mm in the Amatola Mountains. Annual rainfall in the Kei catchment varies from a low of approximately 400 mm in the Upper Kei area around Sterkstroom, to 700 mm in the Middle Kei, to 1000 mm at Kei Mouth (see **Figure 4-2** with MAP data from selected rainfall stations). The highest rainfall area is again in the Amatola Mountains. There is a great variation of the quantity of rainfall throughout the WMA. The rainfall is generally higher in the east than in the west. The distribution of the mean annual precipitation (MAP) of the study area is depicted in **Figure 4-5**.

The seasonal variation of rainfall is very similar in the different regions of the study area and shows clearly the dominance of the summer rainfall. The lowest rainfall is usually between May and July, while the summer peak extends from November to March (see **Figure 4-6** to **Figure 4-8**).

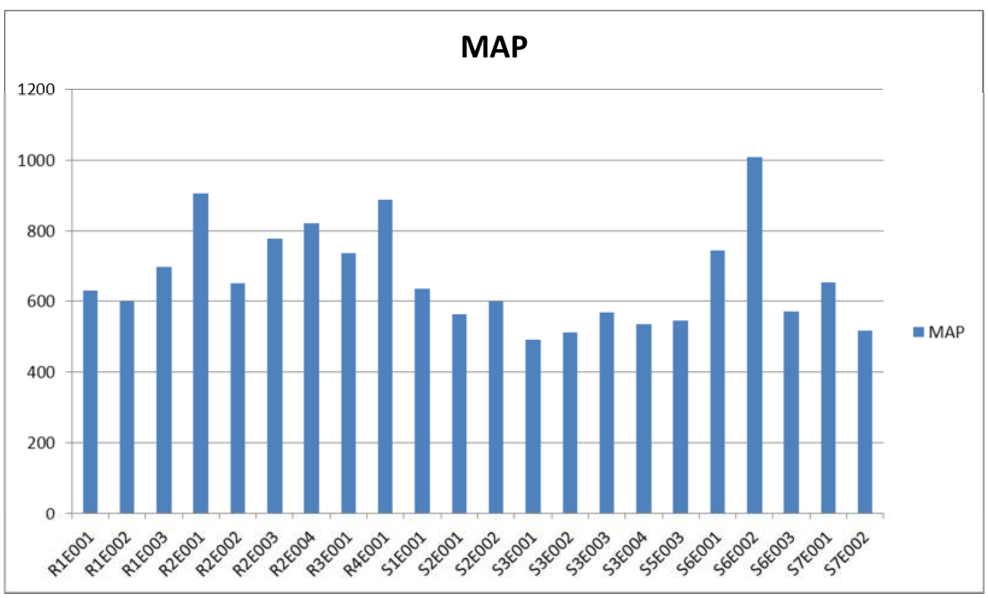
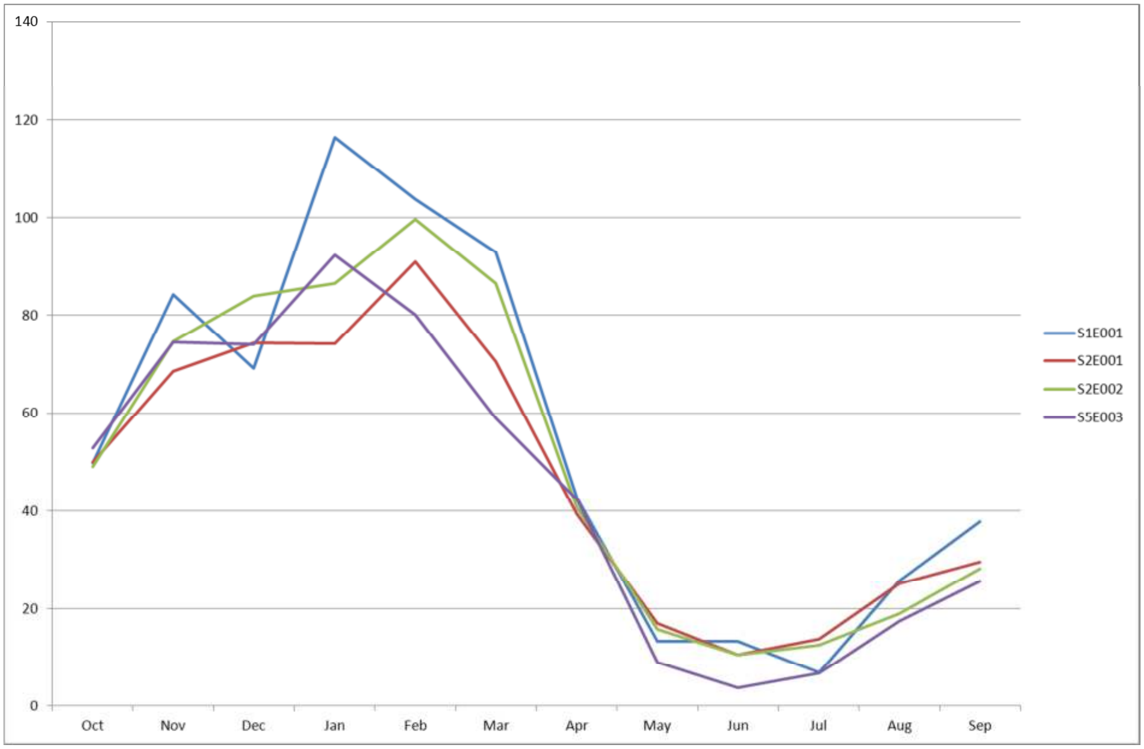


Figure 4-4 **Mean Annual Precipitation (mm/a) for selected DWA rainfall stations in the study area**

Figure 4-5 Distribution of the mean annual precipitation (MAP)

Figure 4-6 **Average seasonal rainfall pattern (mm/a) in Drainage Region R; a) inland climate stations, b) coastal stations (around East London)**



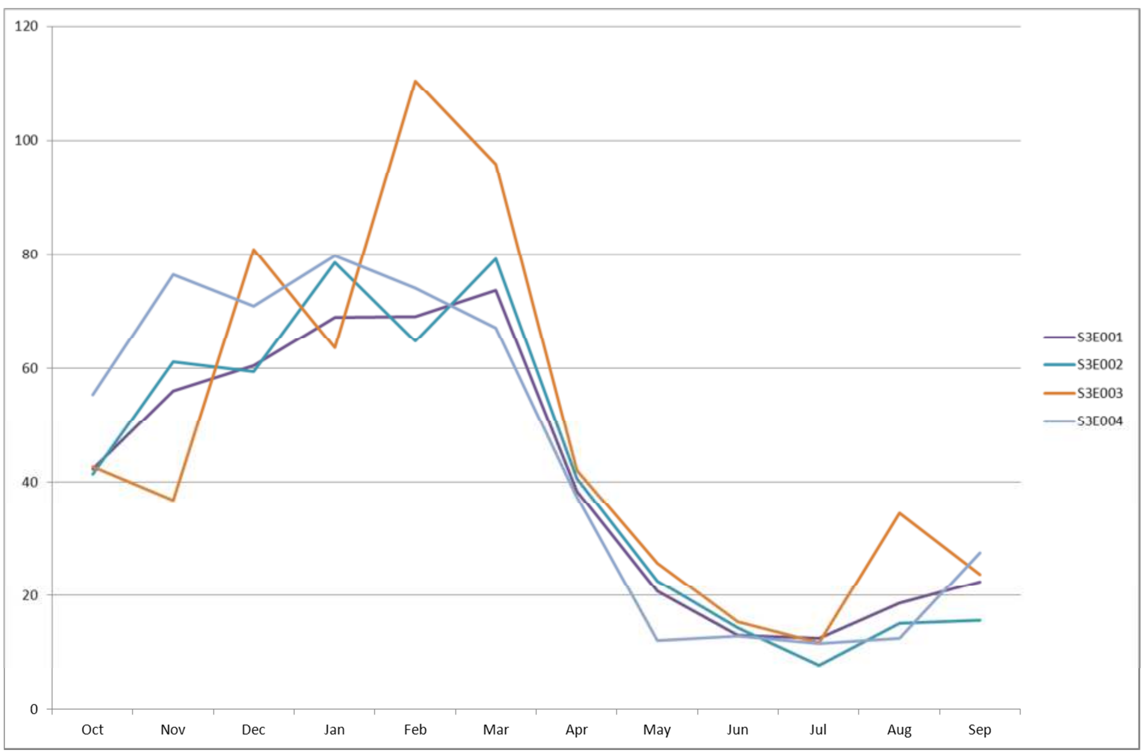


Figure 4-7 **Average seasonal rainfall pattern (mm/a) in Drainage Region S; a) White Kei and Tsomo River catchments (S1, S2 and S5), b) Black Kei catchments (S3, around Queenstown)**

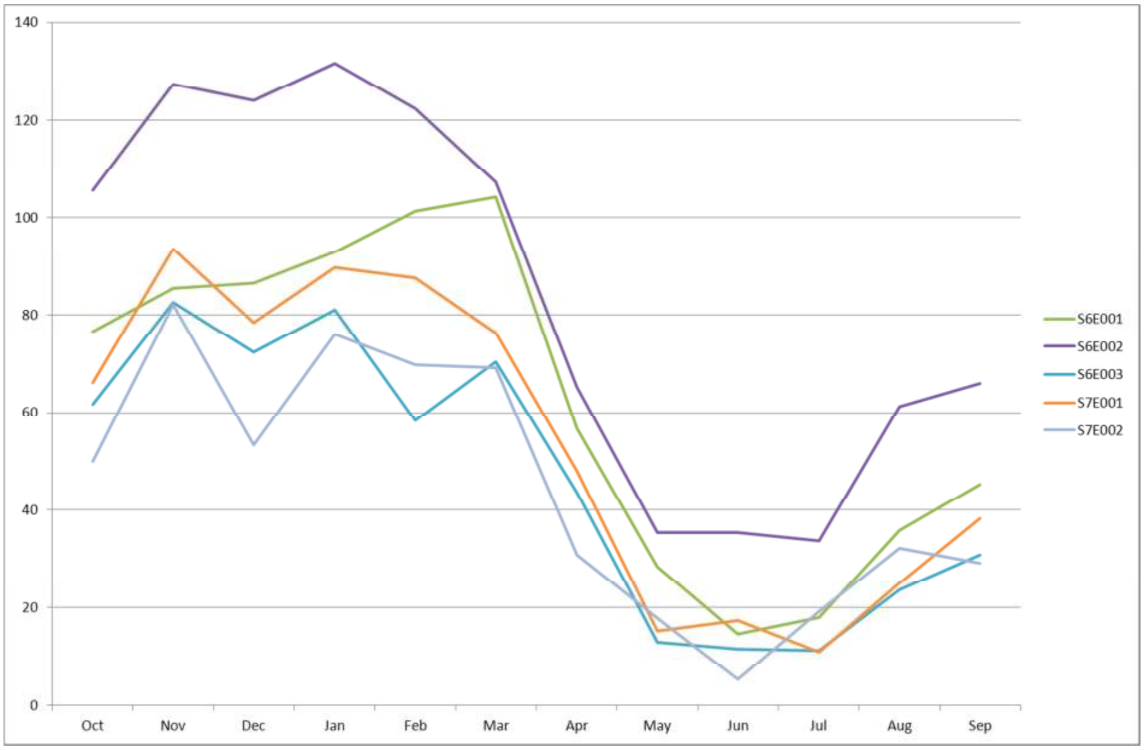


Figure 4-8 Average seasonal rainfall pattern (mm/a) in Drainage Region S – Great Kei catchments (S6 and S7)

The mean annual temperature ranges between 20°C along the coast and 12°C in the North, with an average of 16.1°C for the Mzimvubu to Keiskamma WMA as a whole. Maximum temperatures are experienced in January and minimum temperatures usually occur in July. Frost occurs in the inland areas in winter, typically over the period from mid-May to late August and snowfalls occur on the mountains in winter. The distribution of the mean annual temperature is depicted in **Figure 4-9**.

The relative humidity in the WMA is higher in summer than in winter. It is generally highest in February (the daily mean ranges from 60% in the north-west to 82% in the south-east) and lowest in July (the daily mean ranges from 50% in the north-west to 72% in the south-east). Average potential mean annual gross evaporation (as measured by Symons-pan) for the WMA ranges from 1 700 mm in the north-west to less than 1 200 mm in the south-eastern parts. The mean annual evaporation (MAE) of the study area is depicted in **Figure 4-10**.

Figure 4-9 Distribution of the mean annual temperature

Figure 4-10 Distribution of the mean annual evaporation (MAE)

4.4 GEOLOGY

The Eastern Cape is considered to be South Africa's most geologically diverse province, which comprises mostly sandstones alternating with olive mudstones and grey shale. There are extensive intrusive dolerite sills and dykes with characteristic ring structure formations in the major Karoo and Upper Kei catchment around Queenstown being a notable feature of the geology. Based on the regional geology, the porosity, permeability and transmissivity of the aquifer are different although it is estimated that significant quantities of groundwater could be abstracted, the actual use of ground water is relatively small over most of the area. This is mainly attributed to the generally well-watered nature of the area due to rainfall from inland to the coast, as well as the wide occurrence of perennial surface streams, which reduces the need for groundwater abstraction.

The study area consists predominantly of the Beaufort Series of the **Karoo Supergroup** with the Adelaide subgroup between the coast and the Amatola Mountains, the overlying Tarkastad subgroup north of the Amatola Mountains, and the **Cape Supergroup** (Molteno and Elliot Formations) along the northern boundary. The Geology of the study area is depicted in **Figure 4-11**. An overview of the lithostratigraphy is given in **Table 4-1**.

Table 4-1 Lithostratigraphy of the study area

Group	Subgroup	Formation	Lithology
			Alluvium
Drakensberg			Basaltic lava
			Dolerite Intrusion
		Clarens	Sandstone
		Elliot	Mudstone, sandstone
		Molteno	Mudstone, shale, sandstone
Beaufort	Tarkastad	Burgersdorp	Mudstone, sandstone
		Katberg	Sandstone, mudstone
	Adelaide	Balfour	Mudstone, sandstone
		Middleton	Mudstone, sandstone
		Koonap	Mudstone, sandstone
Ecca		Fort Brown	Shale, mudstone, sandstone
		Ripon	Shale, mudstone, sandstone
Dwyka			Tillite

The Adelaide subgroup comprises mostly mudstones alternating with lithofeldspathic sandstones. The Tarkastad subgroup; especially the Katberg Formation; is characterized by a greater proportion of sandstone and red coloured mudstone. The Molteno formation contains yellow grey sandstones alternating with olive mudstones and grey shale. The Elliot formation which overlies the Molteno formation comprises an upward fining cycle of sandstone, siltstone and mudstone. An overview of the thickness, sandstone/mudstone proportions as well as the percentage of quartz grains within the sandstone bars of the most relevant lithologic units of the study area is given in **Table 4-2**.

Figure 4-11 Geology of the study area

Table 4-2 Characteristics of the lithological units within the study area (after Chevalier et al, 2009)

Lithology	Average thickness (m)	Sandstone (%)	Mudstone (%)	Quartz grains (%)
Clarens Formation	300	90	10	55
Elliot Formation	500	30	70	70
Molteno Formation	600	40	60	80
Katberg Formation	800	90	10	40
Burgersdorp Formation	700	25	75	50
Adelaide Subgroup	5000	25	75	20
Ecca Group	1000	5	-	-
Dwyka Group	300	-	-	-

There are extensive intrusive dolerite sills and dykes throughout the area with characteristic ring structure formations in the Upper Kei catchment around Queenstown. The Amatola mountain range forms the southern boundary of one of these ring structures. The Dolerite intrusions can generally be divided into dykes and sill structures that form an interconnected network exceeding the limits of the study area. Typically dyke structures are vertical intrusions that manifest as straight lines at the surface whereas sills are formed by horizontal intrusions that outcrop in more complex structures (such as rings) according to the surface morphology. Dolerite structures become especially relevant for hydrogeological investigations since the intrusion of magma tends to cause significant fracturing in the surrounding host rock as well as in the dolerite itself. Therefore areas of dolerite structures are frequently preferred for groundwater development in geological settings with usually poor groundwater occurrence. The dolerite structures in the study area have been studied and mapped thoroughly by Chevallier et al (2009). The geological map (**Figure 4-11**) incorporates the data set for dolerite sill structures gained from this study. Cross sections of the study area reflecting the likely network of sill and dyke structures are given in **Figure 4-12**.

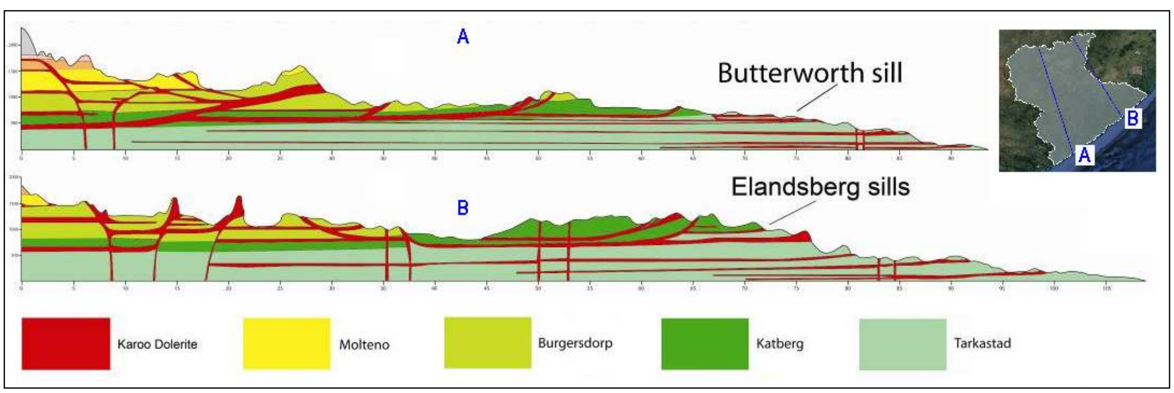


Figure 4-12 Geology cross sections of the study area with schematic system of dolerite dykes and sills (modified after Chevallier et al, 2009)

The predominant lithological strata are shales, mudstones, and sandstones of the Karoo Sequence that have been intruded by dolerite dykes and sills. Quaternary deposits are mostly concentrated in the north of the study area (Queenstown area and further north) where alluvial slope (sheet-washed) and valley (channel-transported) deposits of varying thickness occur. Some quaternary deposits of calcarenite and calcareous sand of aeolian origin also occur in the coastal areas especially in the vicinity of river estuaries where dunes are formed.

The following soil types occur in the Mzimvubu to Keiskamma Water Management Area:

- Moderately deep to deep clayey loams in undulating to steep terrain along the south-western coast of the WMA (between R50B and T90B).
- Moderately deep to deep sandy loams in steep terrain in the south-western part (R10G, R10H, R10J) of the Keiskamma River catchment and in the valley of the Great Kei River (between S32M and S70B).
- Moderately deep to deep sandy loam in undulating terrain in the rest of the study area.

A characteristic of the geology and soils of the area is that once the vegetation is removed by whatever means, erosion of the topsoil is rapid due to the nature of the dispersive soils derived from the underlying geology. This in turn causes high turbidity/suspended solids in rivers and reduced quality in any kind of surface water bodies as well as siltation of dams.

4.5 HYDROGEOLOGY

4.5.1 Aquifer Type

In general the lithology of the study area allows for a separation into three aquifer types as introduced by Smart (1998). This classification is based on the nature of the voids of the rock through which the water is transmitted rather than the boundaries of individual aquifers. The aquifer types are as follows:

- Intergranular
- Fractured
- Intergranular and fractured
- Dolerite

In intergranular aquifers water is transmitted and stored in voids (or pores) between the single grains that form the water bearing layer (aquifer). Usually this is the case in sediments/deposits such as sands or gravel. In contrast, fractured aquifers consist of hard rock that has been fractured by tectonic forces resulting in cracks of different magnitudes within the rock matrix. Flow and storages within this fracture system can differ significantly from the one in a simple porous (intergranular) aquifer. In the intergranular and fractured case water is transmitted and stored in both, the voids between single grains and also the fracture system within the rock matrix.

For the purpose of this study these aquifer types are used as one criterion for the delineation of separate water resource units as introduced in chapter 5. The geological formations and their corresponding aquifer type are presented in **Table 4-3**. The majority of the lithology is classified as intergranular and fractured aquifers. The purely fractured aquifer type is mostly present as the Katberg Formation in the centre of the study area. Dolerite intrusions are present throughout the study area, whereas intergranular alluvium is only present in smaller portions in the north-northwest of the study area.

Table 4-3 Geological formations and their respective aquifer type

Group	Subgroup	Formation	Aquifer type
			Alluvium/Intergranular
Drakensberg			Intergranular/ Fractured
			Dolerite Intrusion
		Clarens	Fractured
		Elliot	Intergranular/ Fractured
		Molteno	Intergranular/ Fractured
Beaufort	Tarkastad	Burgersdorp	Intergranular/ Fractured
		Katberg	Fractured
	Adelaide	Balfour	Intergranular/ Fractured
		Middleton	Intergranular/ Fractured
		Koonap	Intergranular/ Fractured
Ecca		Fort Brown	Intergranular/ Fractured
		Ripon	Intergranular/ Fractured
Dwyka			Intergranular/ Fractured

4.5.2 Recharge

For the estimation of the part of the precipitation that ends up as groundwater recharge two different data sources are used.

As part of the Groundwater Resource Assessment, Phase II (GRA II; DWAF, 2004) groundwater recharge has been estimated for the whole country as percentage of rainfall, mainly based on the Chloride Mass Balance (CMB) method. Groundwater recharge for the study area as calculated in the GRA II project is depicted in **Figure 4-13**.

In addition groundwater recharge calculations as prepared for the DWA Internal Strategic Perspectives (ISP; DWAF, 2004) are used for comparison. In contrast to the GRA II data, the ISP estimations are based on a water balance approach and take into account the different aquifer types (see Section 4.5.1) which are known to allow distinct proportions of the precipitation to infiltrate into the underground and become groundwater recharge.

A detailed comparison and discussion of the numbers obtained from GRA II and ISP data is documented for each Resource Unit in Section 5. A summary for the whole study area is shown in **Table 4-4**.

Table 4-4 Summary of recharge estimates for study area

	GRA II method (million m^3/a)	ISP method (million m^3/a)
Drainage Region R	247.2	286.7
Drainage Region S	568.2	718.6
Drainage Region T9	222.5	138.3
Total in Study Area	1037.9	1143.7

Figure 4-13 Distribution of groundwater recharge (GRA II)

4.6 LAND USE

Land use in the study area is mostly characterised by agriculture. The different land use activities in the study area are shown on **Figure 4-14** and comprise the following:

- Livestock farming (beef, dairy, sheep, goats) throughout the area
- Subsistence farming (maize, vegetables) mainly in the former Ciskei, Transkei and Development Trust areas
- Commercial vegetable farming (tomatoes, cabbages etc) around East London and the Komga and Kubusi areas
- Pineapple farming along the coastal areas
- Several irrigation developments (including citrus) in the former Ciskei and Transkei areas are gradually being rehabilitated. These are located in the Keiskamma catchment below Binfield Park, Sandile and Cata Dams (Keiskammahoek, Zanyokwe and Tyume schemes), in the Klipplaat catchment below Waterdown and Oxkraal Dams (Shiloh scheme), below the Xonxa and Lubisi Dams (Xonxa and Qamata schemes) and from the Ncora Dam (Ncora scheme).
- Commercial afforestation is practised in the higher rainfall areas of the Amatola mountains along the upper catchments of the Keiskamma, Kubusi, Klipplaat and Buffalo Rivers.

The second important characteristic is the vast amount of villages and small communities in the former Transkei and Ciskei areas. These have significant impact on the water resources with respect to their current and future water requirements and the current lack of proper sanitation.

Figure 4-14 Land use

4.7 ECOLOGICALLY SENSITIVE AREAS

The ecological significance/conservation importance of the river systems falling within the Mzimvubu to Keiskamma WMA is described by their Ecological Importance and Sensitivity Classes (EISC), which are summarised in

Table 4-5. The river reaches within the study area exhibit the full range of EISCs from "low" to "very high" and associated Present Ecological Status (PES) and Recommended Ecological Class (REC) ranging from Class B: largely natural, to Class D: largely modified. A map showing the REC of the study area is given in **Figure 4-15**.

Table 4-5 Summary of surface water ecological importance in the Mzimvubu to Keiskamma WMA; REC = Recommended Ecological Class, PES = Present Ecological Status, EISC = Ecological Importance and Sensitivity Class

Classification	REC	PES	EISC	EIS
A – natural	0	0	Very High	5
A/B – Natural/largely natural	0	0		
B – largely natural	36	3	High	9
B/C – largely natural/moderately modified	2	1		
C – moderately modified	46	47	Moderate	64
C/D – moderately/largely modified	2	2		
D – Largely modified	9	42	Low	17

Reaches of the Black Kei (e.g. S31A-F, S32A-M) and White Kei Rivers (e.g. S10A-J), typically exhibit "moderate" to "low" EISCs, corresponding to PESs and RECs of Class C: moderately modified, and Class D: largely modified. These are indicative of their manipulated/degraded condition.

In contrast, most reaches of the Keiskamma River (R10A-M) exhibit a "high" to "very high" EISC, although the PES range from Class C: moderately modified to Class D: largely modified. Most of the coastal rivers (T90A to T90G) have a high to very high EISC.

Accordingly the environmental water requirement of these rivers varies significantly between 9.2% of MAR and 48% of MAR, with an average of 23.6%. However, most of these assessments were undertaken at very low and low level of confidence. Currently there are only 9 intermediate surface water Reserves at a higher confidence level determined by the DWA. The selected EWR sites and associated Ecological Water Requirements (EWR) are given in **Table 4-6**.

The ecologically sensitive areas are divided into four groups:

- Surface water/streams
- Wetlands
- Springs
- Protected areas

Figure 4-15 Recommended Ecological Class (REC) per quaternary catchment and EWR sites

Table 4-6 EWR Sites with Surface Water Reserve in the study area

Quaternary. catchment	EWR Site	Incremental or cumulative	PES	REC	Surface Water Reserve (Mio m^3/a)
R20A	EWR Site 1: Buffalo River	Cumulative up to the EWR Site in R20A	D	D	4.90
R20F	EWR Site 2: Buffalo River	Cumulative up to the EWR Site in R20F	C	C	19.68
S10J	EWR Site 4: White Kei River	Cumulative up to the EWR Site in S10J	C/D	C/D	30.98
S32G	EWR Site 1: Klipplaat River	Cumulative up to the EWR Site in S32G	C	C	12.81
S32K	EWR Site 2: Upper Black Kei River	Cumulative up to the EWR Site in S32K	D	D	15.97
S32M	EWR Site 3: Lower Black Kei River	Cumulative up to the EWR Site in S32M	C/D	C/D	25.50
S60B	EWR Site 1: Kubusi River	Cumulative up to the EWR Site in S60B	C	C	11.64
S60E	EWR Site 2: Kubusi River	Cumulative up to the EWR Site in S60E	C	C	17.23
S70A	EWR Site: Kei River	Cumulative at the outlet of quaternary catchment S70A	C	C	138.04

The surface water system has been described in detail under section 4.2. There are numerous wetlands, springs and protected areas that spread over the entire study area. **Figure 4-16** shows that there are some major protected areas in the western part of the study area and one in the east-southeast. Out of the multitude of wetlands seeps and valleyhead seeps are considered the most relevant for this study since they are in direct contact with the groundwater table and may therefore provide information about the subsurface and groundwater system where no boreholes are present.

Accumulations of seeps are found mostly towards the margins of the study area such as

- in the area about 15 km south of Dordrecht (S10F);
- in the area north of Cala (mainly S50C);
- in the area of Tsomo at then eastern margins (S70D, S70C, S50J, S50G);
- in the area about 30 km south-west of Whittlesea (S32A);
- in and around the protected area north/north-west of Keiskammahoek (S32D, R10F, R10B, S40B);
- in the area about 15 km from King Williams Town (R20D, R10K)
- in the area south of Idutywa (T90A);
- in the area south-east of Butterworth (T90G, T90D).

Springs are locations where groundwater naturally emerges from the Earth's subsurface in a defined flow and in an amount large enough to form a poor or stream-like flow. They usually emerge from a single point, while seeps emerge over a larger area, having no well-defined origin. Seeps generally have a lower flow rate than springs and only rarely have a volume large enough to form a stream. Many seeps and small springs are associated with topographic depressions where the water table intersects the Earth's surface. Larger springs are usually formed where geological structures, such as a faults and fractures, or layers of low-permeability material, force large amounts of water to the surface. Springs provide important habitat for wildlife and plants. Seeps are an important wetland type; they provide habitat for many wetland plant and animal species. The types of springs found in the study area are perched, groundwater fed and thermal or hot springs. Perched and groundwater fed springs are usually cold water springs. Perched springs are seasonal and unlikely to be impacted by groundwater abstraction. They occur above the regional water table. Groundwater-fed springs are permanent in nature, and occur in low-lying areas. They are at a similar elevation as the regional water table.

Chevallier et al (2009) provide statistics of the springs in the study area compiled from data provided by the National Groundwater Data Base (NGDB), the Groundwater Resource Information Project (GRIP), a springs' census of the Great Kei catchment and a spring's assessment study by Maluti Water. The spring data for the study area are incorporated into the map in **Figure 4-16**.

The occurrence of springs in the study area is frequently related to dolerite structures such as the dolerite rings in the Queenstown area, where a notable cluster of springs is found. Generally they might occur at different places along the ring structure, but very commonly on the shallow slopes of the ring. It is observed that the density of seeps decreases with elevation and with slope steepness. Fewer seeps are located in the elevated and steeper parts of the dolerite ring. The majority of springs occur on the lower slopes and on the inner side of the ring. They are a result of water following from shallow dipping cracks and more specifically fractures parallel to the walls of the intrusion. Many of them are associated with wetlands and local landslides and can form the head of first order streams.

In addition, lithological transition zones such as that between the Burgersdorp and Katberg or the Katberg and Upper Balfour (Adelaide) Formations appear to have more springs and seeps on them. The transition is characterised by a higher frequency of alternating sandstone and mudstone than the rest of the sequences which are either mainly sandstone dominated or mainly mudstone dominated. The water percolates through the sandstone and emerges at the contact with the mudstone. The sandstone-rich Katberg Formation does not seem to be favourable for spring's occurrence, except at an intersection with a major dyke cluster. The contact Upper Balfour and Katberg seems to be favourable for spring occurrence. The effect a concentration of springs at a transition between different formations is observed e.g. in the Manzimahle area around Cala in the northeast of the study area, where springs and seeps are concentrated at the base of the sandy Lower Molteno Formation, and at the top of the underlying mudstone rich Burgersdorp Formation.

Figure 4-16 Wetlands, springs and protected areas

4.8 GROUNDWATER USE

There is already notable groundwater use taking place within the boundaries of the study area. The extent to which groundwater resources are being used depends a lot on the location and its specific characteristics. Also the type of groundwater use (e.g. municipal supply, irrigation, industry, etc.) varies a lot according to the respective area. Significant groundwater abstraction volumes registered in the WARMS database are depicted in **Figure 4-17**. The respective type of use is shown in **Figure 4-18**.

Groundwater use per quaternary catchment is also available from the Groundwater Resource Assessment, Phase II (GRA II; DWA, 2004). In general there is a large gap between the numbers from GRA II and WARMS. While the total sum of groundwater use within the boundaries of the study area calculated from the GRA II data equals 35.1 million m³/a, the one calculated from the WARMS data only equals 9.0 million m³/a. In most of the quaternary catchments the annual usage per catchment is far lower after the WARMS database. Only in 16 out of 95 catchments the WARMS number exceeds the GRA II number, accounting for 3.36 million m^3/a. In 34 cases the WARMS database does not indicate any groundwater use while there is notable use according to the GRA II, accounting for 4.37 million m^3/a. The main difference arises out of possibly not registered groundwater use of 22 million m^3/a for agricultural use in the S31 and S32 catchments (see **Table 4-7**).

Table 4-7 Comparison of Groundwater Use between WARMS and GRA II

	WARMS (million m^3/a)	GRA II (million m^3/a)	Comments
Total volume	13.99	35.06	
Urban supply	9.21*	0.24	GRA II only listed for Illinge, Komga and Sterkstroom
Rural supply	1.41**	8.17	Most municipal supply not registered on WARMS
Agricultural use	3.37	26.65	Mainly in S31 and S32
Other	0	0.01	

*domestic and industrial

** taken as Schedule 1, probably partly included in Municipal supply

The current All Towns Reconciliation Strategy Study (DWA, 2010; DWA, in prep.) provides additional information about current and predicted future water for water services. Increasing groundwater usage is expected in the rural areas in the south-east of the study area; especially in the catchments T90A to T90E, T90G, S70C to S70F and S50J where a number of major village clusters are already partly or fully supplied from groundwater resources. The rural villages and the towns in the Great Kei area (e.g. Morgan's Bay and Komga; R30B, S70A) as well as villages in the Amahlati LM (S40A and S40B) rely partly or solely on groundwater resources. The towns of Illinge (S32J), Lady Frere (S10G), Cofimvaba (S50H) and Cala (S50D) towards the north-east of the study area are known to use groundwater as the sole source of water supply.

Figure 4-17 Groundwater use volumes (WARMS)

Figure 4-18 Groundwater use type (WARMS)

4.9 GROUNDWATER QUALITY

4.9.1 Overview

Groundwater chemistry is usually characterized by the concentrations and ratio of the major anions and cations as shown in the Piper diagram in **Figure 4-19**. The graph shows the variety of hydrochemical characteristics across the study area. However, it also indicates the gradual change in chemistry from the Na-Cl dominated groundwater in the coastal areas to the Ca/Mg-HCO_3 dominated groundwater in the Katberg and Burgersdorp formations.

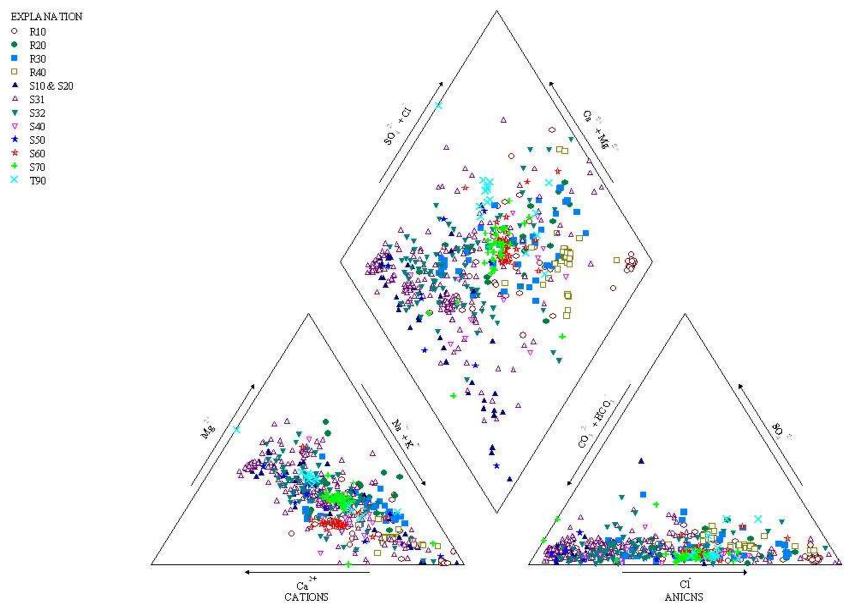


Figure 4-19 **Piper Diagram of all the boreholes in the Mzimvubu-Keiskamma WMA-Western Portion; grouped per secondary and tertiary catchments.**

Groundwater quality is frequently indicated by the parameter Electrical Conductivity (EC), which is a bulk indicator for dissolved matter in water. The upper limit for Class I drinking water is 150 mS/m and the limit for Class II is 370 mS/m (SANS 241). Waters of significantly higher values are not recommended for human consumption and need special treatment. An excerpt of the EC values from the WMS database (DWA, 2010) reflects the groundwater quality within the study area as shown in **Figure 4-20**.

Figure 4-20 Groundwater quality in study area, as indicated by Electrical Conductivity (EC)

4.9.2 Water quality threats

The GRIP database and existing water quality monitoring stations (WMS) were used to identify possible pollution sources in the study area (see **Table 4-8** and

Figure 4-21). Pollution sources in the urban centres mainly comprise industrial sites and waste treatment and deposit infrastructure, while the pollution sources in the rural areas are mainly associated with animal and or human waste. Another area of concern is the intensive agriculture around Queenstown. All of these point and diffuse sources can affect the groundwater quality.

Table 4-8 Pollution sources in the Mzimvubu-Keiskamma WMA.

Pollution sources	Areas
Solid waste site	Mainly around Queenstown and King William's Town
Sewerage treatment works	Urban areas
Formal cemetery	Rural and urban areas
Cattle/dip kraal	Rural areas of former Ciskei and Transkei areas
Abattoir	Rural areas and urban centres
Fuel depot	Urban centres
Industrial sites	East London, Dimbaza and Queenstown
Agriculture	Queenstown
Other (homes and schools)	Rural and urban areas

Based on the analysis of the available data some areas of concern have been identified as shown in **Table 4-9**. However, these seem to be mainly localised contaminations. Long-term water quality data from 9 selected monitoring boreholes across the study area do not indicate any negative trends in water quality.

The main concern with respect to groundwater quality is the wide spread contamination with microbiological pollutants, such as faecal coliforms. This is also indicative in the Nitrate concentration across the study area, as shown in **Figure 4-22**. Previous monitoring results from the Amathole DM have been confirmed during the field work, indicating localised groundwater contamination across the rural areas of the Amathole DM and parts of Chris Hani DM.

Table 4-9 Areas showing groundwater contamination.

Parameter	Areas
Nitrate	Queenstown, Kentani, Tsomo, Lady Frere, Keiskammahoek and Alice
Ammonia	Queenstown
Sulphate	Cathcart
Fluoride	Alice and Queenstown
Faecal coliforms	Kentani, Nqamakwe

Figure 4-21 Possible contamination sources (from GRIP; Jack, 2011)

Figure 4-22 Groundwater quality in study area, as indicated by Nitrate (Jack, 2011)

4.10 Desktop Reserve Determination

As a first approximation the GRDM desktop tool is used to determine the groundwater reserve and the stress index of the 95 quaternary catchments of the study area. The data incorporated into the database of the GRDM tool is adopted and no detailed or updated data on groundwater recharge, Basic Human Needs (BHN), current abstraction or groundwater contribution to baseflow is acquired. The complete table resulting from the calculation of the groundwater reserve and stress index is attached in the appendix. Only some relevant observations are discussed in this section.

A first general observation is the fact that BHN only plays a minor role compared to the groundwater contribution of the baseflow in rivers. On average the BHN only accounts for 7% of the total reserve requirements (BHN plus groundwater contribution to baseflow).

The total reserve for the entire study area is calculated as 369.54 million m³/a. Total numbers on groundwater reserve are not very meaningful since they neither relate to the size of the catchment nor to the remaining contributors of the water balance (mainly groundwater recharge). To point out the relative importance of the groundwater reserve it is useful to refer to the ratio of groundwater reserve and recharge per catchment. **Table 4-10** shows clearly that the major part of the catchments require a groundwater reserve that is less than 50% of the recharge. However, 12 of the 95 catchments show a value above 50% and in two cases (S60A and S60B) the required groundwater reserve; after the GRDM tool; even exceeds the recharge. In these cases the BHN cannot be covered by recharge without reducing the groundwater contribution to baseflow in rivers.

Table 4-10 Frequency of catchments for reserve/recharge ratio classes

Class	< 50%	50…100%	> 100%
Number of catchments	83	10	2

The allocable amount of water is obtained as the difference between recharge rate and groundwater reserve. The total allocable amount of the study area equals 648.89 million m³/a. Out of these only 35.01 million m³/a are currently being used. Except for the catchments where the theoretical reserve exceeds the recharge, the current usage lies far below the total allocable groundwater resources. On average only 5.4% of the allocable resources are currently being used, which indicates that there is significant space for further development.

The stress index of the catchments is a means of referring to the current degree of utilisation. The stress index *I* is usually calculated as the ratio of abstraction to recharge. However, this approach does not take into account the groundwater contribution to baseflow as major discharge pathway and would skew the analysis in a study area with a wide range of river systems and climatic conditions. Hence, the stress index is calculated as (DWAF, 2006; Umvoto, 2009):

$$I = abstraction / (recharge - baseflow)$$

The calculated stress index is shown in **Table 4-11** indicating that groundwater resources in most catchments are not heavily stressed, since most of them show a low stress index between 0 and 20%. Only one out of 95 catchments (S31F) shows a very high stress index in the critical range between 65% and 100%, but in 2 cases the maximum value of 100% is exceeded (S31E and S31G). In these cases groundwater abstraction is already greater than the theoretically available amount (recharge – baseflow). A negative stress index is computed for 2 catchments where baseflow exceeds recharge. These catchments (S60A and S60B) are the same ones that appeared in **Table 4-10** with reserve/recharge ratio greater than 100%.

Table 4-11 Frequency of catchments for stress index classes

Class	<0%	0…20%	20…40%	40…65%	65…100%	>100%
Number of catchments	2	86	3	1	1	2

The catchments in the GRDM desktop assessment with the most unusual parameters (highlighted in red) that require verification are summarised in **Table 4-12**.

Table 4-12 Most striking catchments in GRDM desktop study

Quat. catchm.	Recharge (Mm³/a)	Reserve (Mm³/a)	Reserve (% of Rech.)	Allocable (Mm³/a)	Current use (Mm³/a)	Stress Index (%)
R10K	6.88	3.53	51.37	3.35	0.29	7.5
R20A	8.71	5.07	58.19	3.64	0.03	0.8
R20F	6.79	4.91	72.30	1.88	0.13	2.7
R20G	4.63	4.14	89.46	0.49	0.00	0.0
R40B	6.16	3.33	54.03	2.83	0.04	1.3
S31E	4.87	1.01	20.82	3.86	5.01	129.5
S31F	4.05	1.42	34.94	2.63	1.53	50.2
S31G	3.42	1.00	29.24	2.42	5.59	231.0
S32D	13.34	9.00	67.48	4.34	0.06	1.4
S32E	9.61	7.03	73.14	2.58	0.02	0.8
S32H	4.42	1.04	23.56	3.38	3.20	93.6
S60A	15.09	16.13	106.88	-1.04	0.10	-11.0
S60B	7.75	10.00	129.09	-2.25	0.22	-9.8
S60C	7.60	4.02	52.85	3.58	0.19	5.3
S60D	7.68	5.01	65.19	2.67	0.01	0.4

As a result of the desktop GRDM assessment, the overall conditions of the interplay between recharge, reserve and current abstraction are assessed to be in fair conditions. However, some catchments can be identified that deserve special attention in the detailed analysis provided in Section 5 and Section 6. A map highlighting the quaternary catchments with a high (or negative) stress index is given in **Figure 4-23**.

Figure 4-23 Preliminary groundwater stress index (from Inception Report)

5. RESOURCE UNITS

5.1 DELINEATION OF RESOURCE UNITS

The aim of the delineation of the resource units is to group areas of similar properties to clusters and indicate the required level of detail for each unit. The following information is used for the preliminary delineation of the resource units:

- Quaternary surface water catchments
- Geology
- Aquifer types
- Protected areas
- Stress Index

The delineation is principally based on the **quaternary surface water catchments** acting as the basic unit of assessment. Further information is used for the detailed delineation of clusters of catchments or smaller resource units below catchment scale. If possible, various catchments of similar hydrogeology and ecological importance are lumped to clusters. Other catchments identified as especially relevant (hydrologically, hydrogeologically or ecologically) are analysed in detail and the resulting resource unit may be significantly smaller than the quaternary catchment.

The **geology** of the area is summarised using the aquifer types as introduced in Section 4.4. For the purpose of this study the division into 4 different **aquifer types** is used:

- Intergranular
- Fractured
- Intergranular fractured
    - With dolerite intrusion
    - Without any dolerite intrusion

Clusters of resource units are built on the base of these aquifer types. Catchments of the same type are lumped together if they do not have to be considered in detail for any of the remaining criteria. In some cases the same aquifer type is further split up in accordance with the respective present geological formation. This is especially true in the north of the study area where the intergranular and fractured aquifer type is further split up into the Burgersdorp and Molteno/Elliot Formations.

The smaller portions of intergranular aquifer at the coast and the northern part of the study area do not become separate resource units, since they are mostly coastal dunes or river alluvium of insignificant thickness that are not considered significant resource units.

In general **protected areas** are considered as hotspots within Resource Units since they deserve special attention to account for their ecological importance.

In the GRDM desktop study (section 4.10) potentially relevant catchments have been identified that need special attention in the further analysis. The **stress index** as introduced before is used to identify catchments that need to be excluded from any clustering.

Table 5-1 Criteria for delineation and associated actions for Phase 2

Criteria for delineation	Challenge	Required actions
Aquifer type	Different aquifer behaviour and potential	Develop conceptual model for Resource Unit
Secondary and tertiary drainage	Groundwater discharge into nearest river	Develop conceptual model of surface water – groundwater interaction for each RU
Stress index >40%	Apparently high groundwater use	Verification of groundwater use with hydrocensus, update recharge estimation
Dense rural areas	Expected high groundwater use	Verification of groundwater use from GRIP, update recharge estimation
Protected area	Limited groundwater use allowed	Define as hotspot within RU; define RQOs to limit groundwater use
Wetlands and springs	Possible groundwater contribution	Define as hotspot within RU, if ecologically significant; define capture zone to limit groundwater use

A list of the final Resource Units including the primary, secondary and tertiary criterions applied for their delineation is given in **Table 5-2**. A map of the final delineation of the Resource Units is shown in **Figure 5-1**.

It is remarked that initially quaternary catchments S60A and S60B were treated as separate Resource Units in the Inception Report. This was done as a consequence of the desktop reserve determination using the GRDM software. According to the GRA II data implemented in the software, for these two catchments the baseflow value is higher than the groundwater recharge. Since this is physically not possible, both catchments were taken out of the surrounding Resource Units in order to study the different components of the reserve more in detail. At a later project stage updating the baseflow numbers gained from GRA II data with numbers for the maintenance low flow (MLF) showed that the initially used values for these values were significantly too high. Using the updated data the stress index of the two catchments turned out to be much lower and in the range of the surrounding catchments. Consequently they were not treated separately any longer and integrated into the greater Resource Units.

Similarly, in the inception report protected areas were dealt with as separate units in order to highlight their ecological importance. Later on it was decided that for the process of the reserve determination they could be integrated into the surrounding Resource Units and then only get special attention during the development of the Resource Quality Objectives (RQOs) and the Monitoring Program.

Table 5-2 Table of Resource Units

Resource Unit	Primary Criterion (Aquifer type)	Secondary Criterion (Secondary drainage regions)	Tertiary Criterion (Aquifer stress)
RU1	Intergranular fractured: Adelaide Formation	Drainage: R10 and R50	
RU2		Drainage: R20, R30 and R40	
RU3		Drainage S60 and S70	
RU4		Drainage T90	
RU5	Fractured: Katberg Formation (outliers)		
RU6			
RU7	Intergranular fractured: Ecca and Dwyka Formations		
RU8			
RU9	Fractured: Katberg Formation		
RU10			
RU11	Intergranular fractured: Burgersdorp Formation	Drainage: S10, S20 and S50	
RU12	Intergranular fractured: Molteno and Elliot Formations	Drainage S10 and S20	
RU13		Drainage S50	
RU14	Intergranular fractured: Burgersdorp Formation	Drainage S3	
RU15	Fractured: Katberg Formation (outliers)	Drainage S3	High groundwater use; aquifer stress index > 100%
RU16	Intergranular fractured: Burgersdorp Formation	Drainage S3	High groundwater use; aquifer stress index > 100%
RU17	Intergranular fractured: Burgersdorp Formation	Drainage S3	High groundwater use; aquifer stress index > 40%
RU18	Intergranular fractured: Burgersdorp Formation	Drainage S3	High groundwater use; aquifer stress index > 20%
RU19	Intergranular fractured: Burgersdorp Formation	Drainage S3	High groundwater use; aquifer stress index > 100%
RU20	Intergranular fractured: Burgersdorp Formation	Drainage S3	High groundwater use; aquifer stress index > 20%
RU21	Intergranular fractured: Burgersdorp Formation	Drainage S3	
RU22	Intergranular fractured: Burgersdorp Formation	Drainage S3	

Figure 5-1 Delineation of Resource Units

5.2 RESOURCE UNITS 1 AND 8

5.2.1 Description

Resource units 1 and 8 are located in the south-western part of the study area, comprising the catchments of the Keiskamma River (R10) and some small coastal rivers (R50). Resource Unit 1 extends from the coast inland towards the Amatola Mountains, which forms the northern boundary (see **Figure 5-2**). Resource Unit 8 comprises the R50B quaternary catchment only due to its different geological and hydrogeological properties (see below). The coastal boundary extends from the Great Fish River to the Keiskamma River mouth. The eastern boundary is formed by the surface water divide towards the R20 and R40 catchments.

The towns of Alice, Middeldrift, Keiskammahoek and Dimbaza are situated in the upper portion of Resource Unit 1, while Hamburg and Wesley are located close to the coast. The area is characterised by a vast amount of villages in the Ngqushwa and Nkonkobe local municipalities, which were part of the former Ciskei.

The topography of both resource units is hilly to mountainous with the main rivers and tributaries flowing in the valleys. The elevation ranges from 0 – 1500 m amsl, increasing from the coast to the high mountains in the Amatola Mountain Range with an elevation of up to 1500 masl. The main rivers are the Keiskamma River and the Tyume River. All other tributaries and coastal rivers are classified as 1st order rivers. The upper reaches of the Keiskamma and Tyume rivers are already utilised for bulk water supply and contain several storage dams, e.g. Binfield Park Dam on the Tyume River, Sandile Dam, Cata Dam and Debe Dam on the Keiskamma River and its tributaries. There are no dams on the Keiskamma River or its tributaries below the confluence with the Tyume River.

Temperate climate is experienced in the coastal parts of RU 1 & 8 while inland parts are experiencing more extreme conditions. These variations are related to the elevation and proximity to the sea. Most rainfall occurs during summer. The annual precipitation ranges from 400 – 1500 mm/a with the highest rainfall in the Amatola Mountains. The rainfall also increases from west to east. **Figure 5-4** shows the annual rainfall for 3 different stations that are located in the northern part of RU 1 (R1E001 and R1E003: Keiskammahoek, R1E002: Alice), indicating the high variation of annual rainfall with an average annual rainfall for these stations of approximately 500 mm/a. Alice seems to receive less rainfall in average years than Keiskammahoek. Maximum temperatures for RUs 1 & 8 are experienced in January and minimum temperatures usually occur in July. Frost occurs in the inland areas in winter and also snow occurs on the mountains in winter (e.g. in Hogsback).

The geology of Resource Unit 1 is predominantly made up of the Adelaide Subgroup (Lithofeldspathic sandstone and mudstone) of the Beaufort Group (Karoo Supergroup) with Karoo Dolerite intrusions in the northern part of the Resource Unit and few Alluvium deposits along river valleys and at the coastal strip (see **Figure 5-3**). Resource Unit 8 consists predominantly of the Ecca Group (shale, sandstone and mudstone) of the Karoo Supergroup with few Alluvium deposits found on the coastal plains.

Figure 5-2 Location, topography and drainage for RU1

Figure 5-3 Geology map for RU1

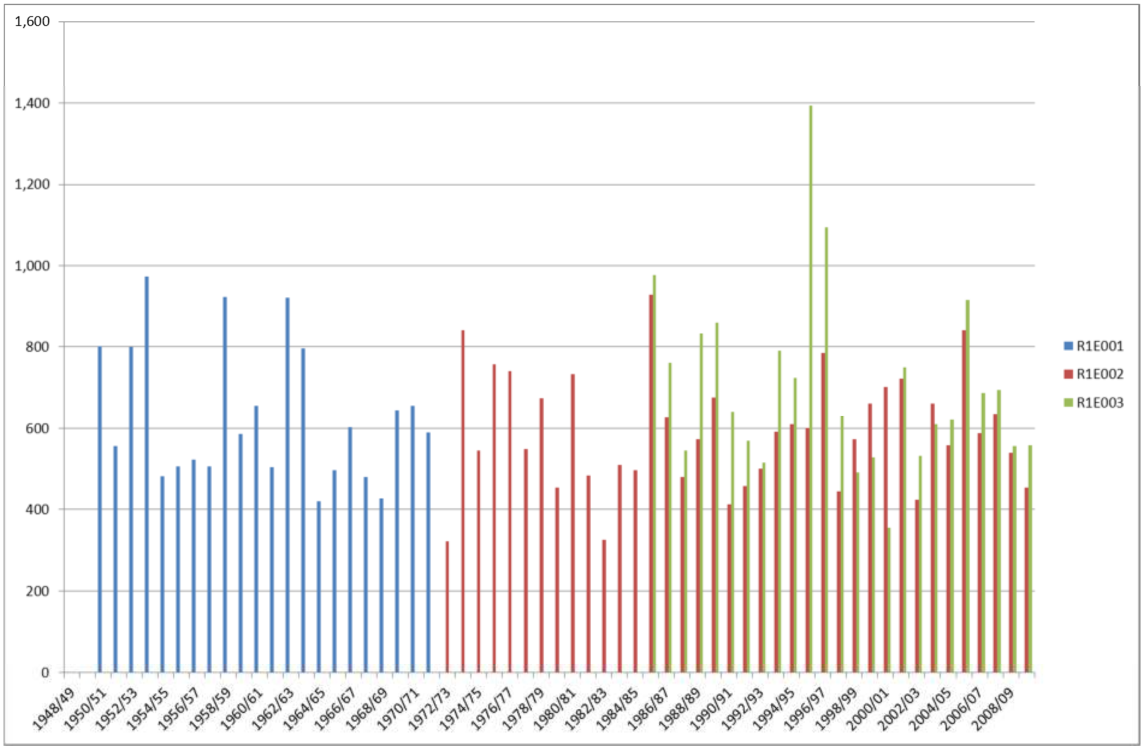


Figure 5-4 Annual rainfall [mm/a] for different weather stations in RU1

The land use varies across the resource units. The northern part is characterised by indigenous forest on the mountains and bushland in the valleys. Built-up areas are clustered together and concentrated in the valleys. The pattern changes south of Alice and Middeldrift, where built-up areas are more scattered (i.e. villages of the former Ciskei) and surrounded by cultivated land and degraded unimproved grassland or degraded thicket bushland (see **Figure 5-5**).

The current status of rivers and catchments in the upper reaches of Resource Unit 1 are mainly defined as largely natural or moderately modified, while the southern part is described as largely modified. The recommended ecological classes are largely natural for the northern part and moderately modified for the southern part.

There are two protected areas straddling the resource unit; viz. the forestry around Hogsback and the most eastern part of the Provincial Nature reserve on the Great Fish River. The northern part of Resource Unit contains a number of seeps and other wetlands that could be groundwater fed (see **Figure 5-6**). A similar pattern of seeps from the wetland mapping can be seen on the eastern resource unit boundary, south of Dimbaza.

Figure 5-5 Land use map for RU1

Figure 5-6 Wetland, springs and protected areas in RU1

5.2.2 Conceptual Aquifer Model

The aquifers in both resource units are considered poor to minor aquifers. They consist predominantly of intergranular/fractured aquifer types with few and irrelevant alluvium intergranular aquifers in river valleys and along the coast. The northern part of Resource Unit 1 comprises some dolerite intrusions that can enhance groundwater occurrence.

The average transmissivity for both resource units is low, ranging from 2.5 to 15 m^2/day in Resource Unit 1 and less than 2.5 m^2/day in Resource Unit 8 (WRC, 2009). In small areas in the northern part of Resource Unit 1 the average transmissivity ranges 15 – 20 m^2/day, which is probably linked to the dolerite intrusions.

The recharge rate for Resource Unit 1 is estimated at an average of 28 mm/a, amounting to a total of 86 million m^3/a recharge. The recharge in Resource Unit 8 is 8.16 million m^3/a, equalling 20 mm/a.

Since all aquifers in the resource units are weathered regolith aquifers of limited thickness, it is assumed that all aquifers are drained by the nearest surface water feature, which is normally a stream or river. The path length between recharge and discharge is considered short, as there are no distinct recharge areas, other than in the Amatola Mountains.

Groundwater emanating from recharge in the Amatola Mountains discharges at springs and seeps along the escarpment and feed the mostly perennial rivers that come from these mountains. Both the Tyume River and the Keiskamma River are considered perennial rivers, as is clear from the hydrological records (see **Figure 5-8**). It is however assumed that some of the downstream tributaries are seasonal, as groundwater discharge is limited to rainfall events.

This pattern is also seen on the piezometric map of water levels across the resource units. While the general flow direction follows the topography, the influence of the main rivers as groundwater drainage is also evident (see **Figure 5-7**).

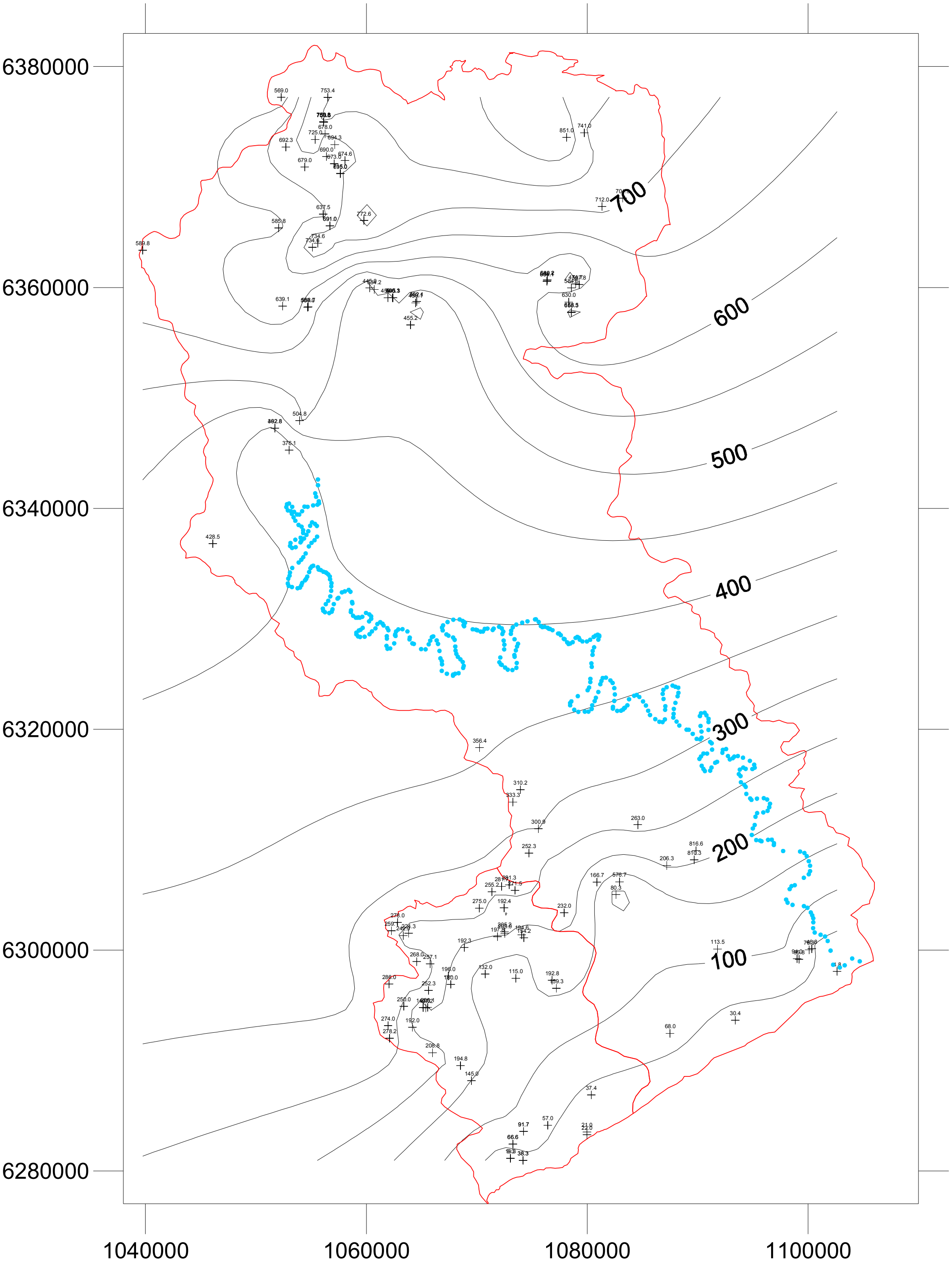
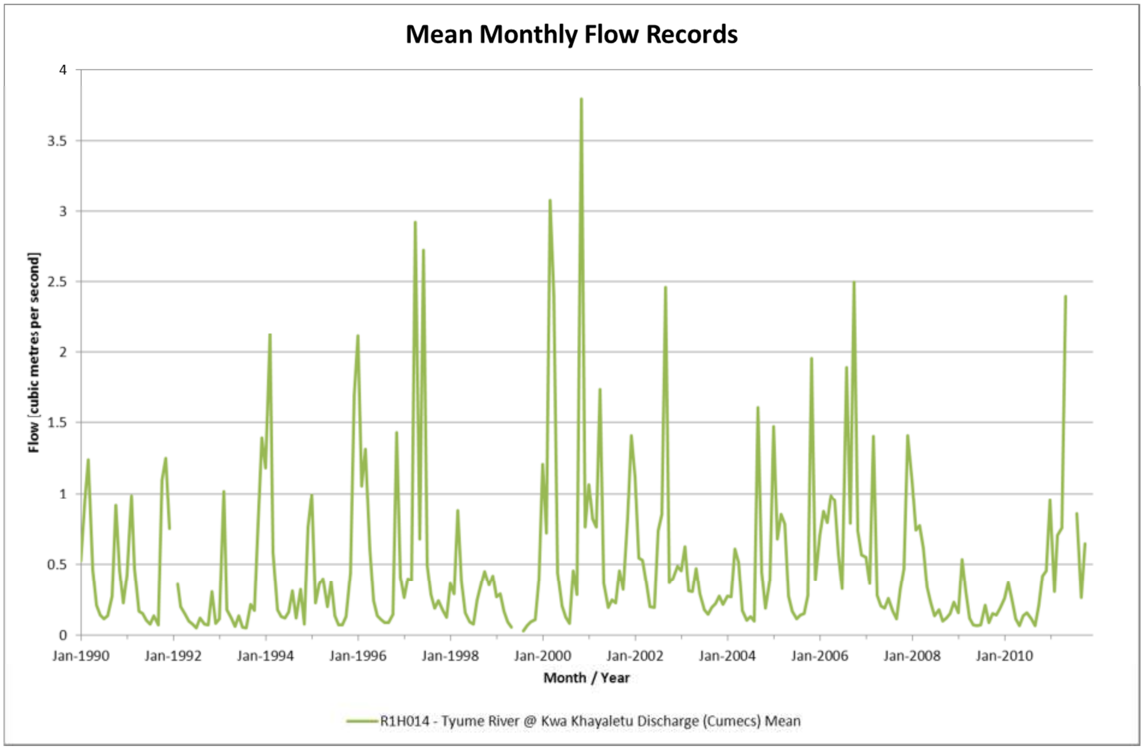


Figure 5-7 Piezometric map for RU1



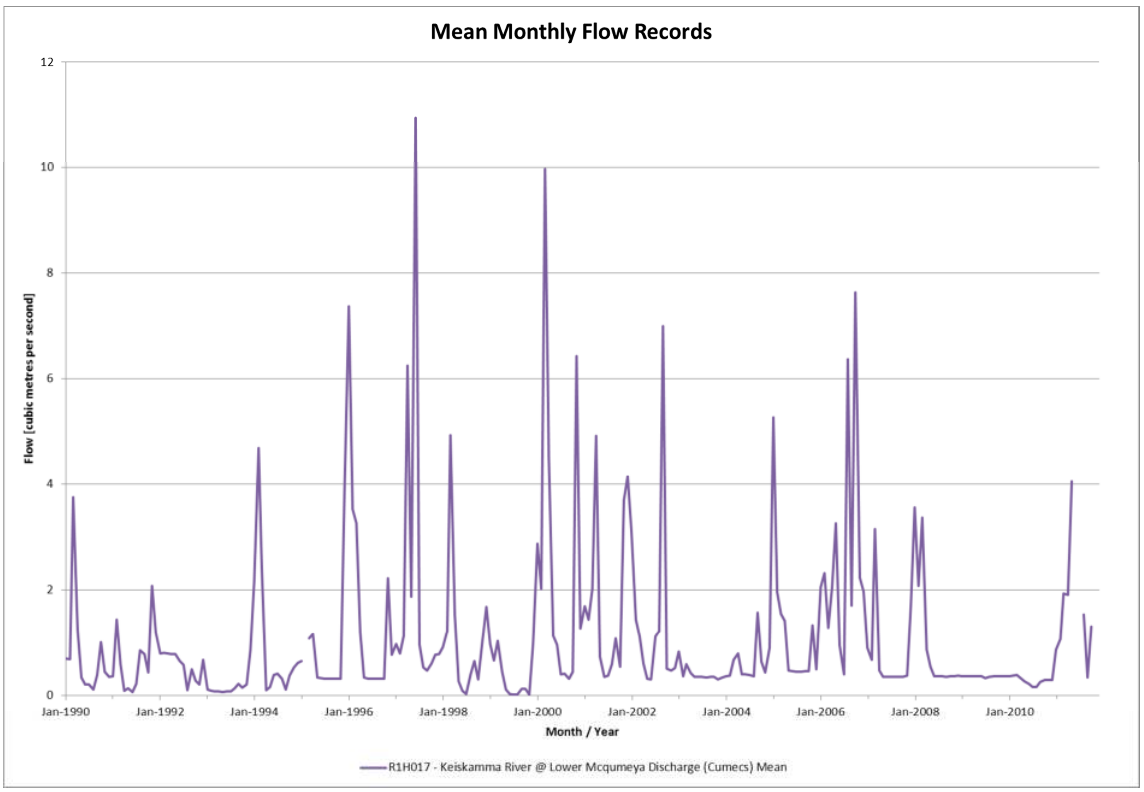


Figure 5-8 River hydrographs in RU1; a) Tyume River upstream of Binfield Park Dam; b) Keiskamma River downstream of Sandile Dam

5.2.3 Current Status

The current status of the resource units is defined by the groundwater use as proportion of recharge and the groundwater quality.

The groundwater use is very limited in both resource units. There is no municipal usage reflected in the All Towns Reconciliation Strategy Study for Resource Units 1 and 8, as some of the previous groundwater schemes have been abolished. The WARMS registered value of 0.75 million m^3/a for Resource Unit 1 is lower than the GRAII value of 1.11 million m^3/a, the former reflecting water supply usage and the latter reflecting mostly agricultural usage. The WARMS value is considered more realistic, as agricultural use is very limited.

The WARMS database indicates a usage of 0.40 million m^3/a for Resource Unit 8, higher than the GRAII value of 0.31 million m^3/a. The WARMS number is accepted as realistic.

Table 5-3 Groundwater use in Resource Unit 1 and 8

Resource Unit	GRA II (Mio m^3/a)	WARMS (Mio m^3/a)	GRIP (%)	All Towns (Mio m^3/a)	Final (Mio m^3/a)
1	1.11	0.75	3%	0.00	0.75
8	0.31	0.40	-	0.00	0.40

Based on the estimates, both resource units are considered in a largely natural status (i.e. minimally used), with a stress index of 1% and 5% respectively.

The hydrochemical characterisation of the aquifers is determined by the geology and the proximity to the sea. While the aquifer close to the coast has a Na-Cl composition (see R10H in **Figure 5-9**) the aquifers further inland show a trend towards HCO_3 dominated water. The groundwater quality is generally acceptable with most boreholes fall in Class 1 with respect to EC (70 – 150 mS/m). However, few boreholes in Resource Unit 1 (north and south of Alice) have EC that falls in the Class II (150 – 370 mS/ml) which is recommended for use for only a short period of time.

There is 1 borehole north of Alice, where the nitrate content exceeds 20 mg/l (falls in Class III) which is not suitable for use. High fluoride exceeding 3.5 mg/l is also found in the resource unit (two boreholes situated in south of Alice). These two boreholes are contaminated and can be toxic if the groundwater is being used by humans. One borehole in Horton has an iron content of 53.5 mg/l. The high iron content causes a salty or repulsive taste to the groundwater.

These are single incidents and do not indicate a widespread groundwater quality problem, although the aquifer is vulnerable to contamination and the vast amount of villages with limited sanitation facilities increases the risk of groundwater pollution. However, long-term monitoring of a borehole south of Alice does not show any negative trend in water quality (see **Figure 5-10**).

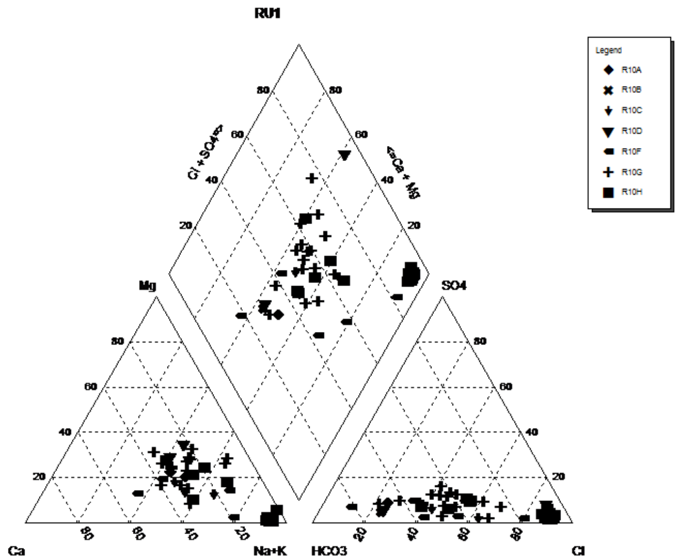


Figure 5-9 Hydrochemical characterisation and groundwater quality in RU1

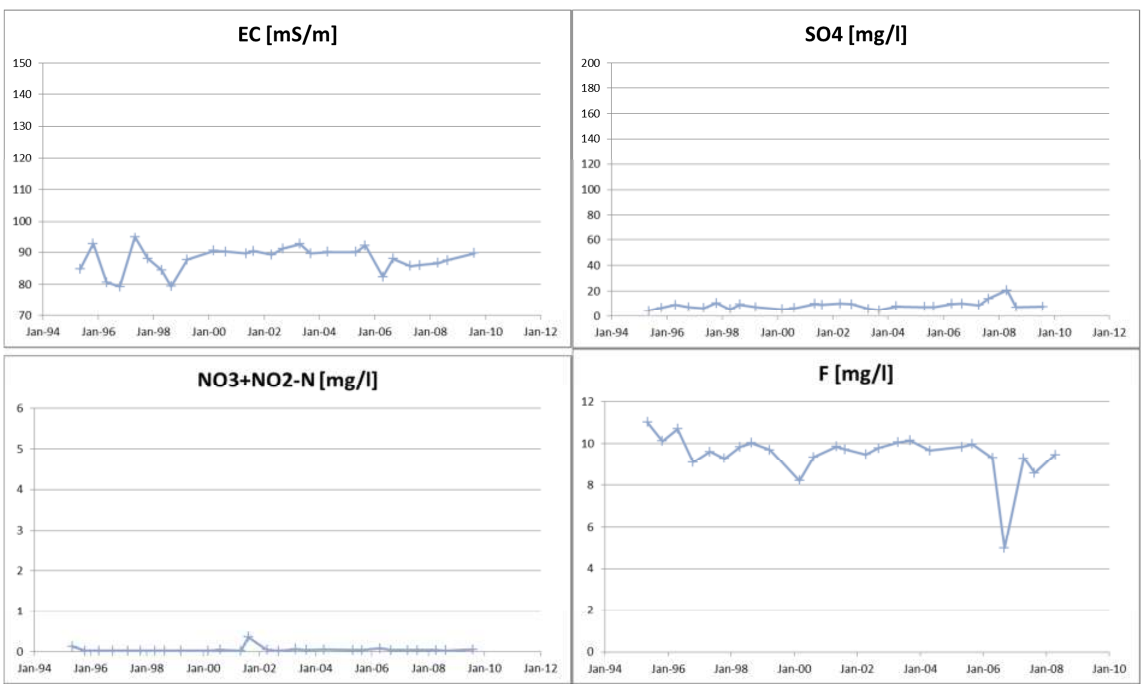


Figure 5-10 Groundwater quality trends in RU1 (90144)

5.3 RESOURCE UNITS 2, 5 AND 6

5.3.1 Description

Resource units 2, 5 & 6 are situated in the southern part of the study area along the coast, between Resource Unit 1 in the west and Resource Unit 3 in the north and east. Resource Units 5 and 6 are subsets of Resource Unit 2, demarcated due to the different geological and hydrogeological characteristics. The resource units comprise the catchments of the Buffalo River (R20), the Nahoon and Gqunube rivers (R30) and the R40 drainage catchments. The coastal boundary extends from the Keiskamma River Mouth to the Greta Kei River Mouth, while the inland boundaries of Resource Unit 2 are delineated by the catchment divides towards the Great Kei, the Kubusi and the Keiskamma rivers.

Resource Unit 2 covers the entire Buffalo City Municipality area of East London, Bisho and King William's Town, as well as areas of the surrounding local municipalities Ngqushwa in the east and Great Kei in the west.

The topography of the resource units is hilly to mountainous with rivers flowing in the valleys. The elevation ranges from 0 along the coast to 900 mamsl at catchment divides. The river systems of the Buffalo River and Nahoon River are heavily utilised for bulk water supply, as they form a critical part of the Amatole Water Supply System for East London and the surrounding towns. There are three dams on the Buffalo River; viz. Rooikrantz Dam in the upper reaches, Laing Dam and Bridle Drift Dam downstream of King William's Town. The Nahoon Dam on the Nahoon River is linked to that system via pipelines.

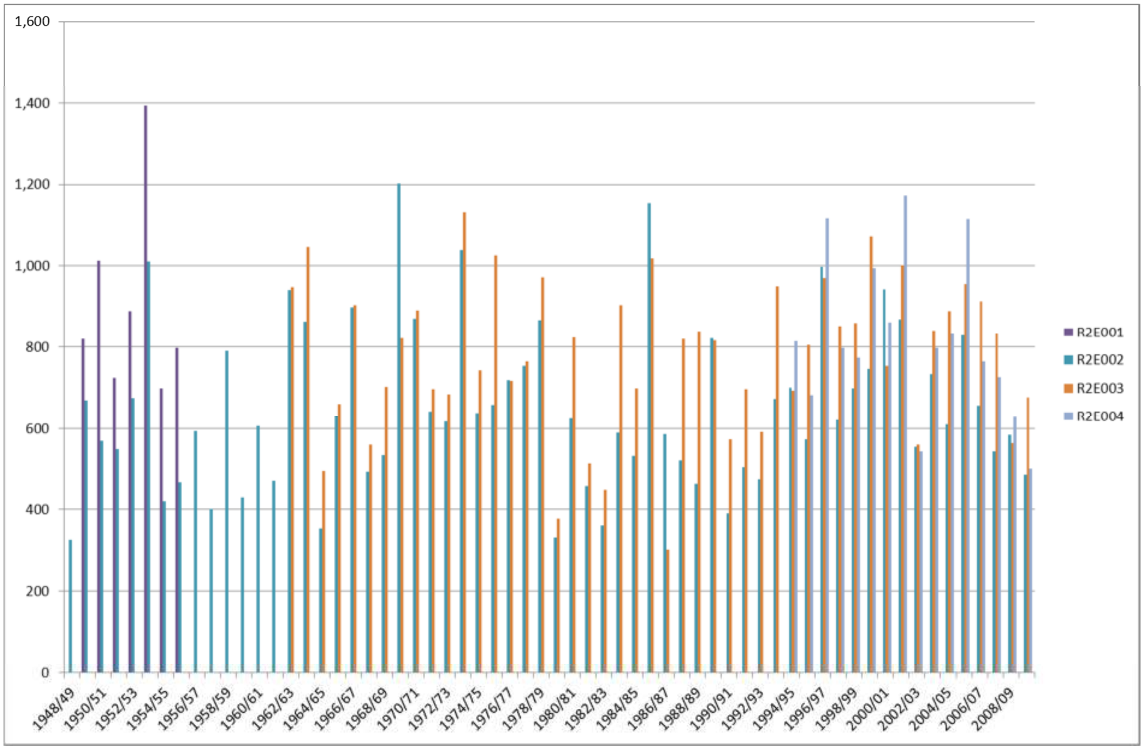
Temperate climate is experienced in the coastal parts of the resource units, while further inland more extreme conditions are prevalent. These variations are related to the elevation and proximity to the sea. The mean annual rainfall ranges from 600 to 1500 mm/a with the highest rainfall occurring along the coast and in the Amatola Mountains in catchments R20A and R20C. The mean annual rainfall, measured at rainfall stations across the R20 catchment, is between 500 and 600 mm/a, while stations around East London indicate mean annual rainfall of above 600 mm/a (see **Figure 5-12**). Maximum temperatures are experienced in January and minimum temperatures usually occur in July. Frost and snow occur in the inland areas in winter (only in RU 2, not in RU 5 and RU 6).

The geology of Resource Unit 2 consists entirely of the Adelaide Subgroup of the Beaufort Group with Karoo Dolerite intrusions and few Quaternary deposits along the coastal portion. The dolerite intrusions are mainly elongated, nearly east-west trending dolerite dykes, some of which form catchment boundaries (e.g. between R20 and R40. Dolerite sills and ring structures are only found in the most northern part of Resource Unit 2.

Both Resource Unit 5 and Resource Unit 6 are delineated separately from Resource Unit 2 as they are made up of the sandstones of the Katberg Formation with few Karoo Dolerite intrusions and small Quaternary deposits along the coast (see **Figure 5-13**).

The land use for the resource units is mainly characterised by the urban and built up areas of East London and surrounds, as well as agricultural areas in the north-western part of the resource unit (see **Figure 5-14**). The majority of the eastern part is covered by thicket bushland. The hills and slopes of the Amatole Mountains is mostly covered with indigenous forest and forest plantations.

Figure 5-11 Location, topography and drainage for RU2



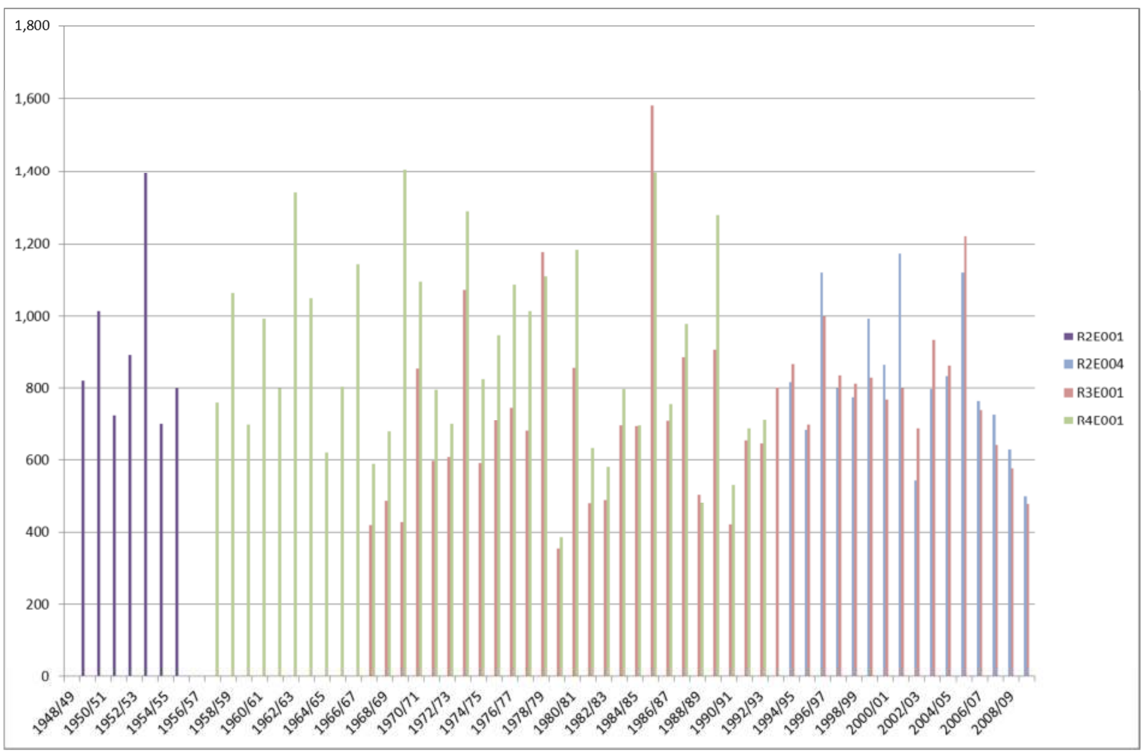


Figure 5-12 **Annual rainfall [mm/a] for different weather stations in RU2; a) within R2 secondary catchments, b) around East London (includes R3 and R4 catchments)**

Figure 5-13 Geology map for RU2

Figure 5-14 Land use map for RU2

Figure 5-15 Wetland, springs and protected areas in RU2

The present ecological status of the rivers and catchments in Resource Unit 2 are mainly described as largely modified, with only few catchments described as moderately modified. The recommended ecological category is mainly moderately modified across the resource unit.

There are some small protected areas in these resource units, mainly along the coast and in the Buffalo River catchment west of East London. The wetland map (see **Figure 5-15**) indicates small wetlands across the resource units, but only few that can be considered groundwater dependent. These occur mainly at the headwaters of perennial rivers, south as a cluster of bigger seeps on the catchment divide between R10 and R20 east of King William's Town.

5.3.2 Conceptual Model

The aquifers in Resource Unit 2 are considered minor aquifers, as they consists predominantly of intergranular/fractured aquifer types with dolerite intrusions, which can increase the groundwater potential. The aquifers in resource units 5 and 6 are considered minor aquifers due to the size of the outcrop, although they comprise of fractured aquifers and dolerite intrusions. The intergranular aquifers in the alluvium deposits can be ignored as they are insignificant in terms of size and thickness.

The average transmissivity for all three resource units is relatively high, especially in the eastern part due to the increased number of dolerite intrusions. For dolerite intrusions, the average transmissivity is greater than 30 m^2/day. The rest of the area has average transmissivity that ranges 2.5 - 15 m^2/day, similar to Resource Unit 1.

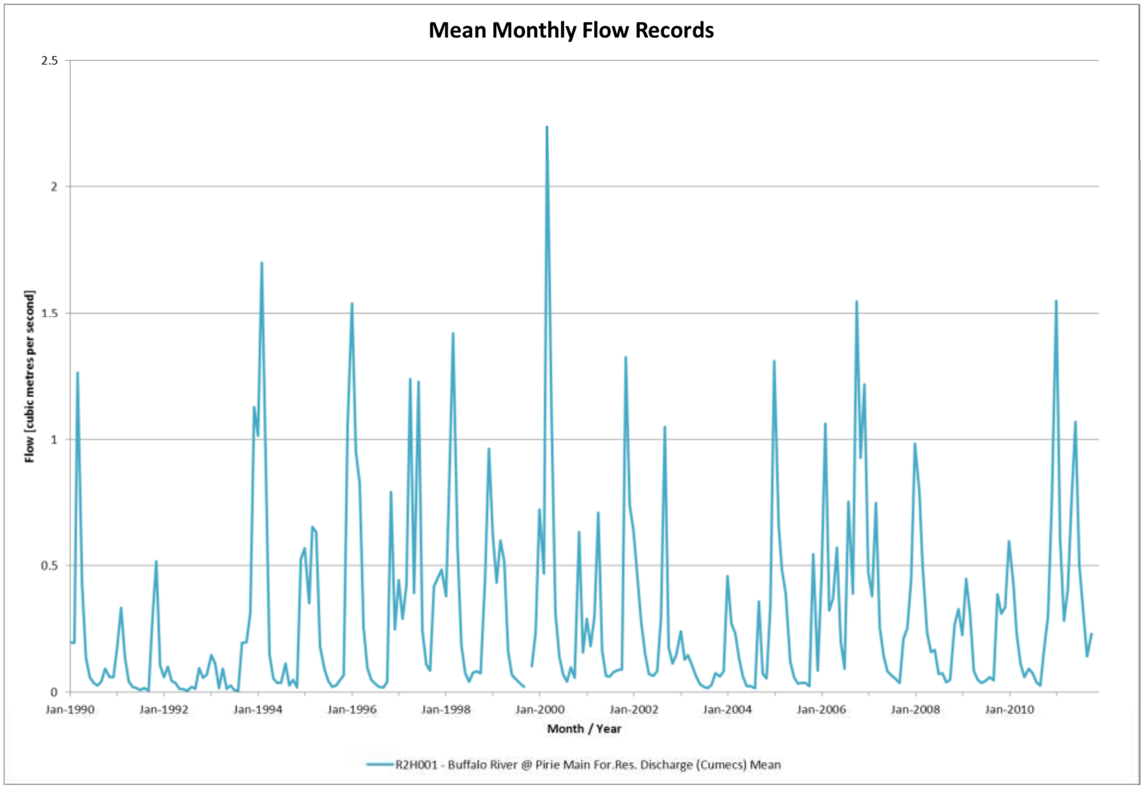
The recharge rate for resource units 2 and 5 is 42 mm/a each, while Resource Unit 6 shows a recharge rate of 63 mm/a, due to the proximity to the high rainfall zone and the fractured nature of the aquifer. The estimated mean annual recharge volumes are then given as 173 million m^3/a for Resource Unit 2, 9.1 million m^3/a for Resource Unit 5 and 3.02 million m^3/a for Resource Unit 6.

Since the aquifers in Resource Unit 2 are weathered regolith aquifers of limited thickness, it is assumed that all aquifers are drained by the nearest surface water feature, which is normally a stream or river. The path length between recharge and discharge is usually considered short, as there are no distinct recharge areas, other than in the Amatola Mountains. However, the occurrence of the elongated dolerite dykes could alter the flow pattern and allow for extended groundwater flow along the dykes.

The resource units 5 and 6 comprise of fractured rock aquifers, which have a high storage potential and longer path ways towards discharge points are possible. It is assumed that most groundwater from these two resource units discharges directly into the sea.

Groundwater emanating from recharge in the Amatola Mountains discharges at springs and seeps along the escarpment and feed the mostly perennial rivers that come from these mountains. The Buffalo River and its tributaries are considered perennial rivers, as is clear from the available hydrological records (see **Figure 5-16** and **Figure 5-17a**). It is however assumed that some of the smaller coastal rivers are seasonal, as groundwater discharge is limited to rainfall events (see **Figure 5-17b**).

This pattern is also seen on the piezometric map of water levels across the resource units. While the general flow direction follows the topography, the influence of the main rivers as groundwater drainage is also evident (see **Figure 5-18**).



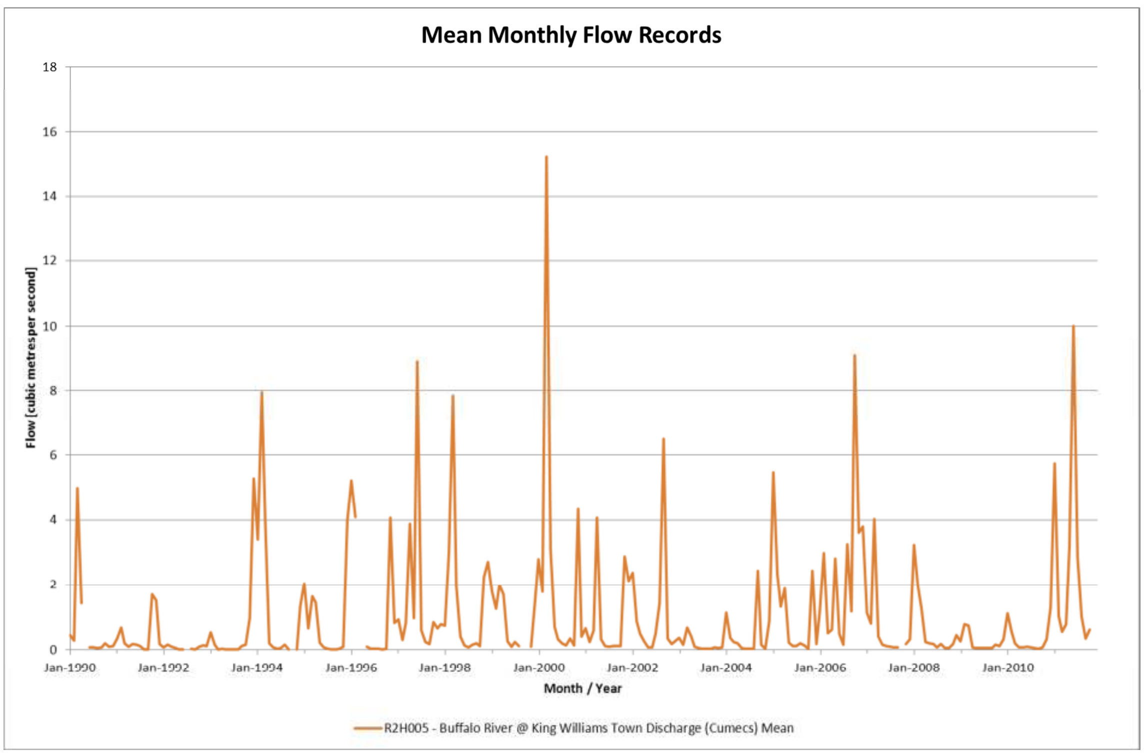
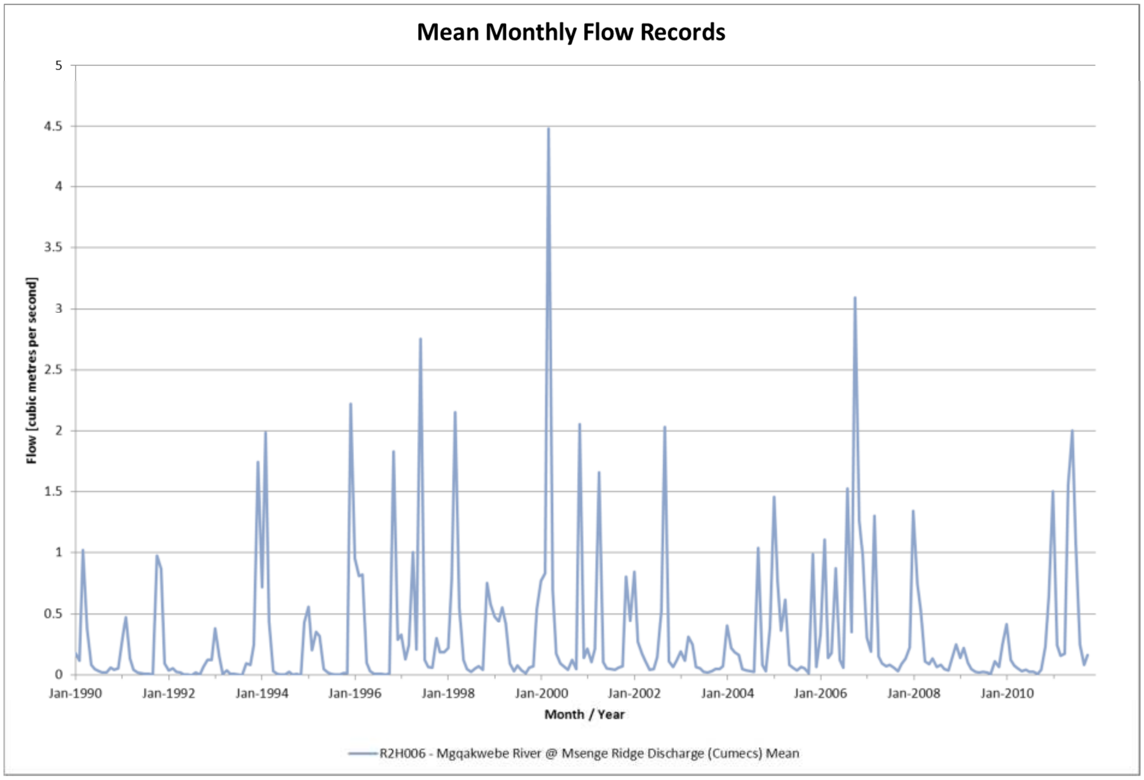


Figure 5-16 River hydrographs in RU2 – Buffalo River; a) upstream of Rooikrantz Dam, b) at King Williams Town



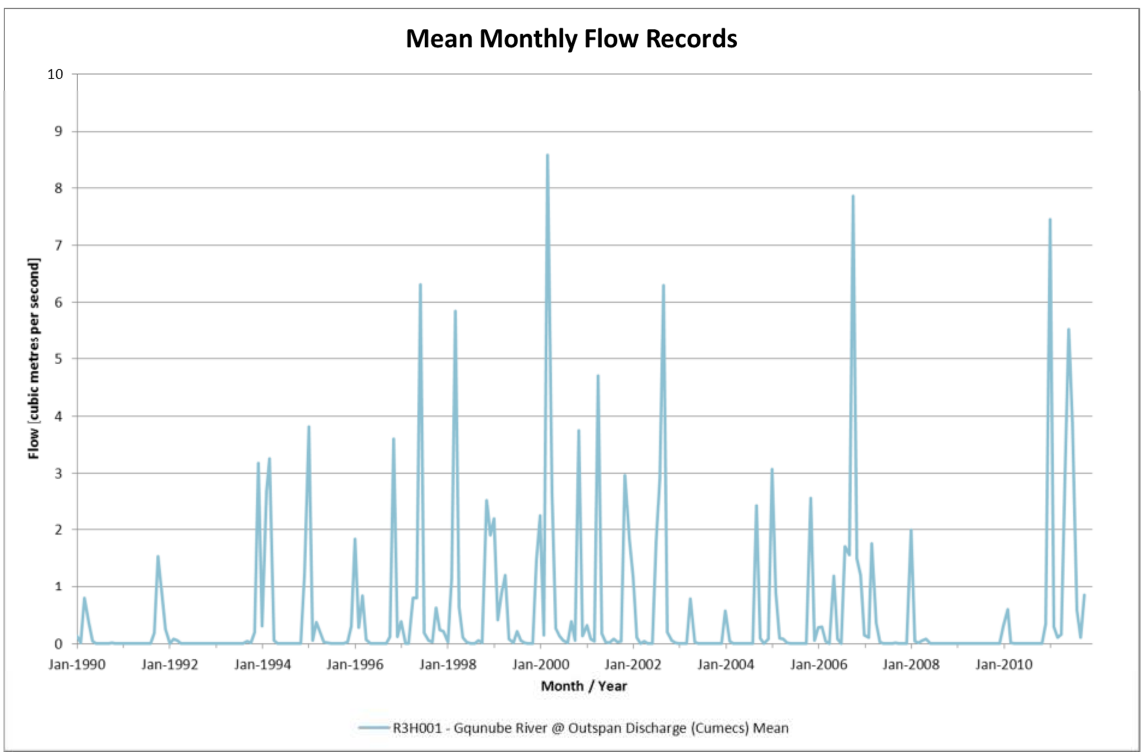


Figure 5-17 River hydrographs in RU2 – tributaries and coastal rivers; a) Mgqakwebe River, b) Gqunube River

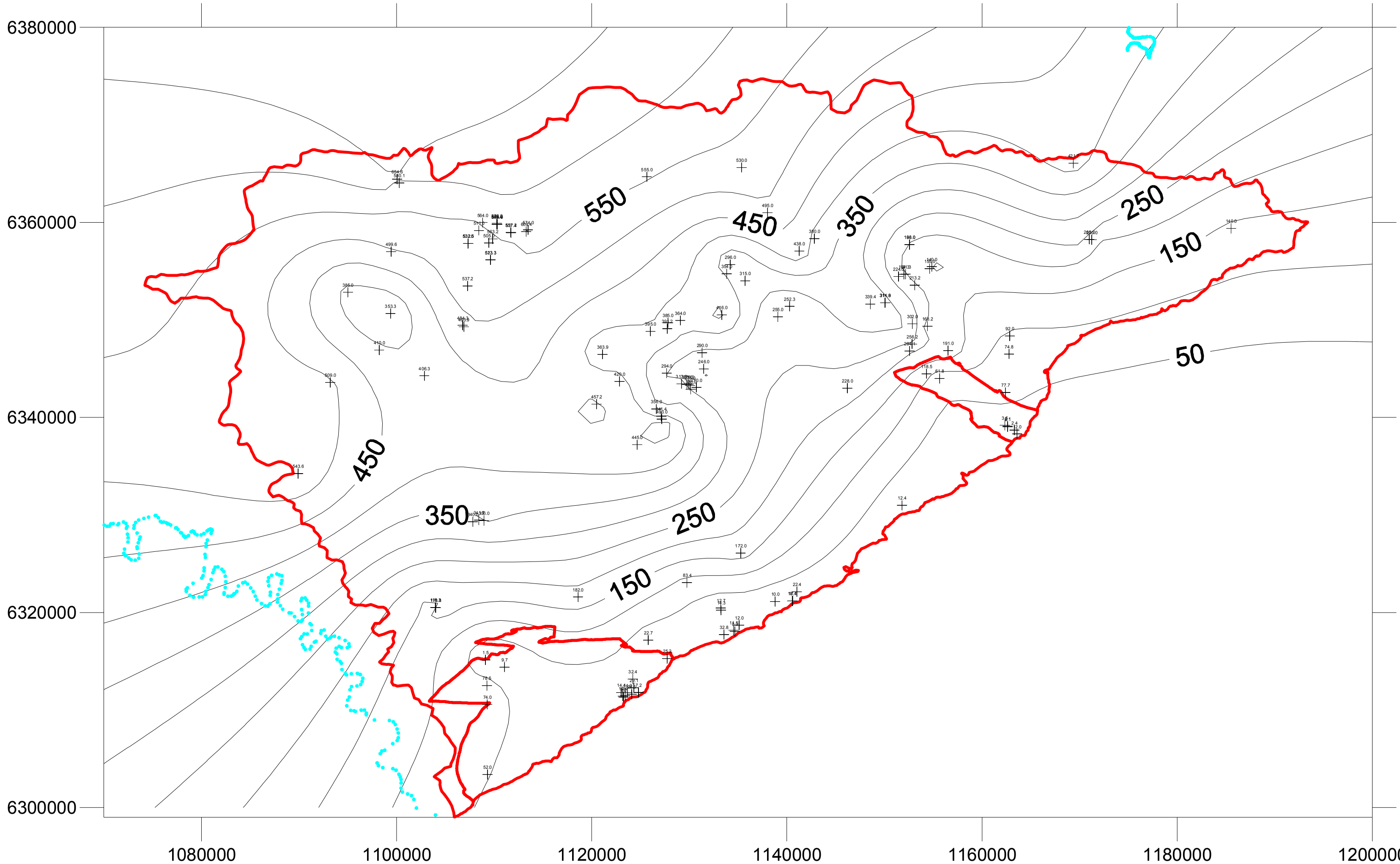


Figure 5-18 Piezometric map for RU2

5.3.3 Current Status

The current status of the resource units is defined by the groundwater use as proportion of recharge and the groundwater quality.

The groundwater use is limited in the three resource units, as most residents are supplied via the bulk water supply system, which takes water from the surface water dams. Some municipal usage is indicated by the All Towns Reconciliation Strategy Study for Resource Unit 2, mainly for the villages and towns in the Great Kei Local Municipality. The usage indicated in GRAII with 1.01 million m^3/a is less than the one in WARMS with 2.65 million m^3/a, which suggests that the latter is questionable. Since the All Towns Study figure does not include any agricultural use, the volume is increased by the agricultural use registered in the WARMS (0.72 million m^3/a).

In Resource Unit 5 there is no municipal usage reflected in the All Towns Study. The WARMS database indicates a higher number than the GRAII. This number is accepted as realistic.

In Resource Unit 6 there is some municipal usage reflected in the All Towns Study. The number of 0.10 million m^3/a is higher than the numbers in GRAII and WARMS. There is hardly any agricultural usage and therefore the number from the All Towns Study is accepted realistic.

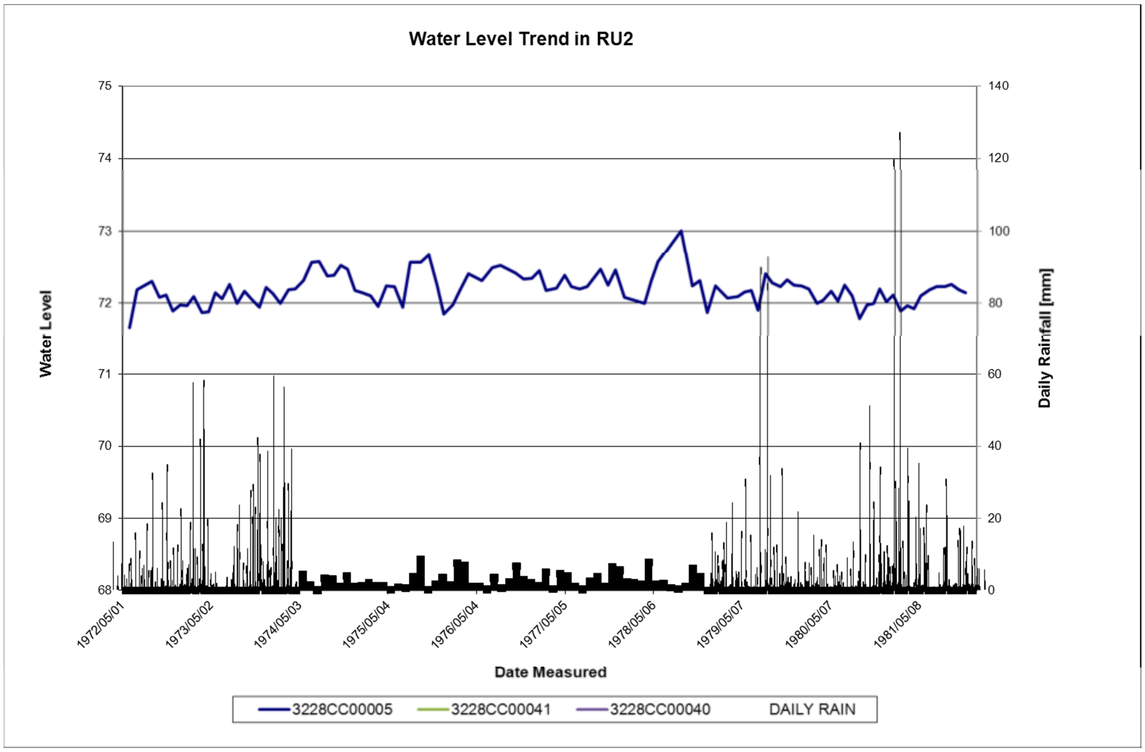
Table 5-4 Groundwater use in Resource Unit 2, 5 and 6

Resource Unit	GRA II (Mio m^3/a)	WARMS (Mio m^3/a)	GRIP (%)	All Towns (Mio m^3/a)	Final (Mio m^3/a)
2	1.01	2.65	0%	1.43	2.15
5	0.08	0.27	-	0.00	0.27
6	0.01	0.04	-	0.10	0.10

Based on the estimates, all three resource units are considered minimally used with a stress index of 1% for Resource Unit 2 and 3% for Resource Unit 5 and 6, respectively. This is also reflected in the long-term water level measurements from boreholes close to East London, which do not show any negative trend in water level fluctuation (see **Figure 5-19**).

The hydrochemical characterisation of the aquifers is determined by the geology and the proximity to the sea. While the aquifer close to the coast has a Na-Cl composition (see RU5 in **Figure 5-20**) the aquifers further inland show a trend towards Ca/Mg-HCO_3 dominated water. The groundwater quality is generally acceptable with most boreholes fall in Class I with respect to EC (70 – 150 mS/m). However, some boreholes in Resource Units 2 and 5 fall in Class II (150 – 370 mS/m) and few boreholes east of King William's Town, west of East London and south of Komga exceed Class II (>370 mS/m). This means the boreholes are contaminated and not suitable for use.

The nitrate content is very high (>20 mg/l) in one borehole east of King William's Town. This parameter usually indicates pollution coming from livestock farming and can increase if livestock is kept in near proximity to the borehole and/or if the groundwater table is near the surface. There are also at least three boreholes with high Iron concentrations; i.e., Ntabozuko (2206 µg/l Fe), Jongilanga (8093 µg/l) and Zozo 1 (5588 µg/l). The borehole in Zozo 1 also has a problem with high chloride content (698 mg/l Cl) which leads to high EC. The high iron and chloride concentrations cause a salty or repulsive taste to the groundwater of these boreholes.



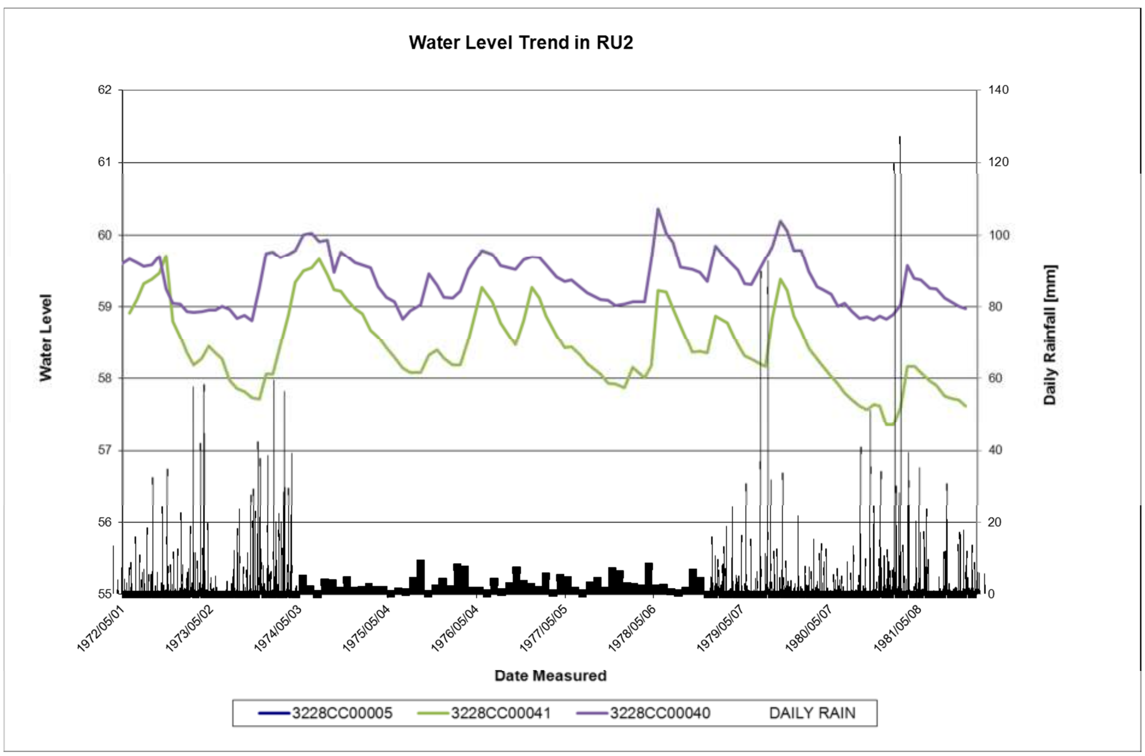


Figure 5-19 Water level trends in selected boreholes from RU2; a) 3228CC00005, b) 3228CC00041 and 3228CC00040

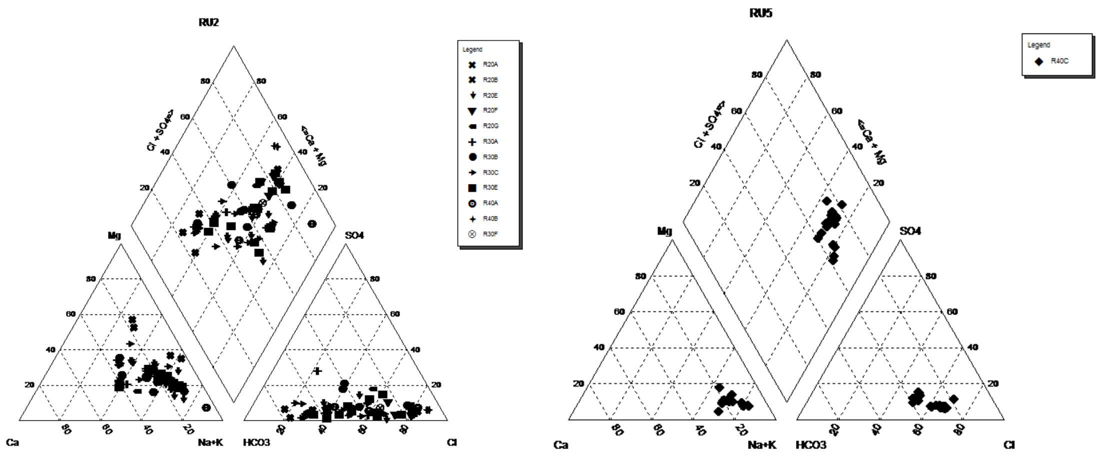


Figure 5-20 Hydrochemical characterisation and groundwater quality in RU2 and RU5

These are considered single incidents and do not indicate a widespread groundwater quality problem, although the aquifer is vulnerable to contamination and the spread of villages with limited sanitation facilities and the vast industrial areas around Bisho increase the risk of groundwater pollution. However, long-term monitoring of a borehole west of Keyser's Beach in Resource Unit 5 does not show any negative trend in water quality (see **Figure 5-21**).

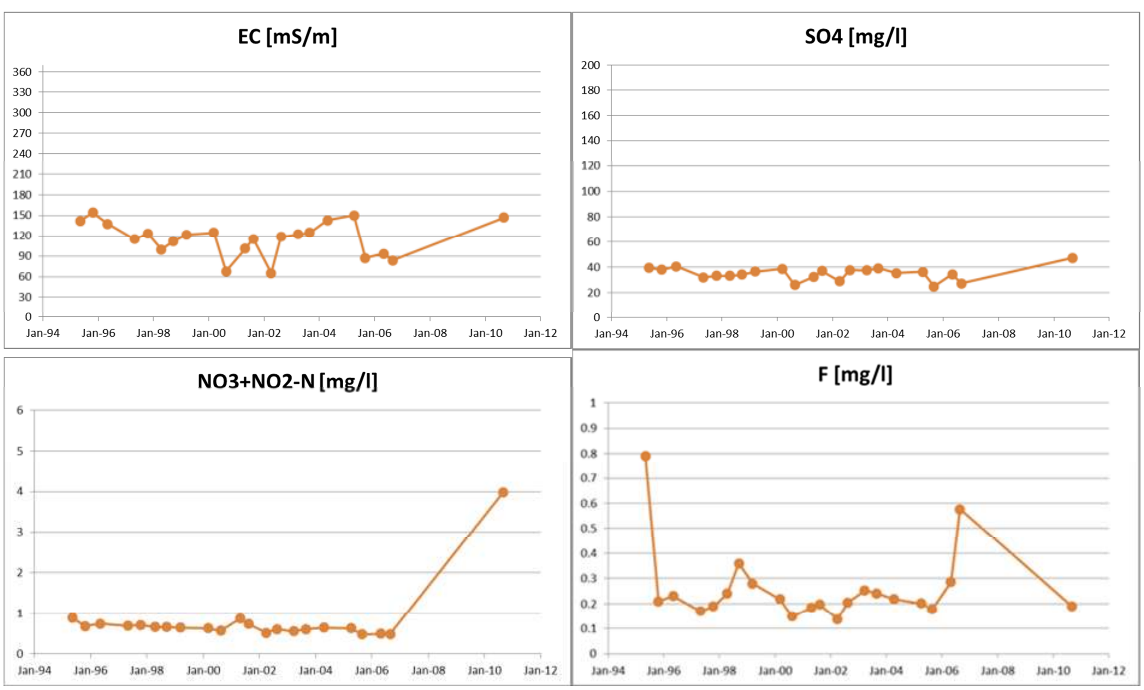


Figure 5-21 Groundwater quality trends in RU5 (Borehole 90061)

5.4 RESOURCE UNIT 3

5.4.1 Description

Resource Unit 3 is located north of Resource Unit 2 and comprises mainly the lower portion of the Great Kei River catchment, incorporating parts of the S40, S50, S60 and S70 catchments. The southern boundary of the Resource Unit is the catchment divide between the Drainage Region R (see Resource Units 1 and 2) and the Drainage Region S, while the eastern boundary is formed by the catchment divide towards the Drainage Region T (see Resource Unit 4). The northern boundary follows the outcrop boundary of the Katberg Formation (see Resource Units 9 and 10).

Towns within the Resource Unit 3 include Stutterheim in the west, Kei Mouth at the coast, Komga at the southern boundary and Butterworth at the eastern boundary.

The Resource Unit 3 is completely drained by the Great Kei River and its tributaries (Tsomo, Kubusi and Gcuwa Rivers). The topography of the resource unit is hilly to mountainous with the rivers flowing in mostly incised valleys. The elevation ranges from 0 to 1400 mamsl, with the high areas in the Amatola Mountain Range (east of Stutterheim).

Temperate climate is experienced in the coastal part RU 3 while inland parts are experiencing more extreme conditions. These variations are related to the elevation and proximity to the sea. The mean annual rainfall of this resource unit ranges 600 - 1500 mm/a with the highest rainfall along the Amatola Mountains (east of Stutterheim) and the coast (see **Figure 5-22**). Maximum temperatures are experienced in January and minimum temperatures usually occur in July. Frost and snow occur in the inland areas in winter.

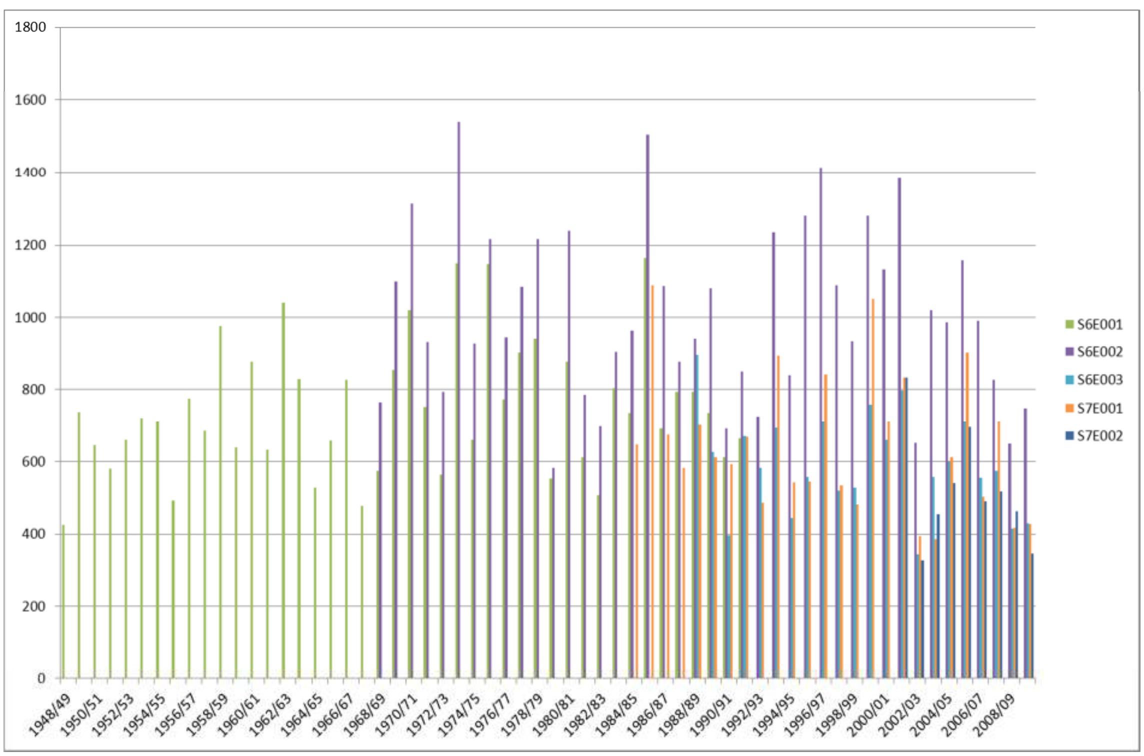


Figure 5-22 Annual rainfall [mm/a] for different weather stations in RU3

Figure 5-23 Location, topography and drainage for RU3

The geology of the Resource Unit 3 is entirely made up of Adelaide Subgroup of Beaufort Group with Karoo Dolerite intrusion across the resource unit. The dolerite intrusions comprise both elongated, nearly east-west trending dolerite dykes and dolerite sills and ring structures (see **Figure 5-24**).

The land use in Resource Unit 3 differs between the part east of the Great Kei River and the western part around Stutterheim. The eastern part of the resource unit is dominated by the scattered villages of the former Transkei area, characterised by the built-up areas surrounded by cultivated land, degraded grassland and natural vegetation (see **Figure 5-25**). The area around Stutterheim is dominated by indigenous forest and plantations along the slopes of the Amatola Mountains and some agricultural area. Natural vegetation along the Great Kei River and major tributaries is thicket bushland, while the higher lying flat areas are covered by grassland.

The tributaries of the Great Kei are utilised for bulk water supply with storage dams on the Kubusi River (Wriggelswade Dam) and Gcuwa River (Gcuwa Dam). Water for domestic use is also taken directly from the Great Kei and other tributaries from weirs and pumping stations.

Most rivers and catchments are described as moderately modified with the lower reaches of the Tsomo River and Great Kei River being largely modified. It is recommended to improve most of the conditions to largely natural and moderately modified, respectively.

The National Wetland Map indicates few seeps at the headwaters of the Kubusi River and its tributaries that can be considered groundwater fed (see **Figure 5-26**). There are also clusters of springs in the north-eastern part of the Resource Units that are probably linked to the dolerite intrusions.

5.4.2 Conceptual Model

The aquifers in Resource Unit 3 are considered minor aquifers, as they consist predominantly of intergranular/fractured aquifer types with some dolerite intrusions, especially widespread in the eastern part of the resource unit, which can enhance the groundwater potential. Alluvium intergranular aquifers are limited to few river valleys.

The average transmissivity across the resource unit ranges from 2.5 to 30 m^2/day. Some areas in the resource unit, mostly linked to dolerite intrusions, show transmissivity values greater than 30 m^2/day. The average recharge rate for Resource Unit 3 is estimated at 38 mm/a, resulting in a total average recharge of 121 million m^3/a.

Since most aquifers in the resource units are weathered regolith aquifers of limited thickness, it is assumed that these aquifers discharge into the nearest surface water feature, which is normally a stream or river. There are no distinct recharge areas for the aquifers. Hence, the path way between recharge and discharge is relatively short. This pattern can be seen in the piezometric map (see **Figure 5-27**), which indicates that the water level generally follows the topography. The influence of the rivers is also evident in the water level map.

The Great Kei River and most tributaries are considered perennial, as evident from the hydrological records (see **Figure 5-28**). However, most of the systems are regulated with storage dams within or upstream of Resource Unit 3.

Figure 5-24 Geology map for RU3

Figure 5-25 Land use map for RU3

Figure 5-26 Wetland, springs and protected areas in RU3

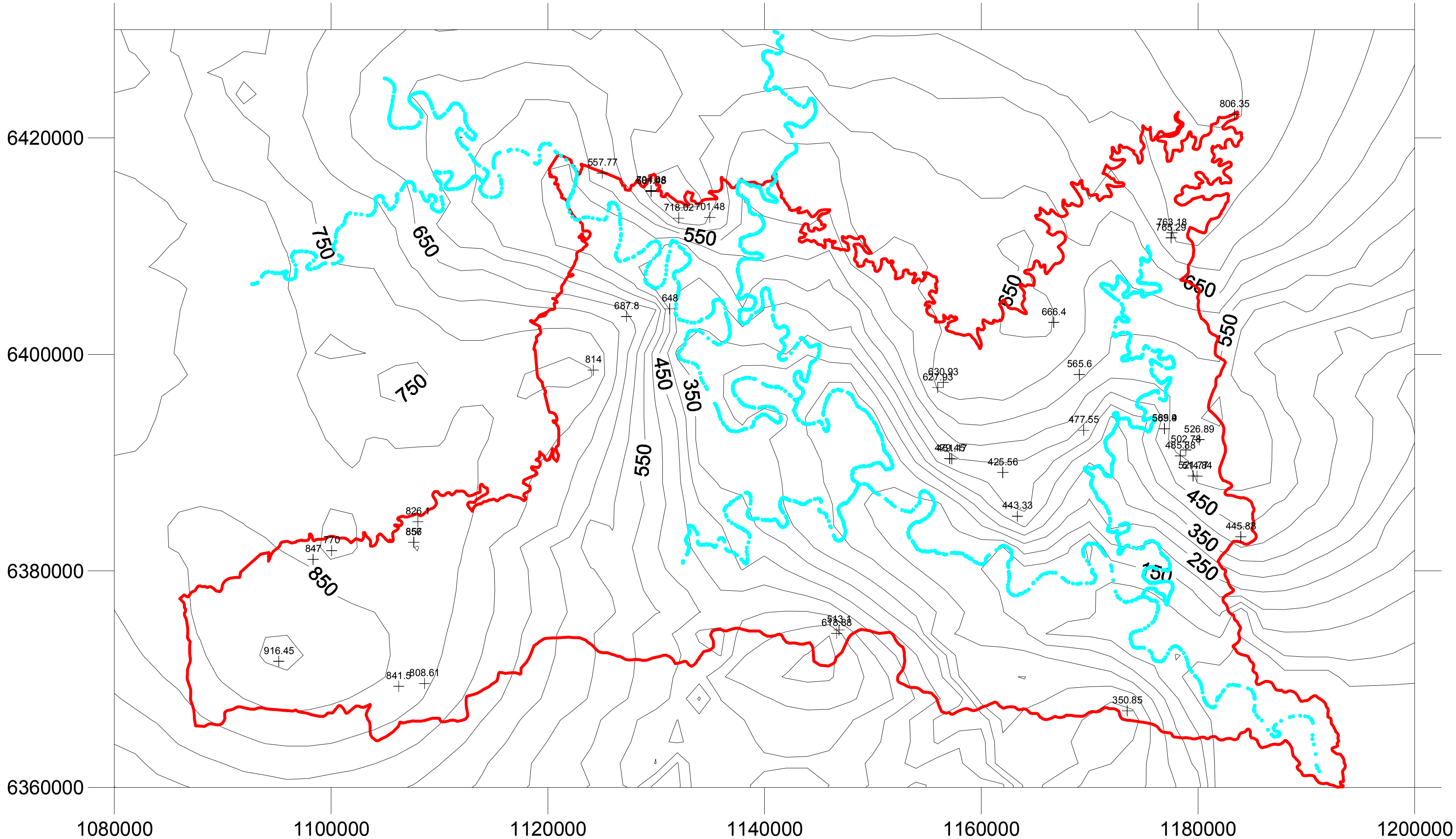
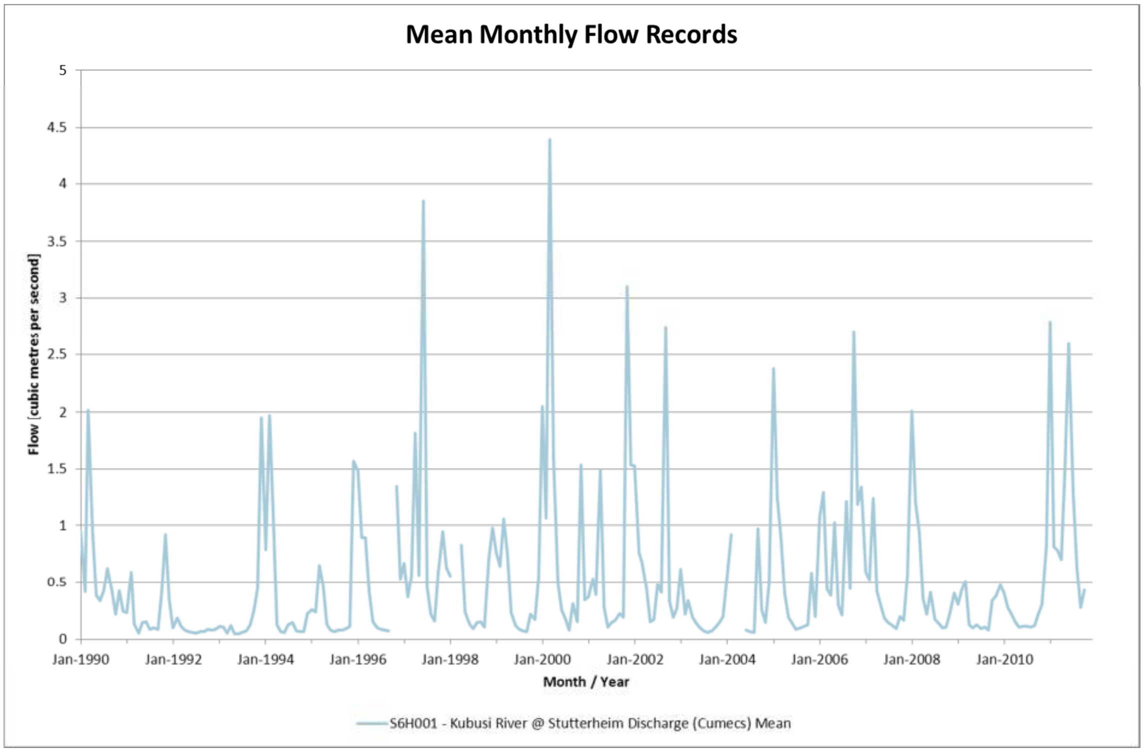


Figure 5-27 Piezometric map for RU3



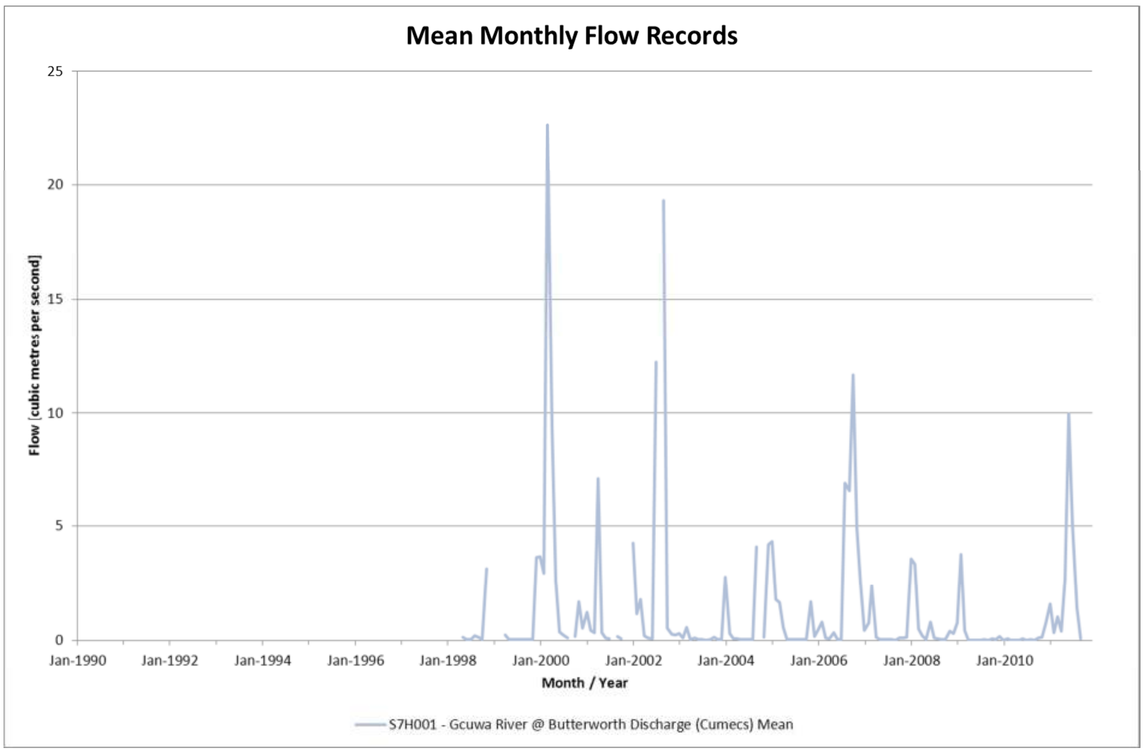


Figure 5-28 River hydrographs in RU3; a) Kubusi River, b) Gcuwa River

5.4.3 Current Status

The current status of the resource unit is defined by the groundwater use as proportion of recharge and the groundwater quality.

The usage indicated by GRAII with 1.40 million m^3/a is significantly higher than the one registered in WARMS. Since there is some municipal usage indicated in the All Towns Study, the higher GRAII number is accepted as realistic.

Table 5-5 Groundwater use in Resource Unit 3

Resource Unit	GRA II (Mio m^3/a)	WARMS (Mio m^3/a)	GRIP (%)	All Towns (Mio m^3/a)	Final (Mio m^3/a)
3	1.40	0.31	-	1.00	1.40

Based on these estimates, Resource Unit 3 is considered minimally modified, with an aquifer stress index of 1%. This is confirmed by long-term water level monitoring from a borehole near Komga, which shows seasonal influence of nearby abstraction and weather patterns, but no long-term negative trend (see **Figure 5-29**).

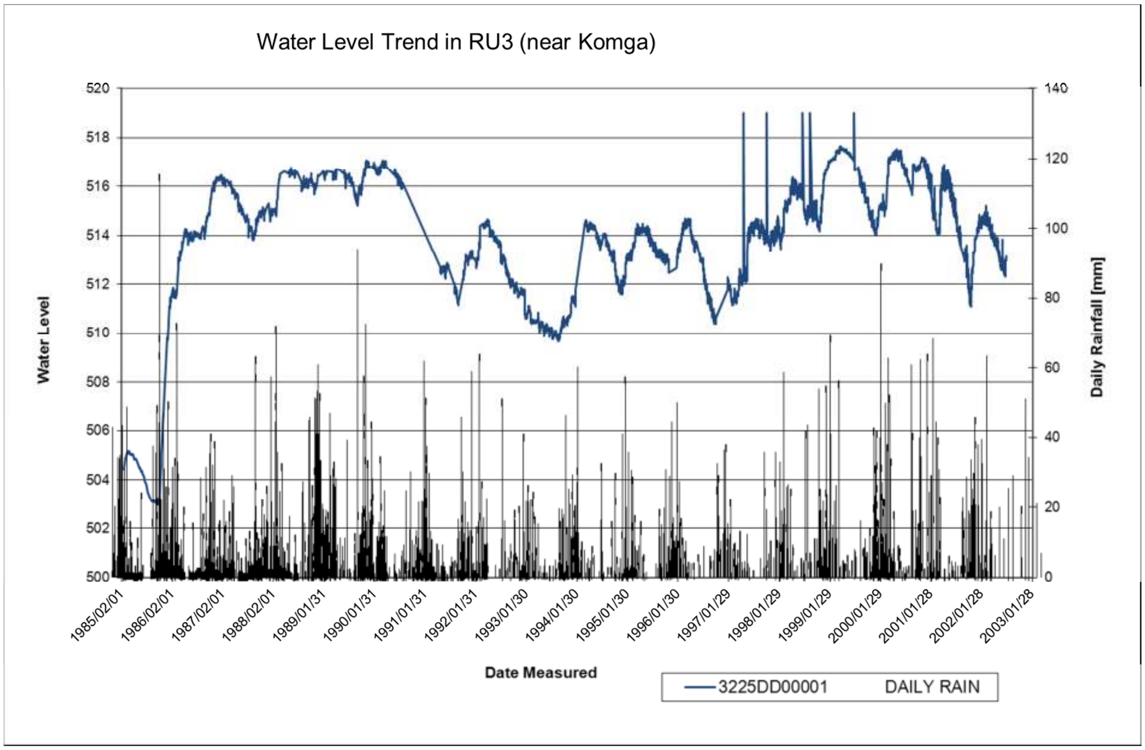


Figure 5-29 Water level trends in selected borehole from RU3

The hydrochemical characterisation of the aquifers is determined by the geology, as the proximity to the sea appears to be of less influence. Over most of the resource unit the aquifers show a mixed water composition between Na-Cl and Ca-HCO_3 (see **Figure 5-30**). The water quality is generally good with all boreholes falling in Class 0 or Class I with respect to EC as indicator.

Based on monitoring results from the Amathole DM, there are two boreholes that have high coliform concentrations, which means the groundwater is not suitable for use by humans without treatment; these boreholes are Tika and Kei Farm boreholes. Ndenxe borehole has high Iron concentration (1979 µg/l). The high iron concentration in the groundwater causes a salty or repulsive taste.

These are considered single incidents and do not indicate a widespread groundwater quality problem, although the aquifer is vulnerable to contamination and the spread of villages with limited sanitation facilities increases the risk of groundwater pollution. Current long-term monitoring of a borehole close to Komga and a borehole north of Stutterheim do not show any negative trend in water quality (see **Figure 5-31**).

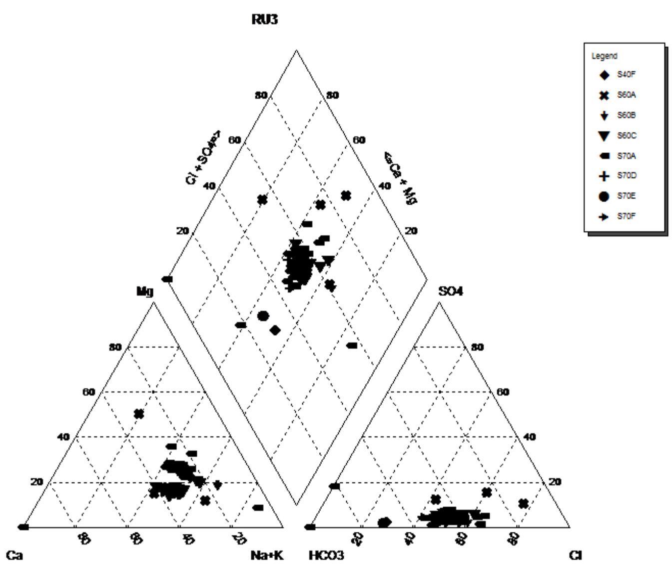


Figure 5-30 Hydrochemical characterisation and groundwater quality in RU3

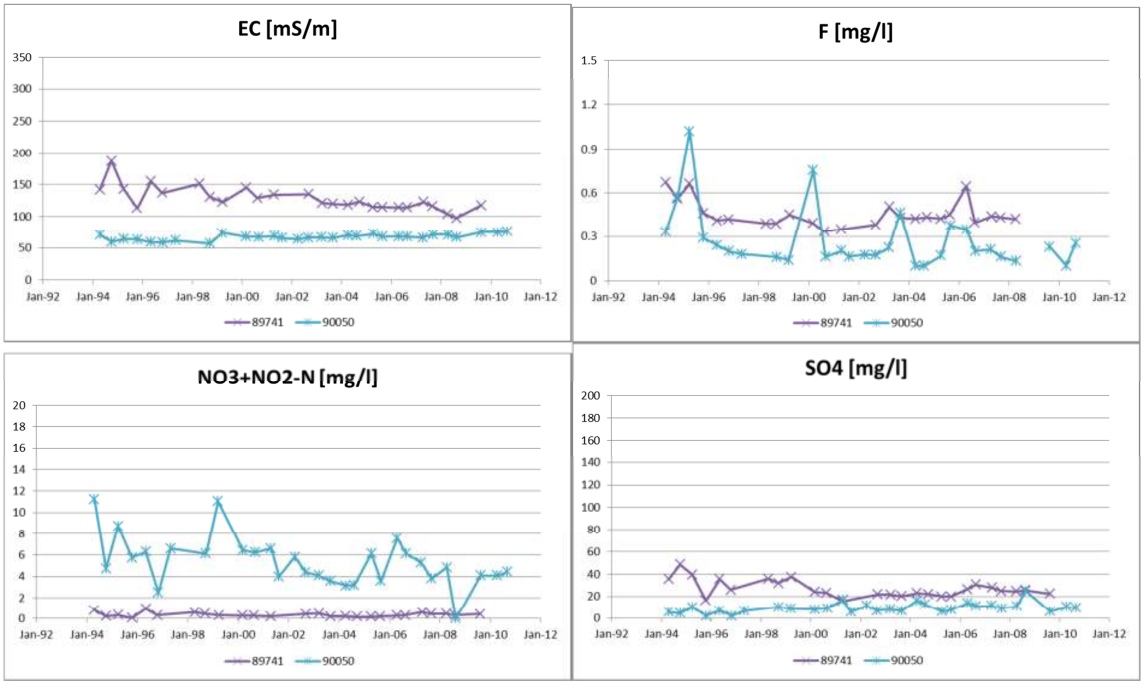


Figure 5-31 Groundwater quality trends in RU3 (Boreholes 89741 and 90050)

5.5 Resource Units 4 and 7

5.5.1 Description

The Resource Units 4 and 7 are located in the south-eastern part of the study area and comprise the T90 catchments (see **Figure 5-32**). The coastal section stretches from the Great Kei River mouth to the Mbashe River mouth. The western and north-eastern boundaries are marked by the surface water divides towards the Great Kei River and Mbashe River, respectively. The north-western boundary deviates from the catchment divide and follows the lithological contact between the Adelaide Group and the Katberg Formation in the north. Resource Unit 7 is a subset of Resource Unit 4 due to the different geological and hydrogeological characteristics.

The topography of both resource units is hilly with rivers flowing within incised valleys. The elevation ranges from 0 mamsl along the coast to 800 mamsl at the catchment divides.

Towns like Kentani and Willowvale are located in Resource Unit 4, while Butterworth and Idutywa are located at the boundaries to Resource Unit 3 and 9, respectively.

Temperate climate is experienced in the coastal part, while inland parts are experiencing more extreme conditions. These variations are related to the elevation and proximity to the sea. Most rainfall occurs during summer. The mean annual rainfall ranges from 600 – 1500 mm/a with the highest mean annual rainfall along the coastal areas. Maximum temperatures are experienced in January and minimum temperatures usually occur in July.

The geology of Resource Unit 4 is mostly made-up of the Adelaide Subgroup of the Beaufort Group with Karoo Dolerite intrusions across the area and Quaternary deposits in some river valleys and along the coast (see **Figure 5-33**). Resource Unit 7 is entirely made up of the Ecca Group of Karoo Supergroup with limited Karoo Dolerite intrusions and few Quaternary deposits.

The resource units are characterised by the vast amount of villages scattered across most of the area. However, the central and north-eastern part or covered with indigenous forest and thicket bushland, while the western and northern part shows more cultivated land and is dominated by natural grassland (see **Figure 5-34**).

The rivers and catchments in Resource Unit 4 and 7 are currently in a largely natural status, and is it recommended to keep them in this ecological status, or improve slightly where possible.

The Dwesa-Cwebe Wildlife Reserve falls within Resource Unit 7. There is no other protected are in Resource Unit 4, but a number of indigenous forests and forest reserves that could be considered protected areas. There is also a widespread occurrence of wetlands and seeps along some of the catchment divides and at headwaters of streams, especially south of Idutywa and south-east of Butterworth (see **Figure 5-35**). These seeps could be groundwater fed.

In addition, there are several clusters of springs across Resource Unit 4, indicating groundwater discharge that is often linked to the dolerite intrusions.

Figure 5-32 Location, topography and drainage for RU4

Figure 5-33 Geology map for RU4

Figure 5-34 Land use map for RU4

Figure 5-35 Wetland, springs and protected areas in RU4

5.5.2 Conceptual Model

The aquifers in Resource Unit 4 are considered minor aquifers, while the aquifers in Resource Unit 7 are poor aquifers. Both resource units comprise intergranular/fractured aquifers with dolerite intrusions of varying degree, and limited alluvium/intergranular aquifer types.

The average transmissivitiy for Resource Unit 4 ranges from 2.5 to 15 m^2/day, whereas the average transmissivity for Resource Unit 7 is <2.5 m^2/day. There are few areas in both resource units with transmissivity values of more than 30 m^2/day. However, these are restricted to dolerite intrusions.

The average recharge rate is 52 mm/a for Resource Unit 4 and 64 mm/a for Resource Unit 7. The total annual recharge volume is then estimated as 122 million m^3/a for Resource Unit 4 and 10.5 million m^3/a for Resource Unit 7.

Since the aquifers in Resource Unit 4 and 7 are weathered regolith aquifers of limited thickness, it is assumed that all aquifers are drained by the nearest surface water feature, which is normally a stream or river (see **Figure 5-36**). The path length between recharge and discharge is usually considered short, as there are no distinct recharge areas. However, the occurrence of the dolerite sills and elongated dolerite dykes could alter the flow pattern and allow for extended groundwater flow along the intrusions. The position of the vast amount of springs in Resource Unit 4 also suggests preferred flow paths along the dolerite dykes and sills.

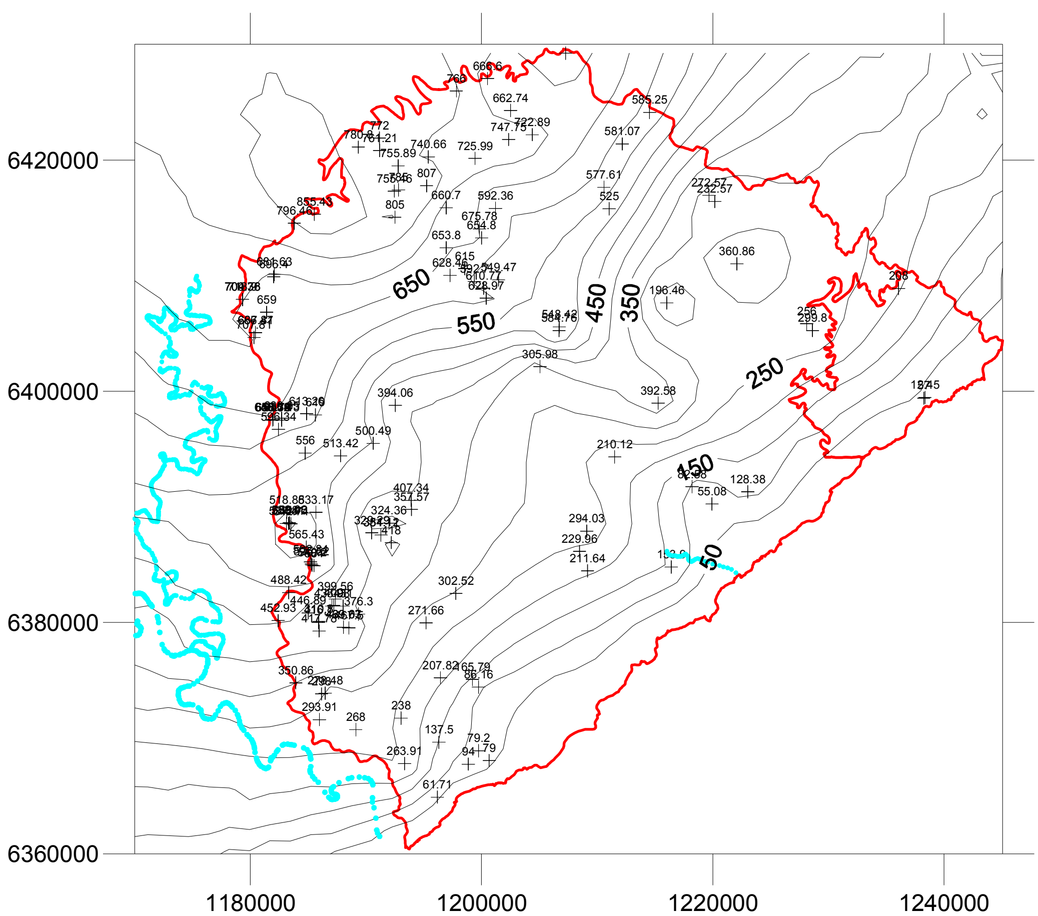


Figure 5-36 Piezometric map for RU4

5.5.3 Current Status

The current status of the resource unit is defined by the groundwater use as proportion of recharge and the groundwater quality.

The All Towns Reconciliation Strategy Study suggests a groundwater usage of 2.40 million m^3/a in Resource Unit 4, which is significant higher than the numbers obtained from GRAII and WARMS. The WARMS confirms that usage is mostly municipal but registered volumes are exceeded significantly. The higher number from the All Towns Study is deemed realistic since actual water requirement figures from groundwater dependent communities were used in the calculations.

For Resource Unit 7 the GRAII indicates some groundwater usage. However, there is no agricultural or domestic usage registered in the WARMS, and the All Towns Study does not indicate any groundwater supply to communities. The total usage is therefore assumed as zero.

Table 5-6 Groundwater use in Resource Unit 4 and 7

Resource Unit	GRA II (Mio m^3/a)	WARMS (Mio m^3/a)	GRIP (%)	All Towns (Mio m^3/a)	Final (Mio m^3/a)
4	1.21	0.79	-	2.40	2.40
7	0.13	0.00	-	0.00	0.00

Based on these estimates, Resource Unit 3 is considered minimally modified, with an aquifer stress index of 1%.

The hydrochemical characterisation of the aquifers is determined by the geology and proximity to the sea. The samples show a trend of changing water composition from Na-Cl dominated water closer to the sea towards Ca/Mg-HCO_3 water further inland (see **Figure 5-37**). The water quality is generally of acceptable quality with most boreholes falling in Class 0 or Class I with respect to EC as indicator.

There are two boreholes north-west of Kentani with elevated EC values that fall in Class II. High nitrate content exceeding 20 mg/l is found only in one borehole which is located south of Kentani. This high concentration of nitrate is possibly linked to human and or animal manure, resulting also in high coliform concentrations in the region, as confirmed by monitoring results from the Amathole DM.

In 5 out of 11 boreholes tested during the field work, faecal and total coliform numbers were significantly higher than the tolerated value. In one case Nitrate and Nitrite was found to exceed the recommended limit (SANS 241) by more than 100%. Generally there seems to be a high concentration in iron and manganese in the area which does not have any health impact but might be problematic in terms of the potential of incrustation and precipitation in water reticulation systems.

However, longer-term monitoring at a borehole east of Butterworth does not show a negative trend in water quality or significantly exceeding of the recommended limits (see **Figure 5-38**).

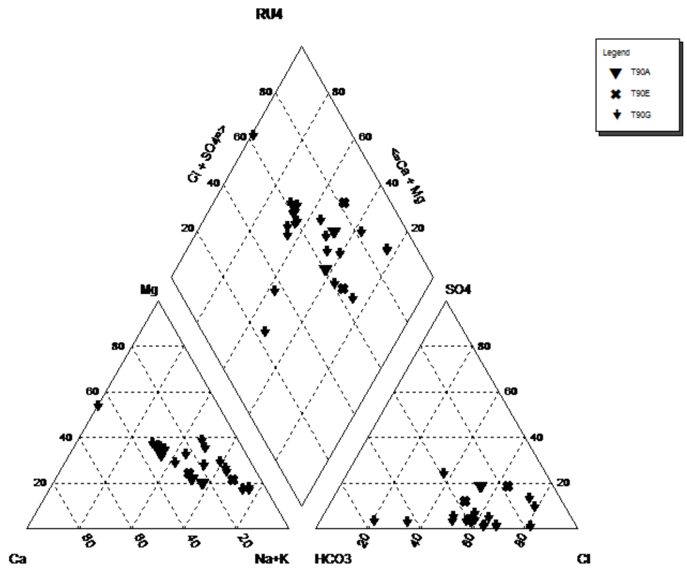


Figure 5-37 Hydrochemical characterisation and groundwater quality in RU4

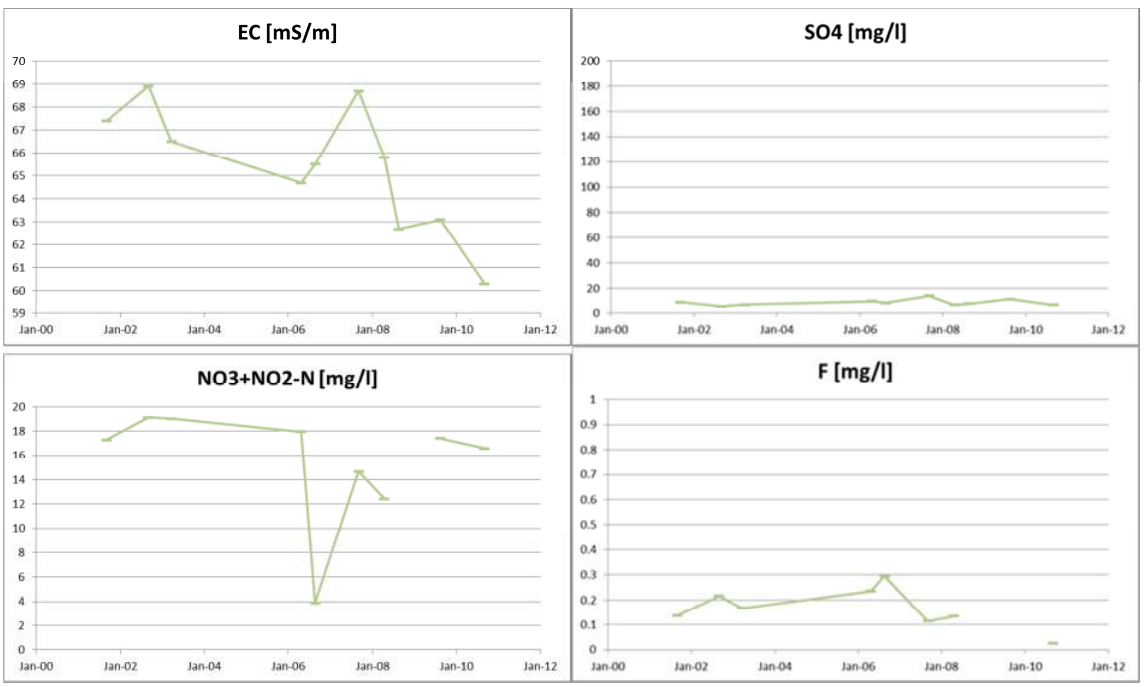


Figure 5-38 Groundwater quality trends in RU4 (Borehole 1-56)

5.6 RESOURCE UNIT 9

5.6.1 Description

Resource Unit 9 is situated north of Resource Units 3 and 4. The north-eastern boundary is formed by the catchment divide between Drainage Region T and Drainage Region S, while the northern boundary is formed by the lithological contact between the Katberg Formation and the Burgersdorp Formation. The western boundary along outcrops of dolerite intrusions separates the two central resource units that are formed by the Katberg Formation.

Hence, the resource unit crosses through several drainage lines, from the T90A in the East, S70C and D (Gcuwa River), S50G, H and J (Tsomo River), S40D and E (Great Kei River) to S10J (White Kei River). The topography of Resource Unit 9 is hilly to mountainous with the rivers flowing in the partially incised valleys. The elevation ranges from 500 to 1100 mamsl.

The towns of Idutywa, Nqamakwe, Tsomo and Cofimvaba are found in this resource unit.

Resource Unit 9 experiences temperate to more extreme climate conditions. Most rainfall occurs during summer. The mean annual rainfall of RU 9 ranges 500 – 800 mm/a with significant annual variation (see **Figure 5-39**). The rainfall increases from north to south of the resource unit and from west to east. Maximum temperatures are experienced in January and minimum temperatures usually occur in July. Frost occurs in winter.

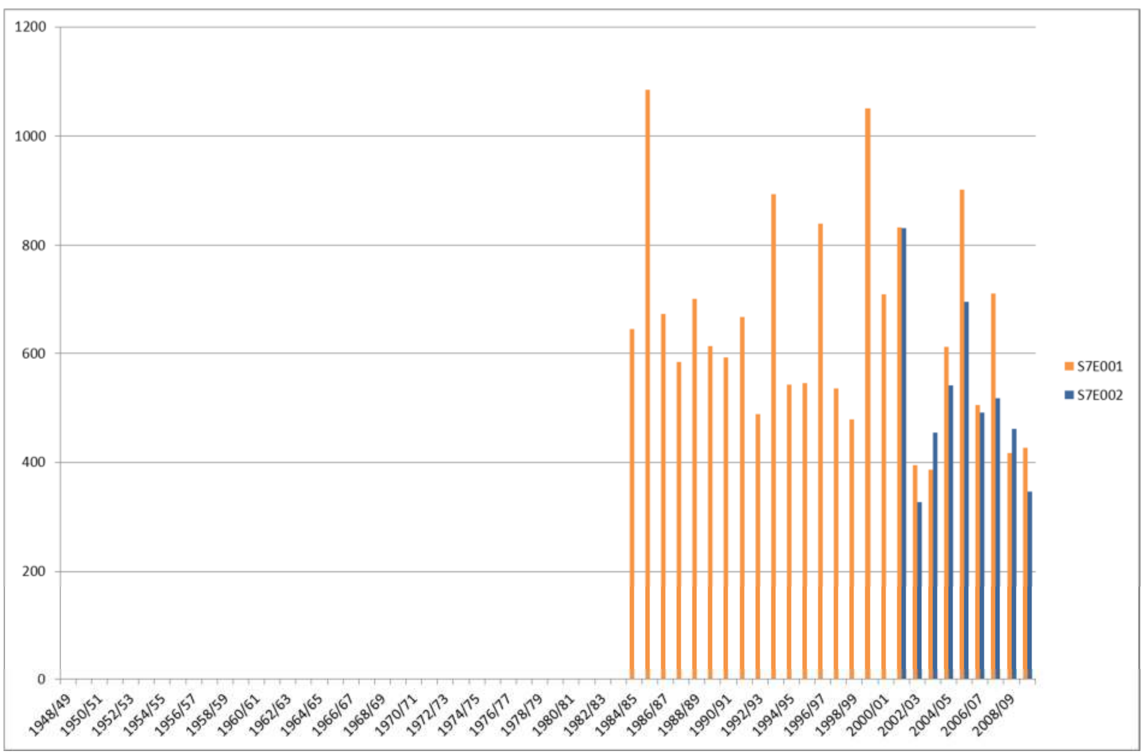


Figure 5-39 Annual rainfall [mm/a] for different weather stations in RU9

Figure 5-40 Location, topography and drainage for RU9

The geology of Resource Unit 9 comprises the sandstones of the Katberg Formation of Tarkastad Subgroup and Karoo Dolerite intrusions, most of which are dolerite sills and ring structures (see **Figure 5-42**). The Katberg Formation is mainly made up of sandstone layers which thin out at the southern boundary of the resource unit and increase in thickness towards the north. The Katberg Formation extends northwards beyond the outcrop boundary, where it is overlain by the Burgersdorp Formation.

The land use in Resource Unit 9 is dominated by the vast amount of villages across the resource unit. These are surrounded by cultivated land and degraded grassland, especially around Idutywa, the Xilinxa Dam and between Tsomo and Cofimvaba (see **Figure 5-43**). There are some forest plantations north of Nqamakwe and indigenous forest patches along the southern boundary.

The rivers and catchments in the eastern part of the resource unit are in a largely modified status, while the catchments in the western part are described as moderately modified. It is recommended to improve all rivers to a higher category. However, most of the larger rivers are regulated with surface water dams, either within the resource unit (i.e. Xilinxa Dam on the Gcuwa River) or further upstream (e.g. Ncora Dam on the Tsomo River and Xonxa Dam on the White Kei River). The hydrological records of the Tsomo River just upstream of the resource unit shows that the river flows throughout the year (see **Figure 5-41**).

The National Wetland Map depicts several clusters of seeps along catchment divides and headwaters (see **Figure 5-44**) that could be considered groundwater fed. In addition, there are clusters of springs, especially in the north-western part of the resource unit, that are most probably linked to dolerite intrusions.

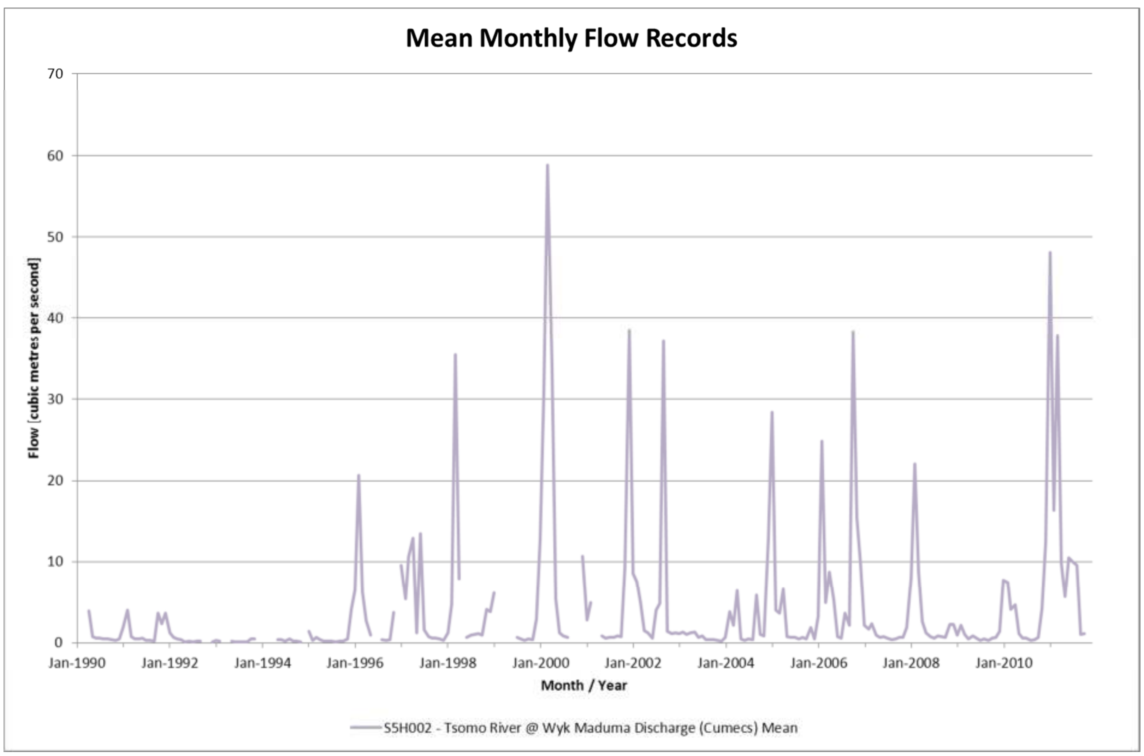


Figure 5-41 River hydrograph in RU9; Tsomo River

Figure 5-42 Geology map for RU9

Figure 5-43 Land use map for RU9

Figure 5-44 Wetland, springs and protected areas in RU9

5.6.2 Conceptual Model

The aquifers in the Katberg Formation are considered fractured aquifers, which is the main criteria to separate Resource Unit 9 and 10 from the integranular / fractured aquifers of the Adelaide Group in the south and Burgersdorp Formation in the north. The Katberg Aquifer is cut into compartments by the dolerite intrusions. The aquifer units are unconfined to semiconfined within Resource Unit 9. However, the aquifers extend towards the north underneath the integranular fractured aquifers of the Burgersdorp Formation, becoming confined.

The average transmissivity for the Katberg Aquifer within Resource Unit 9 increases from south to north and ranges from 5 to 15 m^2/day. The contacts between the Katberg and the dolerite intrusions are considered highly transmissive and show average transmissivities of more than 30 m^2/day.

The average recharge rate for Resource Unit 9 is estimated at 52 mm/a, giving a total recharge of 98 million m^3/a.

Although the aquifers in Resource Unit 9 are considered fractured aquifers with higher storage potential, the shallow groundwater is mainly drained by nearby streams and rivers. However, some deeper flow along dolerite intrusions and into the confined portion of the aquifer towards the north can be expected.

The water level map indicates the general southwards flow and shows the drainage lines of the major rivers. The seeps and springs on the eastern and northern boundaries are also indicative of the groundwater discharge into nearby surface water features.

5.6.3 Current Status

The current status of the resource unit is defined by the groundwater use as proportion of recharge and the groundwater quality.

The All Towns Reconciliation Strategy Study indicates a groundwater use for domestic supply within Resource Unit 9 of 1.34 million m^3/a, which is significantly higher than the numbers obtained from GRAII and WARMS. The WARMS registrations in this Resource Unit are mostly domestic and industrial usage. The higher number from the All Towns Study is accepted suggesting that the registered volumes are exceeded or additional municipal boreholes are being used.

Table 5-7 Groundwater use in Resource Unit 9

Resource Unit	GRA II (Mio m^3/a)	WARMS (Mio m^3/a)	GRIP (%)	All Towns (Mio m^3/a)	Final (Mio m^3/a)
9	0.94	0.27	49%	1.34	1.34

Based on these estimates, Resource Unit 9 is considered minimally modified, with an aquifer stress index of 1%.

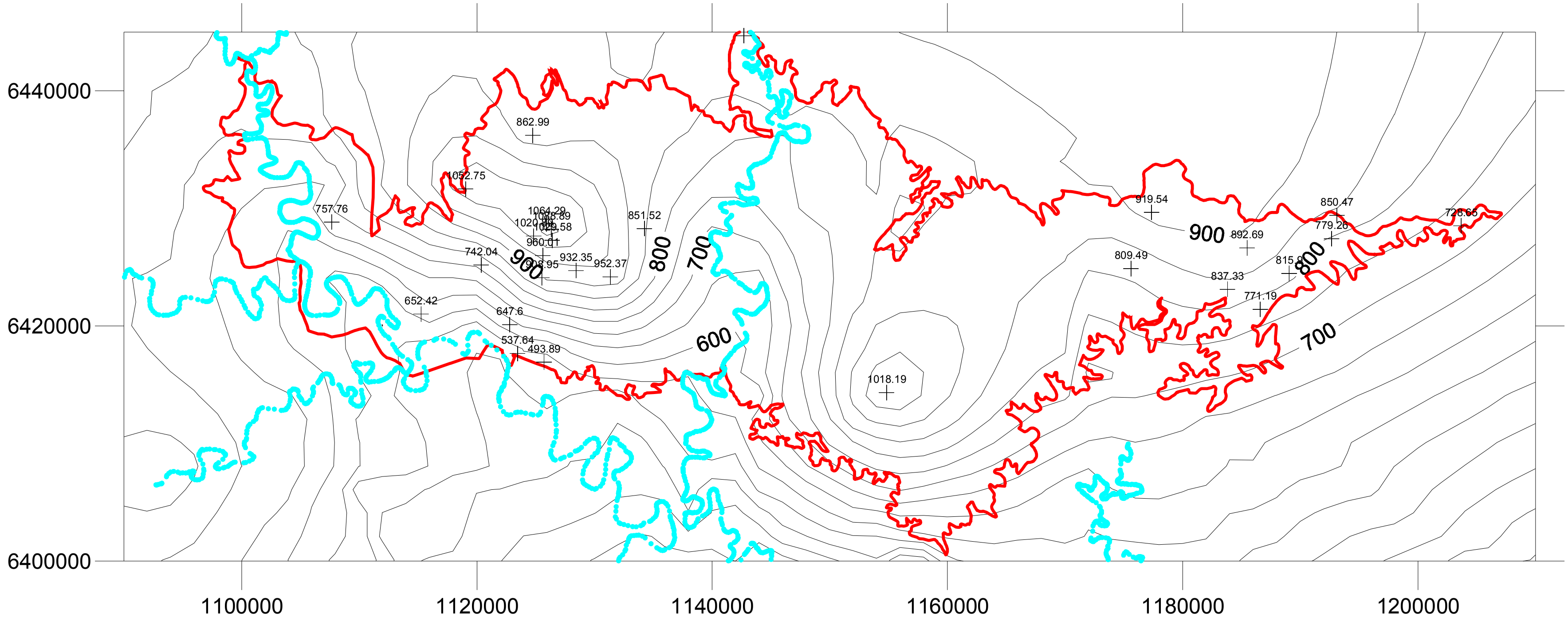


Figure 5-45 Piezometric map for RU9

The hydrochemical characterisation of the aquifers is determined by the geology and catchment. The aquifers in the eastern part are more Na-Cl dominated, while the rest of the resource unit tends towards Ca/Mg-HCO_3 dominated water (see **Figure 5-46**). The water quality is generally good with all boreholes falling in Class 0 or Class I with respect to EC as indicator.

Higher EC values of Class II are found in two boreholes south of Tsomo and two boreholes that are situated in the north and east of Idutywa. High nitrate content exceeding 20 mg/l was found in one borehole south of Tsomo. This high concentration of nitrate is often linked to human and or animal manure, which could also cause the high prevalence of coliform bacteria in the aquifers.

Water samples were taken at 7 selected sites within the Nqamakwe area during the field work. Water quality concerns are mostly due to high faecal and total coliform concentrations. These impurities can cause serious health problems and therefore the affected boreholes deserve special attention in any further analysis. Monitoring data from the Amathole DM confirm the prevalence of coliforms in the groundwater; e.g., the Sokapase and Good Hope boreholes have high concentrations of coliforms.

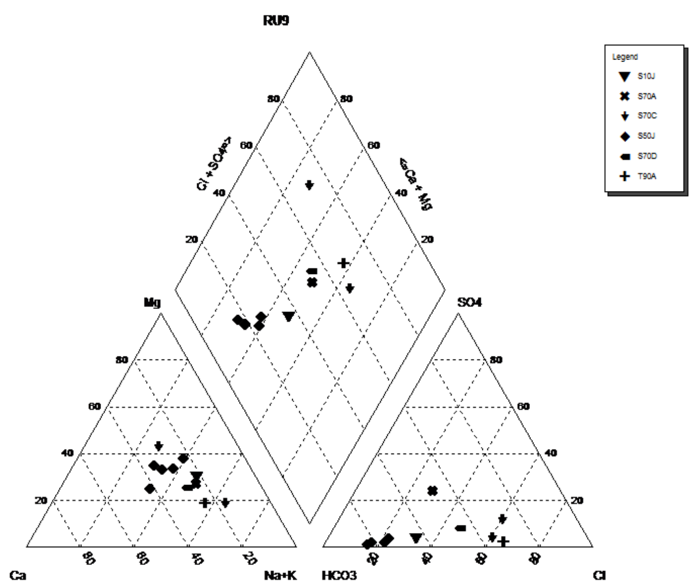


Figure 5-46 Hydrochemical characterisation and groundwater quality in RU9

5.7 RESOURCE UNIT 10

5.7.1 Description

Resource Unit 10 forms the western extension of Resource Unit 9 and is the second significant resource unit that comprises the outcrop area of the Katberg Formation. Similar to Resource Unit 9, the northern and southern boundaries are formed by the lithological contacts between the Katberg Formation and the Adelaide Group in the south, and the Burgersdorp Formation in the north, respectively. The western boundary is the drainage divide between the Mzimvubu-Keiskamma WMA and the Fish-Tsitsikamma WMA (see **Figure 5-48**).

Cathcart is situated in the central part of the resource unit and the towns of Sada and Whittlesea are located in the western part within the village cluster of the former Ciskei.

The topography of Resource Unit 10 is hilly to mountainous with rivers flowing in the valleys. The elevation ranges from 800 to 1800 mamsl and increasing from east to west. The highest mountains are found on the western and southern part of this resource unit, forming part of the Amatola Mountain Range.

The climate is temperate to extreme with most rainfall occurring during summer. The mean annual rainfall ranges from 400 in the valleys to 1500 mm/a in the Amatola Mountains, on the southern part of Resource Unit 10. Precipitation shows a huge annual variability as shown in **Figure 5-47**. The rainfall increases from north to south of the resource unit and from west to east. Maximum temperatures are experienced in January and minimum temperatures usually occur in July. Frost and snow occur in winter in this resource unit.

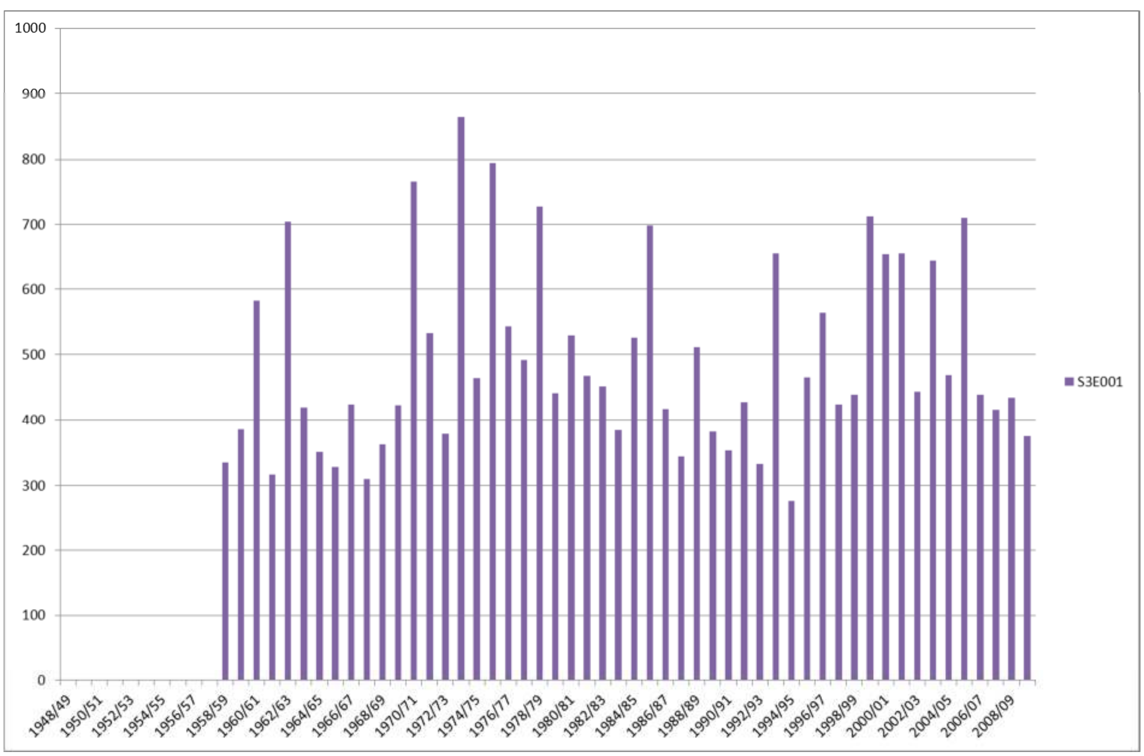


Figure 5-47 Annual rainfall [mm/a] for a weather station in RU10 (Waterdown Dam)

Figure 5-48 Location, topography and drainage for RU10

The resource unit contains the upper reaches of the Black Kei River (S31A and B), the Klipplaat River and its tributaries (S32D to H), the lower reaches of the Black Kei River above the confluence with the White Kei River (S32K to M), the Thomas River and its tributaries (S40) as well as tributaries of the Kubusi River (S60C). Storage dams are built on some of these rivers; e.g. Waterdown Dam on the Klipplaat River and Oxkraal Dam on its tributary.

The geology of Resource Unit 10 is characterised by the Katberg Formation of the Tarkastad Subgroup and Karoo Dolerite intrusions with Alluvium deposits in the wider valleys, mainly in the north-western part. The most important geological feature of this resource unit is the huge dolerite ring structure, called “Cathcart Ring”, which with a diameter of about 50 km extends from the northern to the southern boundary of the resource unit (see **Figure 5-49**). There are other, but significantly smaller dolerite intrusions in the western part.

The land use varies greatly across the resource unit with three distinct zones (see **Figure 5-50**). The extent of the Cathcart Ring is dominated by natural and partly degraded grassland with some indigenous forests and forest plantations. The most north-western part of Resource Unit 10 is mainly covered by shrubland and low fynbos with cultivated land around villages. The area around Sada / Whittlesea is characterised by the built up areas of the scattered villages of the former Ciskei, surrounded by cultivated land and grassland.

The rivers and catchments in Resource Unit 10 are mainly considered as largely modified, except S32G (Sada / Whittlesea) and the most eastern areas (S40E and S60C and D), which are described as moderately modified.

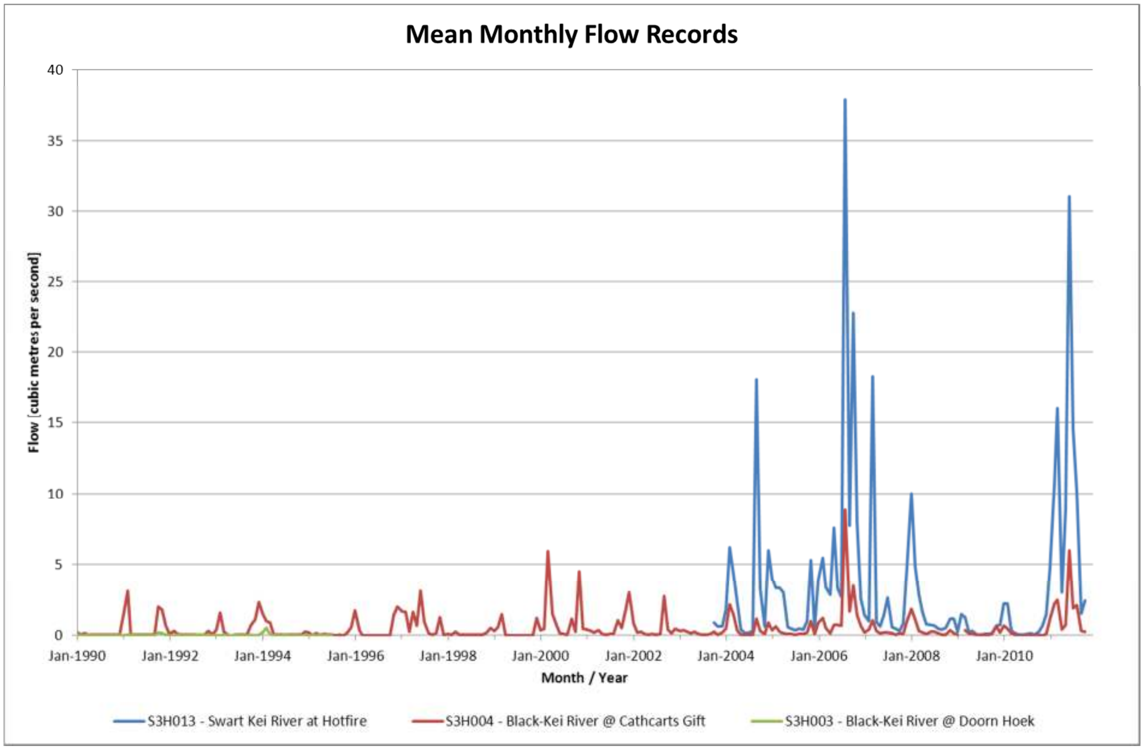
There are several protected areas in the resource unit; viz. the Tsojana Nature Reserve in the west, two smaller protected areas west and north-west of Cathcart and the Hogsback Forestry in the south. Along the slopes of the Amatola Mountain Range, seeps and wetlands are formed that might be groundwater fed, as these also forms the headwaters of the streams, draining northwards.

Despite the possible groundwater contribution from these seeps towards the river flow, the upper reaches of the Black Kei River are considered seasonally flowing (see S3H003 and S3H004 in **Figure 5-52a**). The main contribution to the high flows in the lower reaches of the Black Kei River appear to come from other tributaries, like the Klaas Smits River in Resource Unit 16 and 19 (see section 5.10) and the Klipplaat River. The Klipplaat River originates in the Amatola Mountains and feeds the Waterdown Dam south of Sada. Flow records from the gauging station downstream of the dam clearly indicate the influence of the dam and the regulation of flow (see **Figure 5-52b**).

Figure 5-49 Geology map for RU10

Figure 5-50 Land use map for RU10

Figure 5-51 Wetland, springs and protected areas in RU10



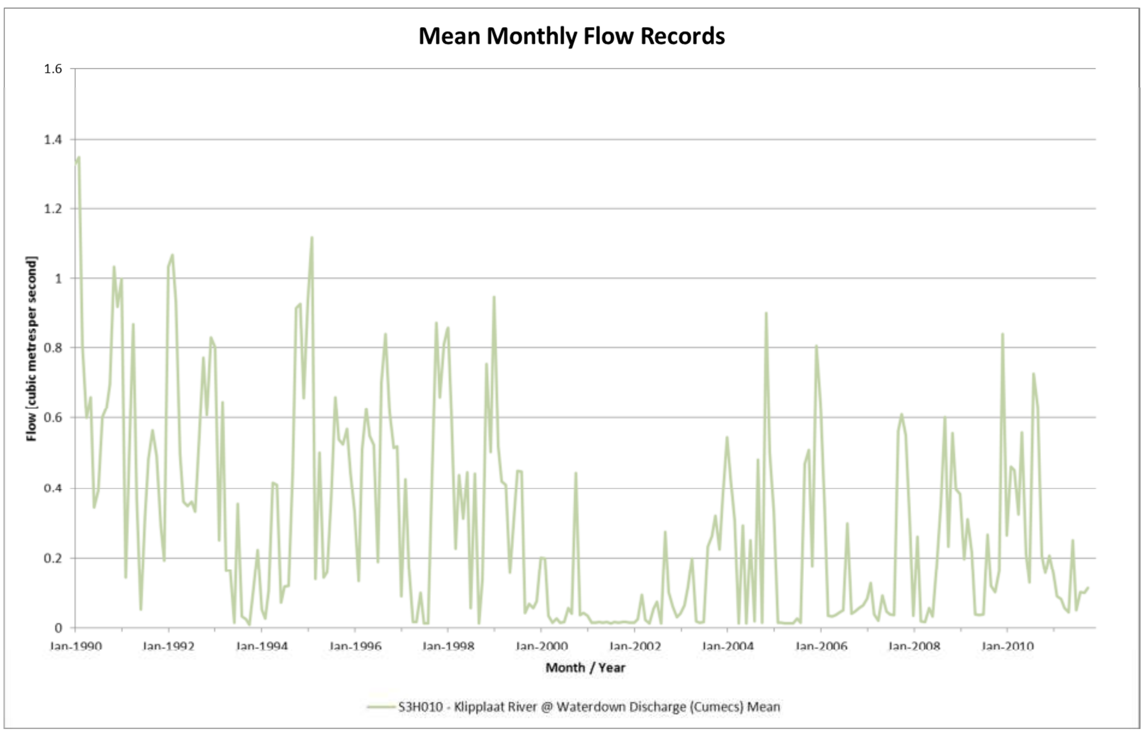


Figure 5-52 **River hydrographs in RU10; a) Black Kei River along profile, b) Klipplaat River downstream of Waterdown Dam**

5.7.2 Conceptual Model

The aquifers in Resource Unit 10 are considered fractured aquifers, comprising the sandstones of the Katberg Formation. Groundwater occurrence and flow is enhanced through the dolerite intrusions, which create a significant fracture network at the contact zones between the intrusion and the host rock (see **Figure 5-53**). Some alluvium/intergranular aquifers are overlying the Katberg aquifer in valleys of the north-western part.

The average transmissivity given for Resource Unit 10 in Chevallier et al. (2010) ranges from 2.5 to 10 m^2/day. However, areas close to dolerite intrusions show an average transmissivity of greater than 30 m^2/day.

The recharge rate for Resource Unit 10 is estimated as 39 mm/a, resulting in a total recharge for this resource unit of 186 million m^3/a.

Although the aquifers in Resource Unit 10 are considered fractured aquifers with higher storage potential, the shallow groundwater is mainly drained by nearby streams and rivers. However, some deeper flow along dolerite intrusions and into the confined portion of the aquifer towards the north can be expected.

Resource Unit 10 is the only resource unit in the study area that shows groundwater flow towards the north, due to the major drainage divide of the Amatola Mountain Range on the southern boundary. The water level mainly follows the topography indicating the short flow paths between recharge and discharge and the drainage by the major rivers (see **Figure 5-54**).

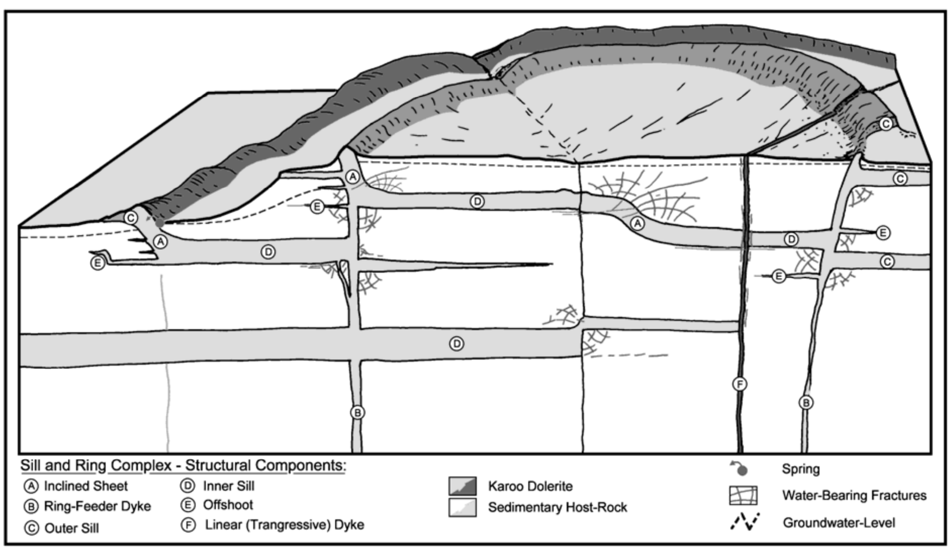


Figure 5-53 Hydro-morphotectonic model of a dolerite sill- and ring-complex, showing zones of greater fracture density and the potential groundwater – surface water interaction in RU10. (After Chevallier et al., 2001, presented in Woodford and Chevallier, 2002a).

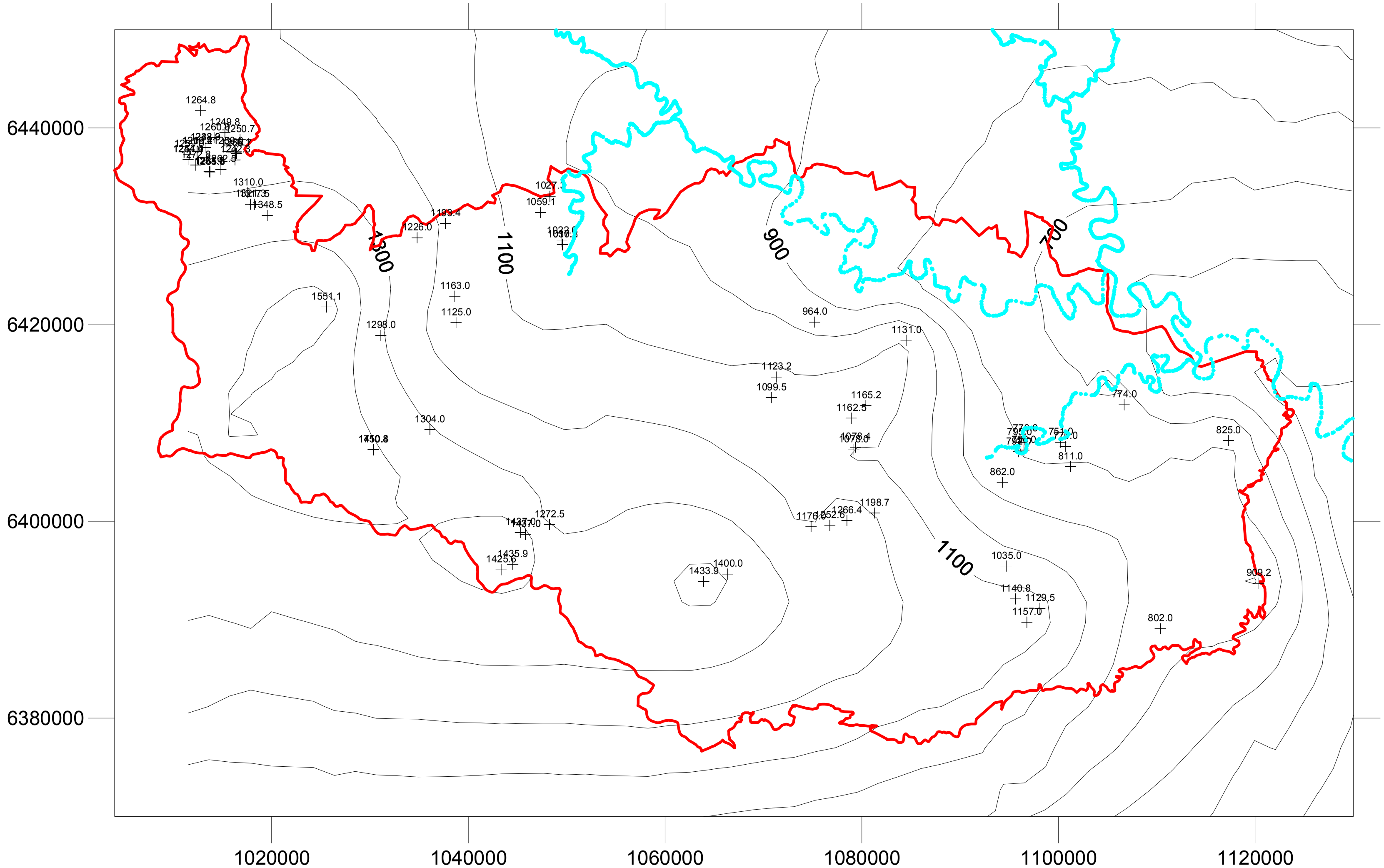


Figure 5-54 Piezometric map for RU10

5.7.3 Current Status

The current status of the resource unit is defined by the groundwater use as proportion of recharge and the groundwater quality.

The GRAII data indicates a very high groundwater usage of 5.28 million m^3/a. It is known that there is widespread groundwater usage in the rural villages of the area. The WARMS reflects numerous entries for mostly domestic and industrial use with unrealistically low registered volumes. The All Towns Reconciliation Strategy Study confirms the usage for domestic supply, but indicates a volume much lower than the GRAII. Therefore a usage equal to half of the annual volume indicated by GRAII is used, which lies between the GRAII and All Towns Study numbers and allows for the agricultural use in the eastern part of the resource unit.

Table 5-8 Groundwater use in Resource Unit 10

Resource Unit	GRA II (Mio m^3/a)	WARMS (Mio m^3/a)	GRIP (%)	All Towns (Mio m^3/a)	Final (Mio m^3/a)
10	5.28	0.20	-	1.45	2.64

Based on these estimates, Resource Unit 10 is considered minimally modified, with an aquifer stress index of 1%. This is confirmed by long-term water level monitoring from a borehole north of Sada / Whittlesea, which shows seasonal influence of nearby abstraction and weather patterns, but no long-term negative trend (see **Figure 5-55**).

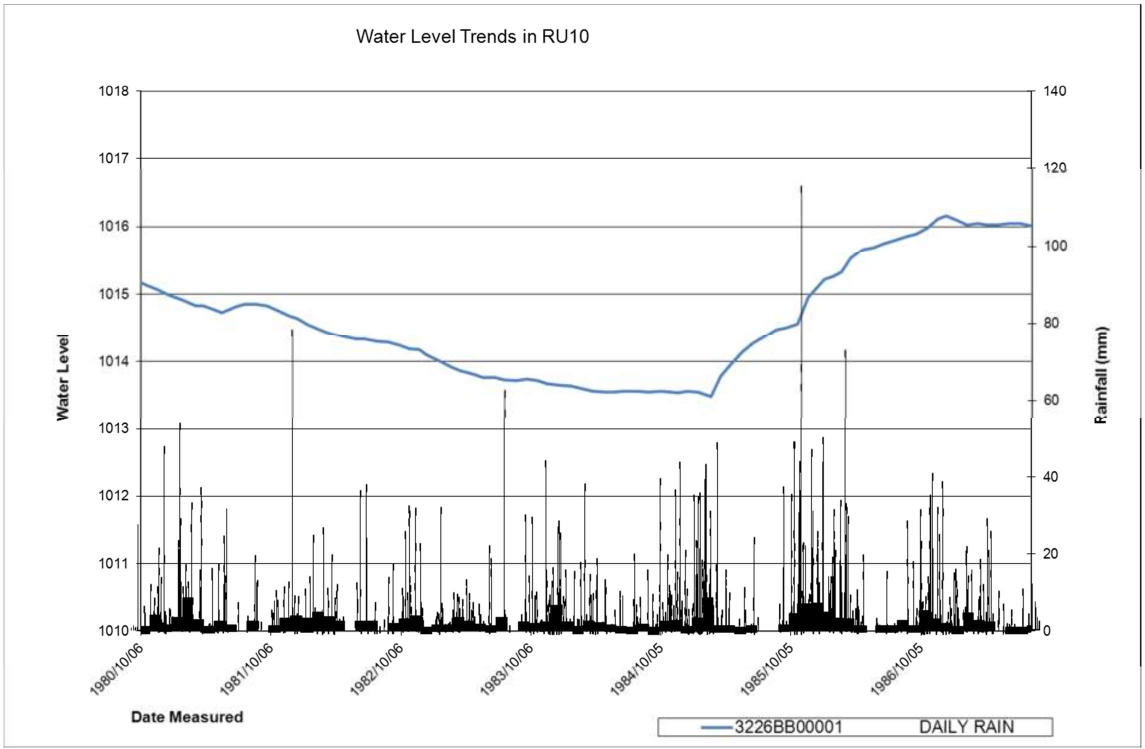


Figure 5-55 Water level trends in selected borehole from RU10

The hydrochemical characterisation of the aquifers is determined by the geology and catchment signature. The aquifers show a trend from Na-Cl dominated water in the central part of Resource Unit 10 to Ca-HCO_3 dominated water towards the lower reaches of the Black Kei River (see **Figure 5-56**). The water quality is generally good with most boreholes falling in Class 0 or Class I with respect to EC as indicator.

Class II EC is found in few boreholes around S32H and S32K; and in one borehole north-east of Cathcart. High nitrate content that exceeds 20 mg/l is found in few boreholes around S32H and S32K of the resource unit. However, these are considered isolated incidents.

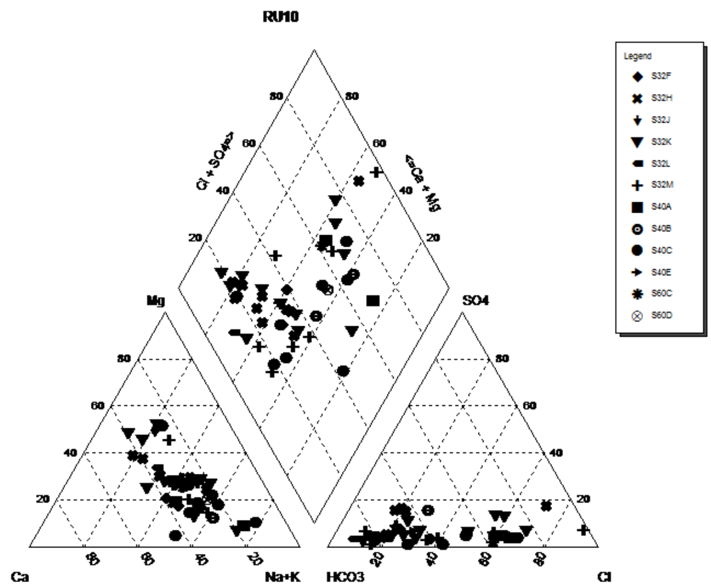


Figure 5-56 **Hydrochemical characterisation and groundwater quality in RU10**

5.8 RESOURCE UNIT 11

5.8.1 Description

Resource Unit 11 is located north of Resource Unit 9, comprising the middle reaches of the Tsomo River (S50D – S50H) in the east, the middle and lower reaches of the Indwe River (S20B – S20D) and the middle reaches of the White Kei River (S10B – S10J) in the west. The eastern boundary is formed by the catchment divide towards the T Drainage Region, while the western boundary is the catchment divide between the Black Kei (S31, S32) and White Kei (S10) catchments. The southern and northern boundaries follow geological lithological contacts; viz. between the Katberg Formation and Burgersdorp Formation in the south and between the Burgersdorp Formation and the Molteno Formation in the north.

The main towns in this resource unit are Cala in the far north-east and Lady Frere. All three rivers are utilised for water supply, for domestic use and agriculture. The Xonxa Dam on the White Kei River, the Lubisi Dam on the Indwe River and the Ncora Dam on the Tsomo River were originally built for extended irrigation downstream of these dams.

The topography of RU 11 is hilly to mountainous on the northern boundary with rivers flowing in mostly wide valleys. The elevation ranges from 800 to 1600 mamsl with the lowest topography at the confluence of White Kei and Indwe. The highest elevation is found along the escarpment on the northern boundary and in the north-western part.

The climate conditions in Resource Unit 11 are temperate to more extreme conditions with frost and snow occurring in winter in this resource unit. Most rainfall occurs during summer. Mean annual rainfall ranges from 400 – 1500 mm/a with a very high mean annual rainfall along the escarpment between Cala and the Ncora Dam. The rainfall increases from west to east of the resource unit. However, rainfall shows a high annual and spatial variation, as is evident from rainfall records across the resource unit (see **Figure 5-57**) Maximum temperatures are experienced in January and minimum temperatures usually occur in July.

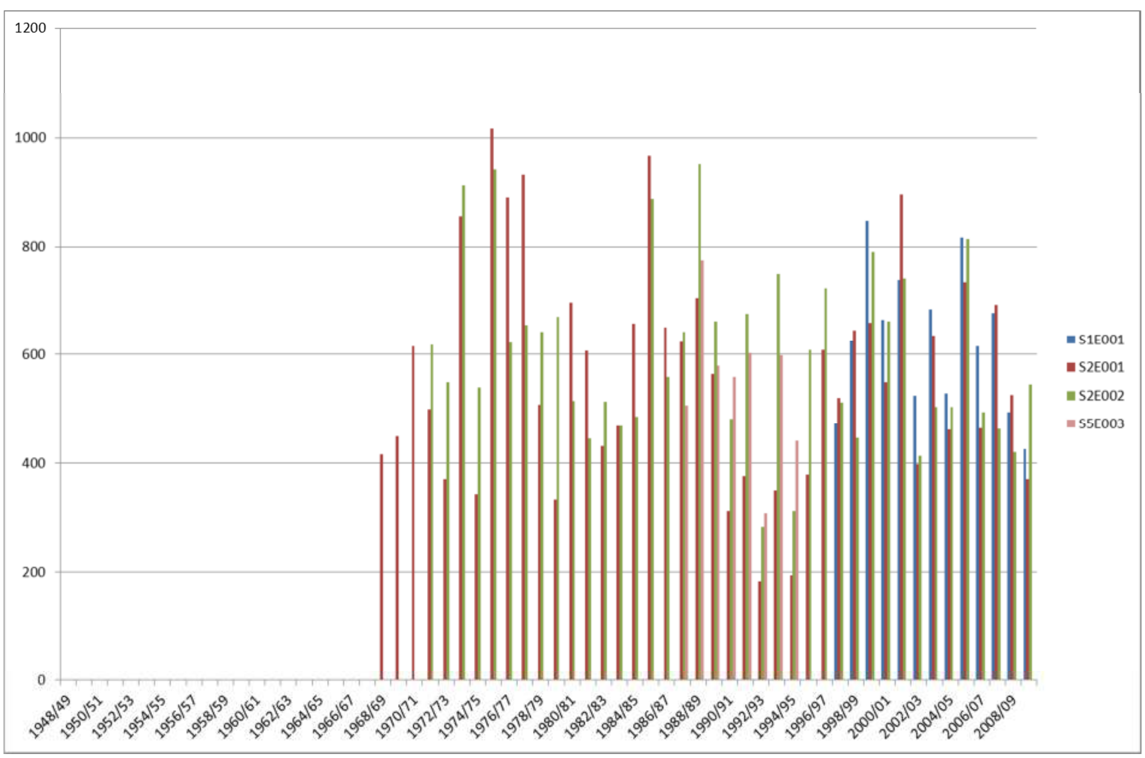


Figure 5-57 Annual rainfall [mm/a] for different weather stations in RU11

Figure 5-58 Location, topography and drainage for RU11

The geology of Resource Unit 11 is made up of the Burgersdorp Formation of the Tarkastad Subgroup with Karoo Dolerite intrusions across the area. Within the wide valleys, these geological units are overlain by Quaternary deposits (see **Figure 5-59**). In some areas along the northern boundary, outcrops of the Molteno Formation are found, overlying the Burgersdorp Formation.

The whole resource unit is characterised by the vast amount of villages of the former Transkei, which are surrounded by cultivated land and degraded grassland (see **Figure 5-60**). There are some indigenous forests along the Indwe River downstream of the Lubisi Dam and forest plantations in the Tsomo River catchments. Patches of shrubland and low fynbos are found across the resource unit that are clearly linked to dolerite outcrops.

Rivers and catchments in Resource Unit 11 are mainly in a moderately modified (Tsomo River) to largely modified status (White Kei and Indwe Rivers). Only catchment S10D is considered largely natural.

Only few seeps and wetlands are indicated on the National Wetland Map that could be considered groundwater fed. However, there are several clusters of springs across the resource units, most of which are probably linked to the dolerite intrusions.

5.8.2 Conceptual Model

The aquifers in Resource Unit 11 are considered minor aquifers, as they consist of intergranular/fractured aquifer types of limited effective thickness with dolerite intrusions, which are overlain by alluvium/intergranular aquifers in some places.

The average transmissivity for this area varies significantly and ranges from 2.5 to 30 m^2/day. In areas around dolerite intrusions it can be greater than 30 m^2/day, while the transmissivity reduces to less than 2.5 m^2/day along the northern boundary, at the contact zone to the Molteno Formation.

The recharge rate for Resource Unit 11 is estimated at 32 mm/a, resulting in a total average recharge of 133 million m^3/a.

Since most aquifers in the resource units are weathered regolith aquifers of limited thickness, it is assumed that these aquifers discharge into the nearest surface water feature, which is normally a stream or river. There are no distinct recharge areas for the aquifers. Hence, the path way between recharge and discharge is considered relatively short. The occurrence of the dolerite intrusions can result in locally changing flow pattern and pathways across surface water divides.

This pattern can be seen in the piezometric map (see **Figure 5-62**), which indicates that the water level generally follows the topography. The influence of the rivers is also evident in the water level map. All major rivers and significant tributaries in the resource unit are considered perennial, as is evident from flow records of the Tsomo River at the southern boundary towards Resource Unit 9 (see **Figure 5-41**).

Figure 5-59 Geology map for RU11

Figure 5-60 Land use map for RU11

Figure 5-61 Wetland, springs and protected areas in RU11

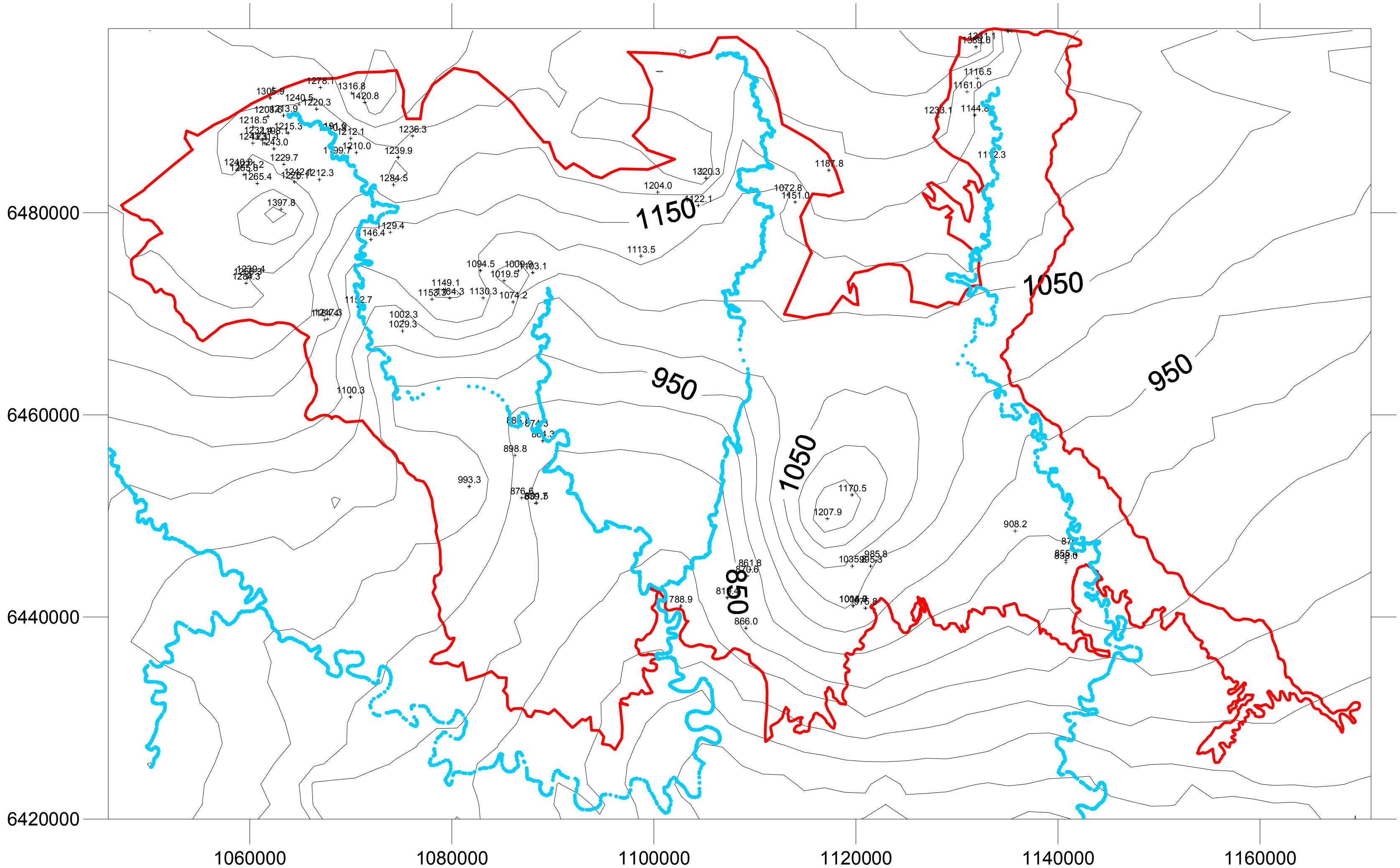


Figure 5-62 Piezometric map for RU11

5.8.3 Current Status

The current status of the resource unit is defined by the groundwater use as proportion of recharge and the groundwater quality.

The usage of groundwater for domestic supply of the rural villages in the area is widely known as confirmed by the GRIP as well as the All Towns Reconciliation Strategy Study. This usage to a large degree seems to be registered in the WARMS. It is unknown why the GRAII number is that much lower. The higher number of 5.44 million m^3/a obtained from the All Towns Study is accepted as realistic.

Table 5-9 Groundwater use in Resource Unit 11

Resource Unit	GRA II (Mio m^3/a)	WARMS (Mio m^3/a)	GRIP (%)	All Towns (Mio m^3/a)	Final (Mio m^3/a)
11	1.71	5.09	89%	5.44	5.44

Based on these estimates, Resource Unit 11 is considered minimally modified, with an aquifer stress index of 4%.

The hydrochemical characterisation of the aquifers is determined by the geology and catchment signature. The aquifers show a clear trend from Na-HCO_3 in the upper reaches of the White Kei River to Ca/Mg-HCO_3 in the lower reaches of the White Kei River and Indwe River (see **Figure 5-63**). The aquifers in the Tsomo River catchments have Cl/HCO_3 mixed water. The water quality is generally good with most boreholes falling in Class 0 or Class I with respect to EC as indicator.

The Class II EC is found in only one borehole located in Lady Frere that also shows high nitrate content exceeding 20 mg/l.

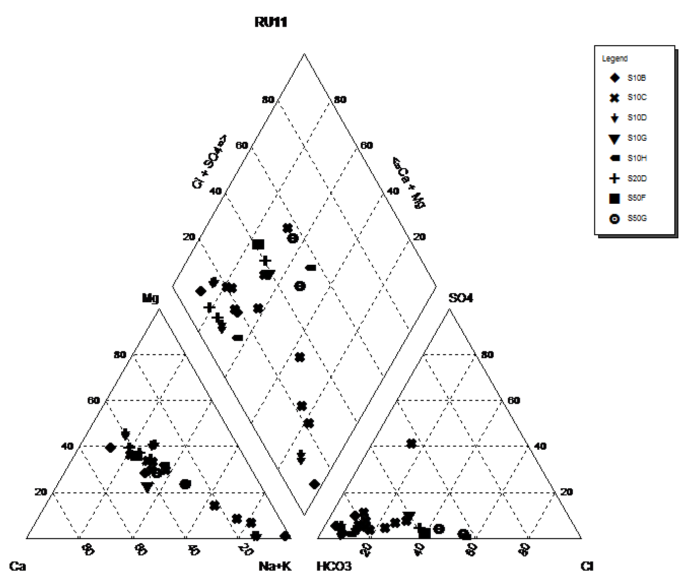


Figure 5-63 Hydrochemical characterisation and groundwater quality in RU11

5.9 RESOURCE UNITS 12 AND 13

5.9.1 Description

RU 12 and RU 13 are located on the northern boundary of the Mzimvubu-Keiskamma WMA north of Resource Unit 11. The northern boundary is formed by the catchment divide towards the Upper Orange WMA and forms also the study area boundary, while the eastern boundary is formed by the divide with the Drainage Region T. The southern and western boundary is the lithological contact between the Molteno Formation and the Burgersdorp Formation. Resource Unit 13 covers the upper reaches of the Tsomo River (S50A to S50D), while Resource Unit 12 covers the upper reaches of the Indwe River (S20A and S20B) and the White Kei River (S10A to S10C, and S10F). The most western part of Resource Unit 12 falls within the upper reaches of the Klaas Smits River (S31A). The only significant town in the resource units is Indwe at the Doring Dam on the Indwe River.

The topography of both resource units is hilly to mountainous. The elevation ranges from 1100 to 2100 mamsl. The highest mountains are along the north-eastern boundary of Resource Unit 13 and are part of the Drakensberg Mountain Range.

Extreme climate conditions are experienced in both resource units with frost and snow occurring in winter. Most rainfall occurs during summer, with mean annual rainfall ranging from 400 to 800 mm/a in Resource Unit 12 and from 500 to 1500mm/a in Resource Unit 13. Maximum temperatures are experienced in January and minimum temperatures usually occur in July.

The geology of both resource units is made up of the Molteno Formation and Elliot Formation with Karoo Dolerite intrusions and few Quaternary deposits along river valleys. Outcrops of the Clarens Formation and Drakensberg Group deposits form the slopes of the Drakensberg Mountain Range along the northern boundary of Resource Unit 13 (see **Figure 5-65**).

The land use varies widely across the resource units (see **Figure 5-66**). The western part of Resource Unit 12 is covered by natural grass, partly degraded grassland and shrubland, while the eastern part of Resource Unit 12 consists of urban or built up areas surrounded by cultivated land and grassland. A number of mines and quarries are found across the resource unit. The southern part of Resource Unit 13 is similar to the eastern part of Resource Unit 12 around Indwe, but with less cultivated land. The northern part of Resource Unit 13 shows cultivated land and plantations with thicket bushland and indigenous forests at the slopes of the Drakensberg Mountains.

All catchments in Resource Units 12 and 13 are considered moderately modified. It is recommended to improve the ecological status for all catchments to largely natural, except for S10A, which was approved to stay as moderately modified.

The wetland map indicates only few seeps and wetlands that could be considered groundwater fed (see **Figure 5-67**). However, there are numerous clusters of springs which indicate groundwater discharge.

Figure 5-64 Location, topography and drainage for RU12 and 13

Figure 5-65 Geology map for RU12 and 13

Figure 5-66 Land use map for RU12 and 13

Figure 5-67 Wetland, springs and protected areas in RU12 and 13

5.9.2 Conceptual Model

The aquifers in Resource Unit 12 and 13 are considered poor to minor aquifers as they consist of intergranular/fractured aquifer types with limited thickness. The occurrence of interganular aquifers in the alluvium deposits can be neglected as these are very thin and do not extend beyond the limits of the small river valleys. Dolerite intrusions can slightly enhance the groundwater potential in these resource units.

Both Resource Unit 12 and 13 have generally low transmissivities between 2.5 and 10 m^2/day. In selected areas, closely linked to dolerite intrusions, the average transmissivity can be greater than 30 m^2/day.

The recharge rate for Resource Unit 12 is 28 mm/a, resulting in a mean total recharge of 52 million m^3/a. The recharge rate for Resource Unit 13 is slightly higher with 41 mm/a, due to the higher rainfall along the Drakensberg Mountains. The estimated mean total recharge is then 55 million m^3/a.

Since most aquifers in the resource units are perched or shallow aquifers within the weathered regolith zone of the Molteno and Elliot formations and are of limited thickness, it is assumed that these aquifers discharge directly into the nearest surface water feature, which is normally a stream or river. There are no distinct recharge areas for the aquifers. Hence, the path way between recharge and discharge is considered relatively short. The occurrence of the dolerite intrusions can result in locally changing flow pattern and pathways across surface water divides.

The occurrence of springs along the southern escarpment verifies these interpretations. As shown by Chevallier et al (2010), most of the springs in Resource Unit 13 are linked either to the Molteno – Burgersdorp contact or the dolerite intrusions (see **Figure 5-68**).

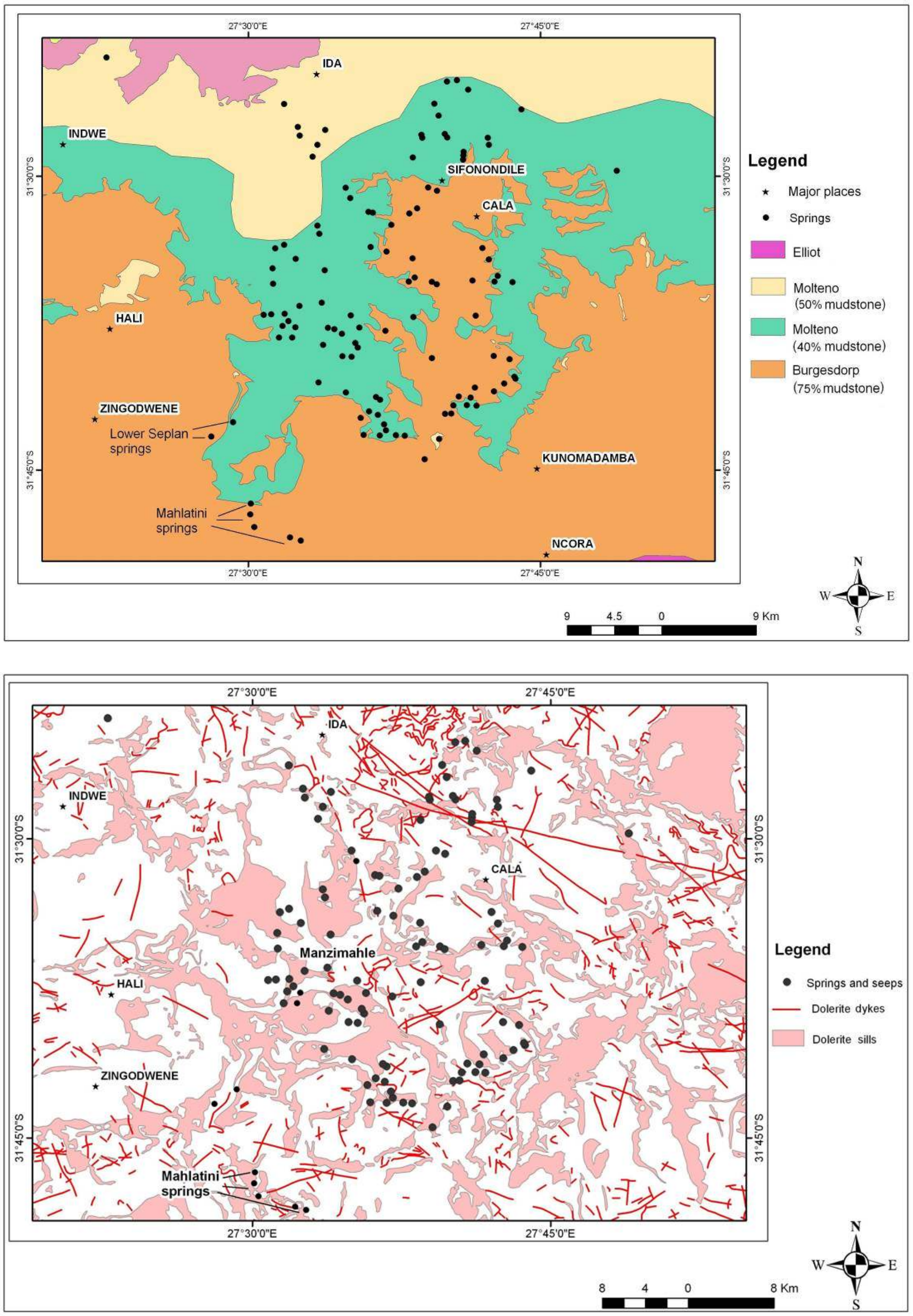


Figure 5-68 **Distribution of springs of the Manzimahle area (Resource Unit 13; a) with respect to the Burgersdorp – Molteno contact; b) with respect to dolerite sills (from Chevallier et al, 2010)**

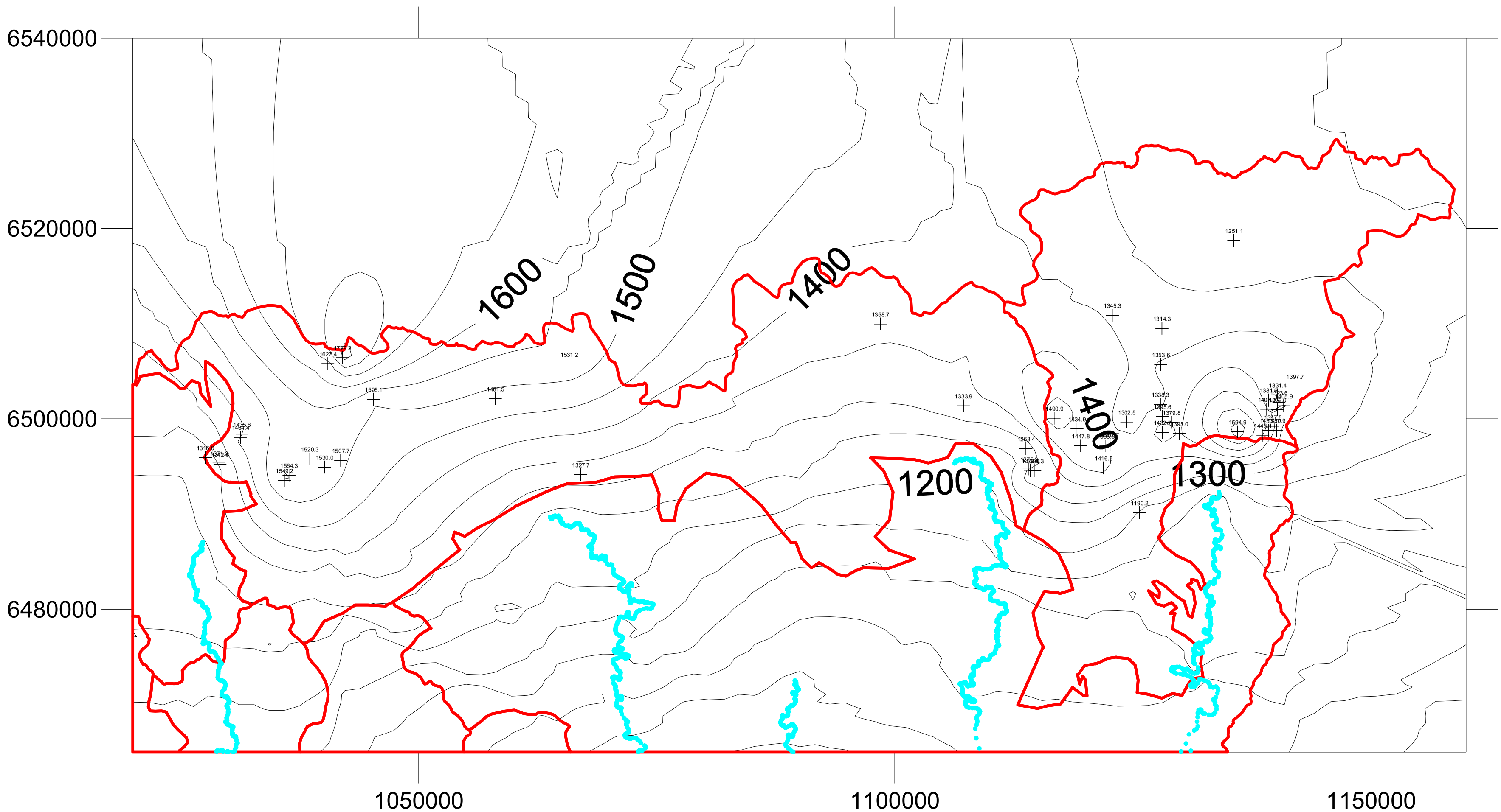


Figure 5-69 Piezometric map for RU 12 and 13

5.9.3 Current Status

The current status of the resource unit is defined by the groundwater use as proportion of recharge and the groundwater quality.

For Resource Unit 12 the abstraction volume obtained from the GRAII with 1.59 million m^3/a is much higher than the one obtained from WARMS, which is in the same order as the one from the All Towns Reconciliation Strategy Study. The GRAII number is deemed unrealistically high. Therefore the municipal/domestic usage derived from the All Towns Study is increased by the WARMS registered amount that reflects agricultural usage.

In Resource Unit 13 there is no municipal usage reflected in the All Towns Reconciliation Strategy Study, although it is known that several of the villages rely on water from springs. The WARMS database indicates an abstraction volume of 0.44 million m^3/a, slightly higher than the GRAII number. This higher number is accepted as realistic.

Table 5-10 Groundwater use in Resource Unit 12 and 13

Resource Unit	GRA II (Mio m^3/a)	WARMS (Mio m^3/a)	GRIP (%)	All Towns (Mio m^3/a)	Final (Mio m^3/a)
12	1.59	0.31	-	0.37	0.68
13	0.23	0.44	-	0.00	0.44

Based on these estimates, both Resource Unit 12 and Resource 13 are considered minimally modified, with an aquifer stress index of 6% and 1%, respectively.

The hydrochemical characterisation of the aquifers is determined by the geology. Over most of the resource unit the aquifers show a mixed water composition between Na-Cl and $Ca\text{-}HCO_3$ (see **Figure 5-70**). The water quality is generally good with most boreholes falling in Class 0 or Class I with respect to EC as indicator. EC concentration that falls in Class II is found in only one borehole that is situated in the northern part of S31A of Resource Unit 12.

However, these are considered isolated incidents. Long-term monitoring at boreholes and a spring in or at the boundary of Resource Unit 12 north of Sterkstroom do not show negative trends in water quality (see **Figure 5-71**).

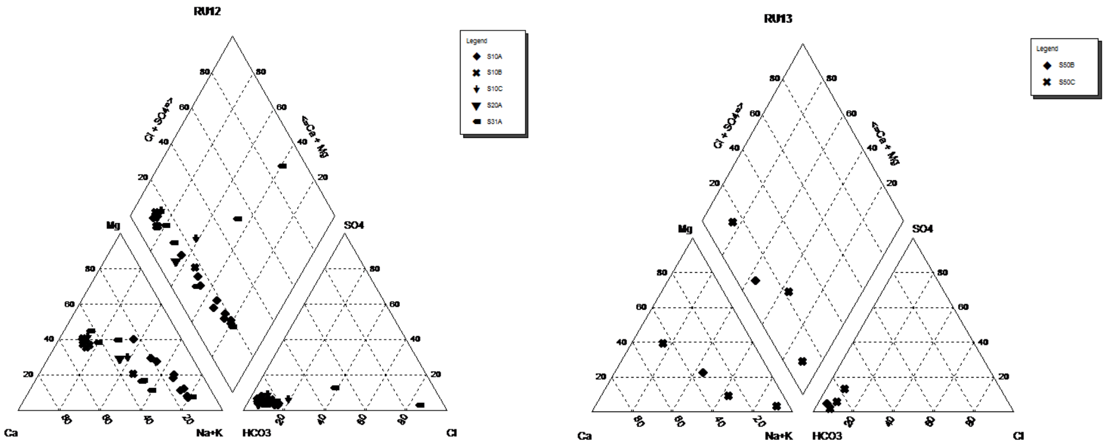


Figure 5-70 Hydrochemical characterisation and groundwater quality in RU12 and 13

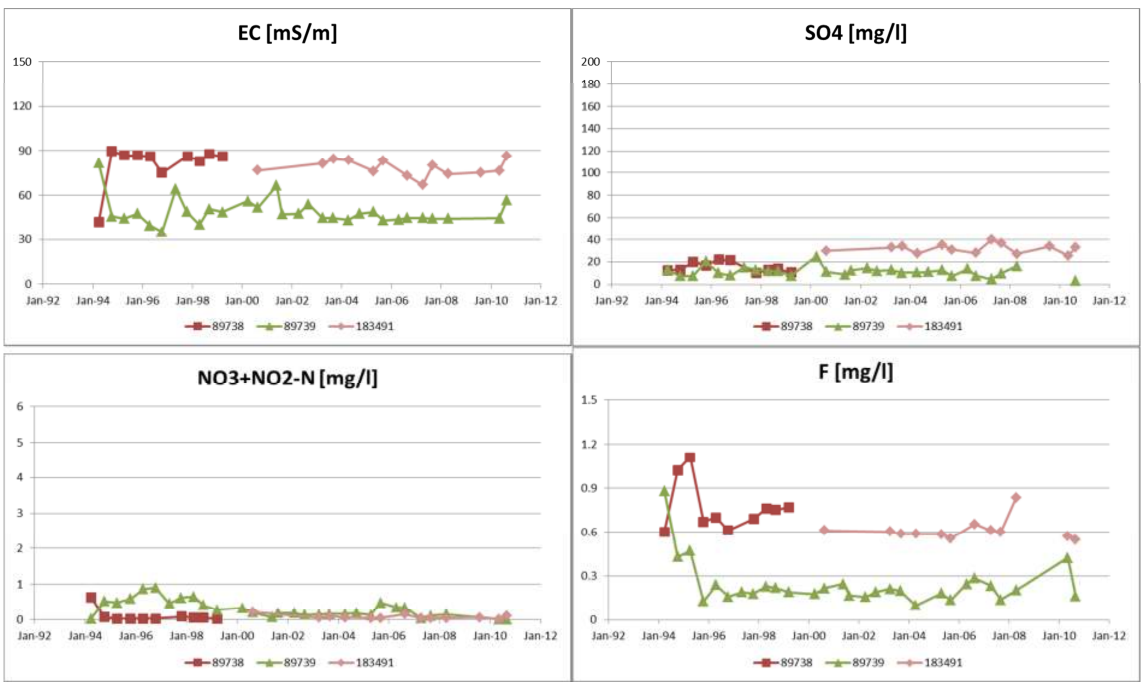


Figure 5-71 Groundwater quality trends in RU12 (Boreholes 89738and 183491, spring 89739)

5.10 RESOURCE UNITS 14 TO 22

5.10.1 Description

The Resource Units 14 to 22 are located on the north-western portion of the Mzimvubu to Keiskamma WMA (see **Figure 5-72**). They comprise the S31 catchments of the Klaas Smits River and the middle reaches of the Black Kei River S32C, S32H and parts of S32K. The northern and western bloundary is formed by the catchment divide with the Upper Orange WMA and Fish to Tsitsikamma WMA, respectively. The eastern boundary is the catchment divide between the S31 catchments and the S10 catchments of the White Kei River in the east, while the north-eastern boundary follows the lithological contact between the Burgersdorp Formation and the Molteno Formation. The southern boundary is formed by the lithological contact between the Burgersdorp Formation and the Katberg Formation, forming Resource Unit 10 in the south.

The different resource units within this block are mostly separated by catchment boundaries, due to the relatively high groundwater usage in single catchments that warrant separate assessment and management of the groundwater resource. Less stressed catchments are merged into bigger resource units; Resource Unit 14 comprising catchment S32C and parts of S32H, Resource Unit 20 comprising catchment S31C and parts of S32B, and Resource Unit 22 comprising catchment S32J and parts of S32K.

The catchment S31G is split into two resource units; Resource Unit 15 and 16; due to the difference in geology (see below). These resource units were also considered part of the most stressed catchment in the study area.

Queenstown is situated in Resource Unit 17, forming the major town in this area. Sterkstroom is in Resource Unit 21 at the boundary to Resource Unit 12.

The topography of the resource units is hilly to mountainous in some areas with wide and flat valleys in the central part of the area. The elevation ranges from 1100 – 1850 mamsl, with the highest mountain ranges along the north-eastern and north-western boundary.

Temperate to extreme climatic conditions are experienced in all these resource units with hot summers, and frost and snow occurring in winter. The annual rainfall for these resource units ranges between 400 and 700 mm/a. The rainfall increases from north to south of the resource unit and from west to east. However, there is a high spatial and temporal variability of precipitation (see **Figure 5-74** for annual rainfall from weather stations around Queenstown). Maximum temperatures are experienced in January and minimum temperatures usually occur in July.

The geology of these resource units is mainly made up of the Burgersdorp Formation of the Tarkastad Subgroup with Karoo Dolerite intrusions. Quaternary deposits cover most of the wide valleys, especially in the north-western part of the area.The slopes along the north-western boundary in Resource Unit 20 and 21 are formed by the Molteno Formation overlying the Burgersdorp Formation.

The Karoo Dolerite intrusions form dolerite sills and ring structures of 10 to 15 km in diameter that are most prominent in Resource Unit 15, 17 and 22 (see **Figure 5-73**). Elongated dolerite dykes, as occurring in the Adelaide Group, are not typical in these resource units.

Only Resource Unit 15 comprises outcrops of the Katberg Formation of the Tarkastad Subgroup, instead of the Burgersdorp Formation, inside a dolerite ring structure.

Figure 5-72 Location, topography and drainage for RU14 to 22

Figure 5-73 Geology map for RU14 to 22

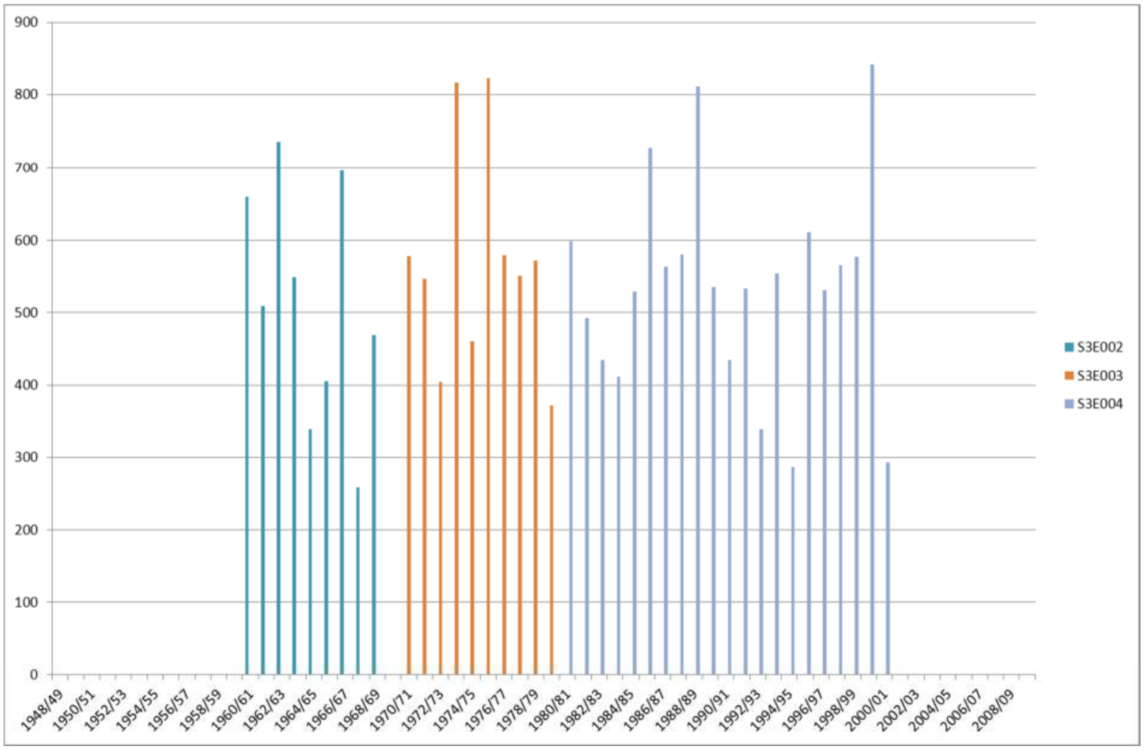


Figure 5-74 Annual rainfall [mm/a] for different weather stations in RU15 and 17 (around Queenstown)

The land use varies significantly across the area and between resource units (see **Figure 5-75**). The south-western part (i.e. Resource Unit 14 and parts of Resource Unit 19 and 20) is dominated by temporary cultivated land in and between the valleys of the Black Kei River and Klaas Smits River, and surrounding the built-up areas of small towns like Thornhill and Tentergate. This area forms the most northern part of the former Ciskei.

This pattern extends towards the northern boundary (i.e. Resource Unit 19, 20 and 21), but with sore scattered cultivated land and increase in degraded grassland. The higher lying areas in all these resource units are covered by thicket bushland.

The south-eastern part (i.e. Resource Unit 18, 17 and 22) is dominated by Queenstown and surrounding villages, but does not show any significant extent of cultivated land, except small patches around Lesseyton west of Queenstown (Resource Unit 18) and Illinge east of Queenstown (Resource Unit 22). The majority of these resource units is covered by natural grassland.

The central part of this area, south of Queenstown (i.e. Resource Units 15 and 16) are also dominated by natural grassland, but exhibit significant amount of permanent cultivated land in the valleys of the Klaas Smits River. There are also patches of indigenous forest in the northern part of Resource Unit 15.

Figure 5-75 Land use map for RU14 to 22

All catchments in this area are considered largely modified, except S31B in Resource Unit 21, which is moderately modified. This present status is due to extensive use of the surface water resources for agriculture and livelihood support. It is currently recommended to improve the ecological status of all catchments to the next level; i.e. largely natural for S31B and moderately modified for all other catchments. However, there are only few larger storage dams in the area and no storage dams on the major rivers

The upper reaches of the Klaas Smits River, the Black Kei River and their tributaries are considered ephemeral rivers with extended periods of flow ceasing during the year. The WR90 and WR2005 datasets show these catchments as perennial, although with extreme low flow during certain times of the year. The hydrology of the catchments is dominated by floods during and after rainfall events and extreme low flow or ceasing flow during dry periods. An analysis of flow records from selected flow gauging stations shows the extended periods of no flow and low flow in these rivers (see **Table 5-11**). Low flow was defined as flow less than 10% of the average river flow.

The station S3H003 on the Black Kei is situated in Resource Unit 10 but provides relevant information with respect to the expected inflow from the neighbouring resource unit. The station S3H004 on the Black Kei is located upstream of the confluence with the Klipplaat River, while station S3H013 is situated downstream of all tributaries, just upstream of the confluence with the White Kei River. The significant increase in average flow along the Black Kei River is evident from a comparison of the flow records from the latter two stations (see **Figure 5-76a**).

The two stations at the Klaas Smits River are situated at the end of Resource Unit 21 and 19, respectively. They show a slight increase in flow, but very similar response to weather pattern (see **Figure 5-76b**).

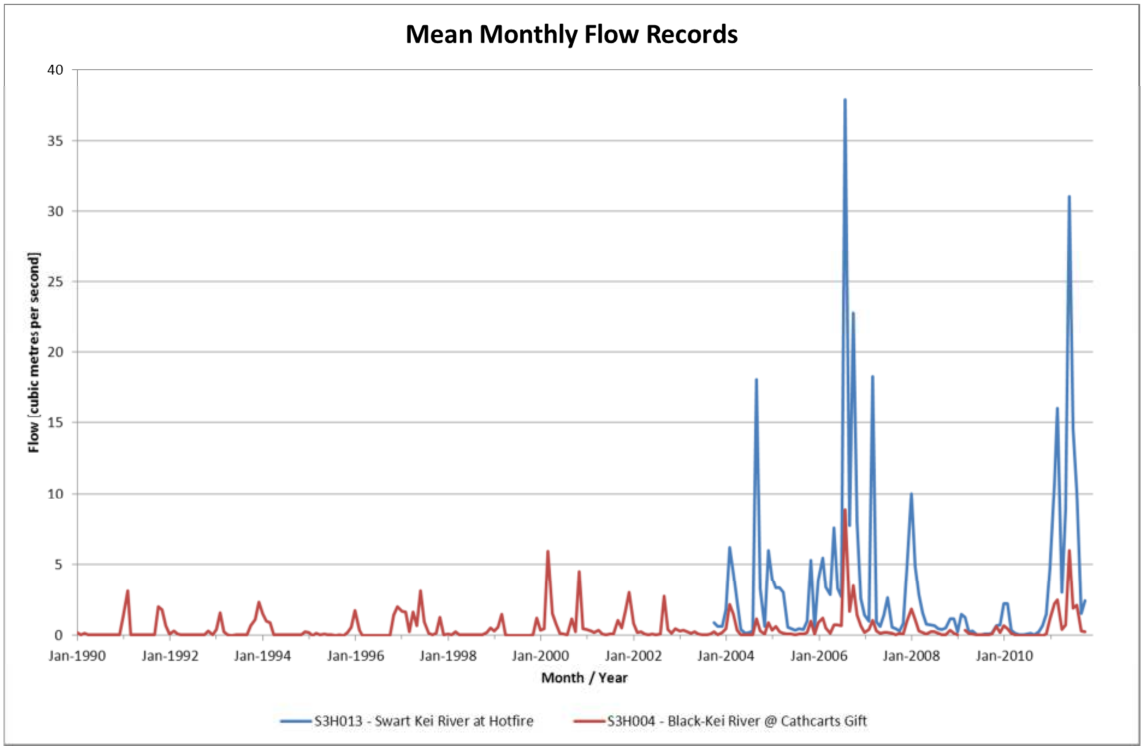
The station S3H010 is located just downstream of the Waterdown Dam in Resource Unit 10 and, hence, is impacted by the releases from the dam.

Table 5-11 Flow statistics for selected flow gauging weirs in Resource Units 14 to 22

River	Station	Years of record used	Average flow [m^3/sec]	Average no flow days per year	Average length of low flow period
Black Kei	S3H003	15	0.05	308	328
	S3H004	22	0.51	45	208
Klaas Smits	S3H002	17	0.21	241	289
	S3H006	31	0.33	153	241
Klipplaat	S3H010	22	0.30	2	145
Black Kei	S3H013	8	3.6	1	9

The National Wetland Map shows a number of seeps and wetland across the resource units (see **Figure 5-77**). However, most of these wetlands are actually farm dams or other man-made feastures and are therefore discarded for identifying groundwater discharge zones. There are few springs mapped in the northern area (i.e. Resource Unit 19, 20 and 21), but some of these look conspicuous with respect to their topographic and geological setting.

However, there is a large number of springs in the area east (Resource Unit 22) and north of Queenstown (Resource Unit 17), mainly linked to dolerite ring structures (see **Figure 5-78**).



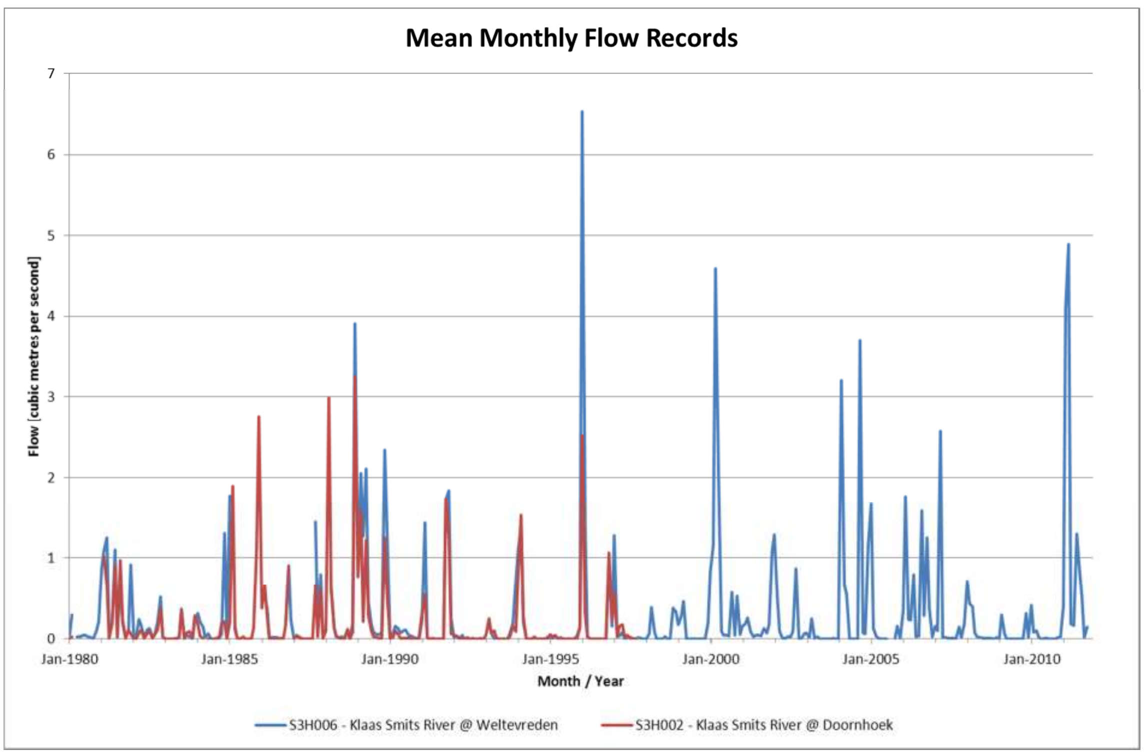


Figure 5-76 River hydrographs in RU14 to 22; a) Black Kei River, b) Klaas Smits River

Figure 5-77 Wetland, springs and protected areas in RU14 to 22

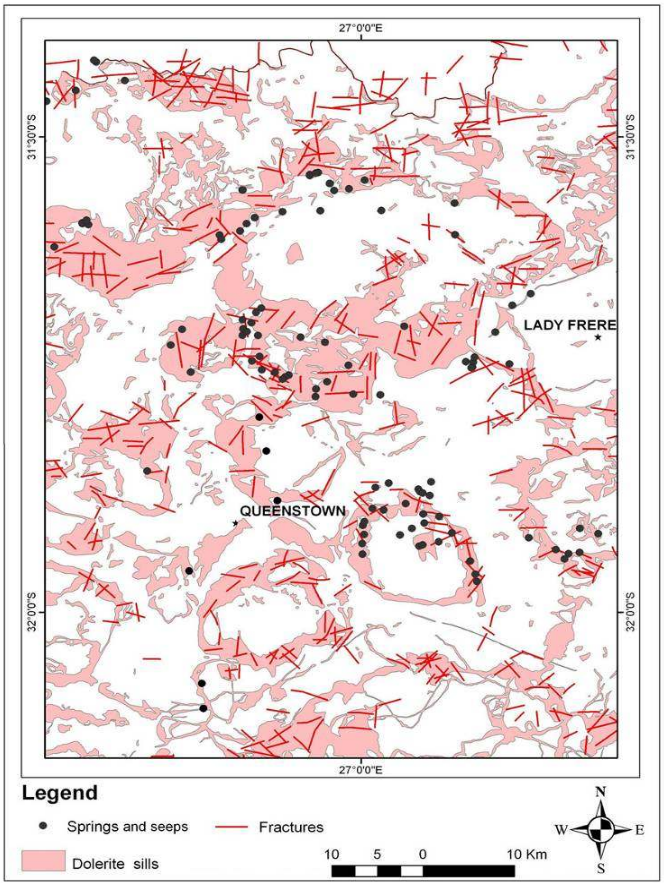


Figure 5-78 Location of springs and seeps in relation to dolerite intrusions in the Queenstown cluster area (after Chevalier et al, 2009)

5.10.2 Conceptual Model

The aquifers in all resource units, except Resource Unit 15, are minor aquifers of the intergranular/fractured aquifer type. However, due to the intrusion of dolerite sills and the development of the dolerite ring structures, the groundwater potential is significantly enhanced, and the combined aquifers can be considered major aquifers in some parts of the resource units.

The alluvium deposits in the wide valleys constitute intergranular aquifers of some significance for providing water supply and maintaining low conditions in the rivers.

The aquifer in Resource Unit 15 is considered a major aquifer due to its fractured nature and the combination with the dolerite sills and ring structure.

The average transmissivity for all these resource units ranges between 5 and 20 m^2/day. This is increased to above 30 m^2/day in areas with significant impact of the dolerite intrusions. The small outcrops of the Molteno Formation along the northern boundary show an average transmissivity of less than 2.5 m^2/day.

The recharge rate for the resource units is relatively low and ranges between 14 and 28 mm/a. The lowest recharge occurs in the northern parts in Resource Unit 20 and 21, while the highest recharge rate is estimated for Resource Unit 18. Hence, the average recharge volume varies between 2.33 million m^3/a in Resource Unit 16 and 14.9 million m^3/a in Resource Unit 14. The recharge volumes per resource unit are given in **Table 5-12** below.

Table 5-12 Recharge rates and recharge volumes per Resource Unit

Resource Unit	Average Recharge Rate [mm/a]	Average Recharge Volume [million m^3/a]
14	24	14.9
15	24	3.48
16	20	2.33
17	23	5.30
18	28	7.74
19	20	8.94
20	14	12.4
21	19	8.49
22	25	7.30

Since most aquifers in the resource units are weathered regolith aquifers of limited thickness or alluvium intergranular aquifers along the wide river valleys, it can be assumed that these aquifers discharge into the nearest surface water feature, which is normally a stream or river. The fractured aquifer of the Katberg Formation in Resource Unit 14 behaves in a similar pattern due to its limited extent.

There are no distinct recharge areas for the aquifers. Hence, the path way between recharge and discharge is considered relatively short. The occurrence of the dolerite intrusions can result in locally changing flow pattern and pathways across surface water divides.

This pattern can be seen in the piezometric map (see **Figure 5-79**), which indicates that the water level generally follows the topography. The influence of the rivers, especially the Klaas Smits River and to a lesser degree the middle reaches of the Black Kei River, is also evident in the water level map.

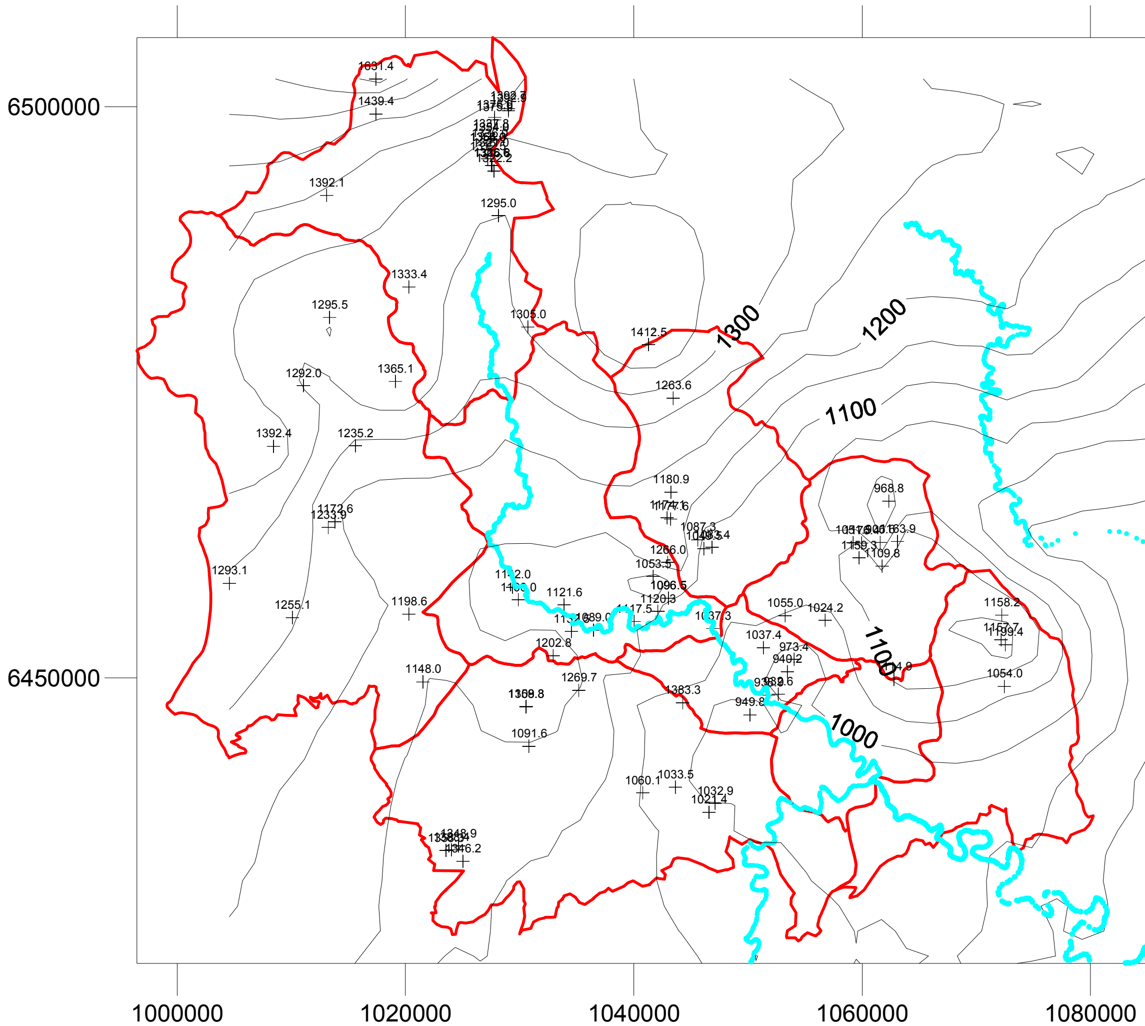


Figure 5-79 Piezometric map for RU14 to 22

5.10.3 Current Status

The current status of the resource unit is defined by the groundwater use as proportion of recharge and the groundwater quality. The summary of groundwater use is shown in Table 5-13 and detailed reasoning provided below.

Table 5-13 Groundwater use in Resource Units 14 to 22

Resource Unit	GRA II (Mio m^3/a)	WARMS (Mio m^3/a)	GRIP (%)	All Towns (Mio m^3/a)	Final (Mio m^3/a)
14	2.27	0.24	-	0.66	1.14
15	3.13	0.12	-	0.00	1.56
16	2.67	0.08	-	0.00	1.34
17	1.53	0.53	-	0.00	0.76
18	0.91	0.07	-	0.00	0.91
19	5.01	0.29	-	0.00	1.00
20	2.76	0.80	-	0.14	1.38
21	1.08	0.18	-	0.30	1.08
22	0.79	0.15	-	1.11	1.26

For Resource Unit 14 GRAII data indicates a very high groundwater usage of 2.27 million m^3/a. It is known that there is widespread groundwater usage in the rural villages of the area. The WARMS reflects numerous entries for mostly domestic and industrial use with sometimes unrealistically low registered volumes. The All Towns Reconciliation Strategy Study confirms a high usage but yet indicates a number of 0.66 million m^3/a much lower than the GRAII. Therefore a usage equal to half of the annual volume indicated by GRAII is used, which also lies in between the GRAII and All Towns Study numbers. This finding is supported by the fact that long-term water level measurements do not show a declining trend (see **Figure 5-80**).

For Resource Units 15, 16 and 17 GRAII data indicates much higher usage than the WARMS. There is no municipal usage detected by the All Towns Reconciliation Strategy Study.

The site visit and interviews with farmers in Resource Unit 15 and 16 have shown that there is some groundwater usage for irrigation taking place. The annual usage at one single farm amounts to a total of approximately 0.1 million m^3/a which is equivalent to 50% of the registered usage in this catchment. While generally surface water is used for irrigation in this area, it was reported that farmers use groundwater to augment their supply. It was also reported that groundwater abstraction rates had to be reduced as a consequence of low water tables during the 2009/2010 drought period.

Most irrigation in the area of agricultural irrigation along the R67 going south from Queenstown (within Resource Unit 16) is happening using treated effluents from Queenstown's sewage treatment plants, which explains the very limited extent of the area of irrigation as seen on earth observation imagery. However, it was reported that a borehole was previously used for irrigation and stock watering of a relatively small farm next to the road. Currently this is no longer the case because the pump was stolen and surface water from the near river is used. There is no indication of a declining water table in this area (see **Figure 5-81**).

The site visits and interviews in Resource Unit 17 have shown that groundwater is used to a certain degree, but strictly for domestic use in the rural settlements north and northeast of Queenstown. Irrigation of cultivated land is very little in this area and limited to some minor cases using surface water such as in the valley along the Cacadu River near Mqonci (Dubeni). Long-term records of the groundwater level do not indicate any negative trend in this area (see **Figure 5-82**).

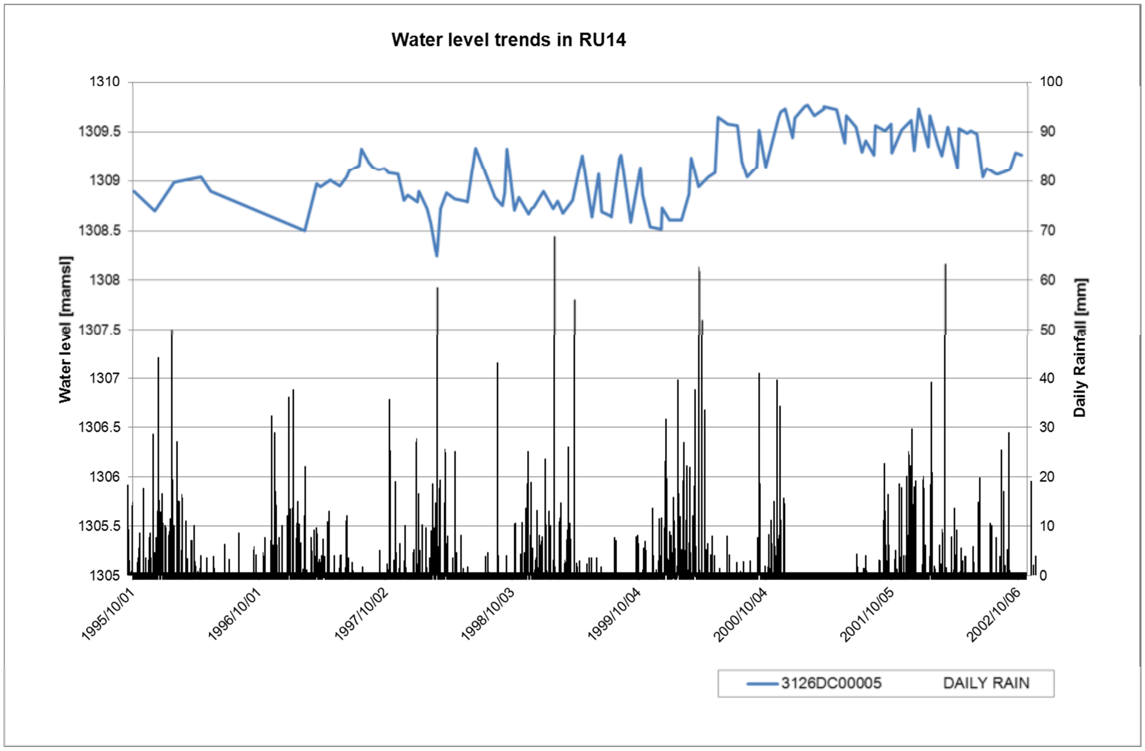


Figure 5-80 Water level trends in selected borehole from RU14 (3126DC00005)

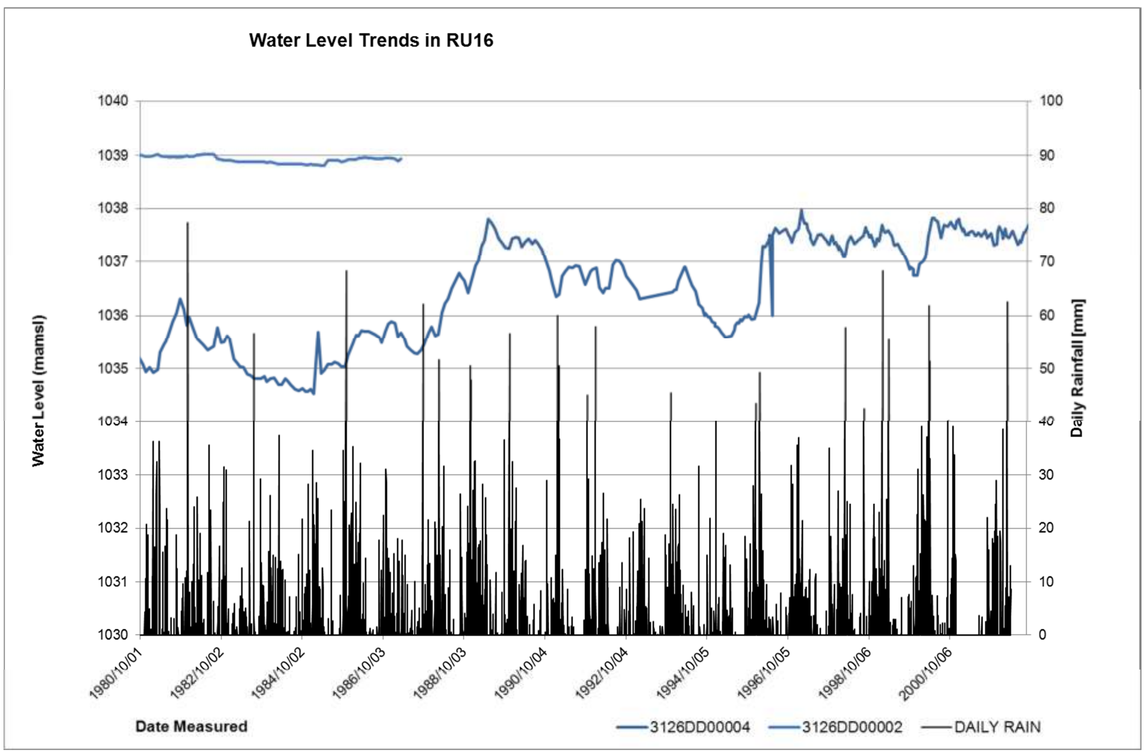
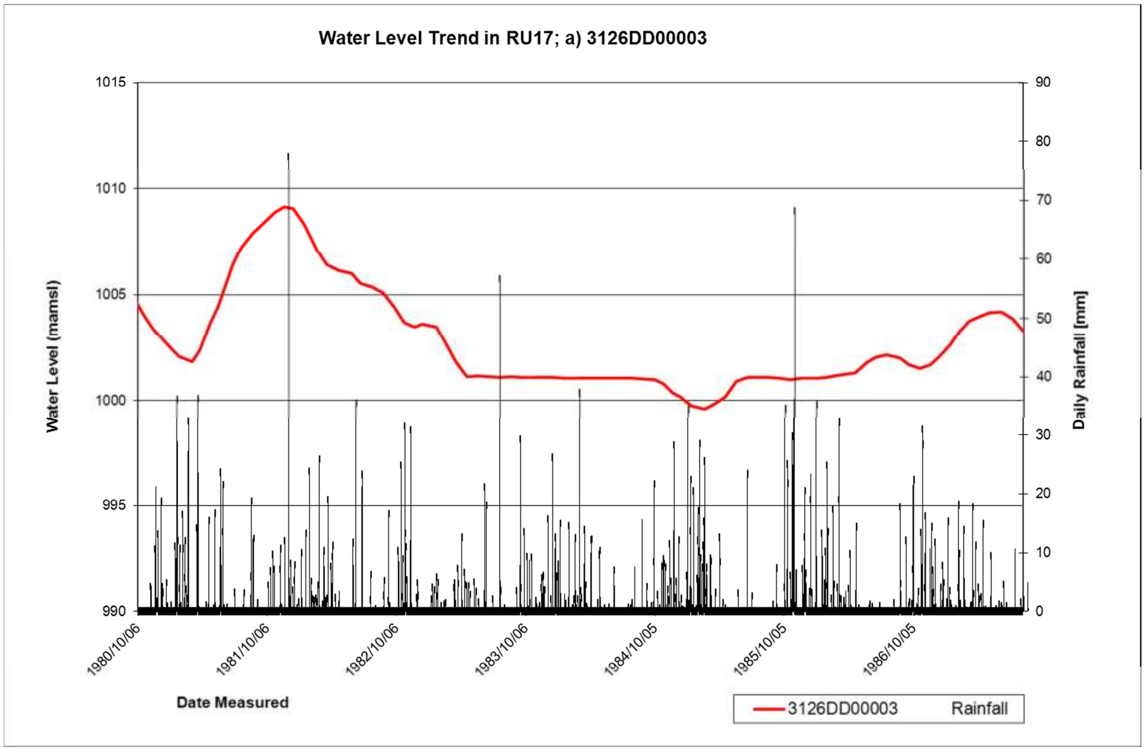


Figure 5-81 Water level trends in selected boreholes from RU16



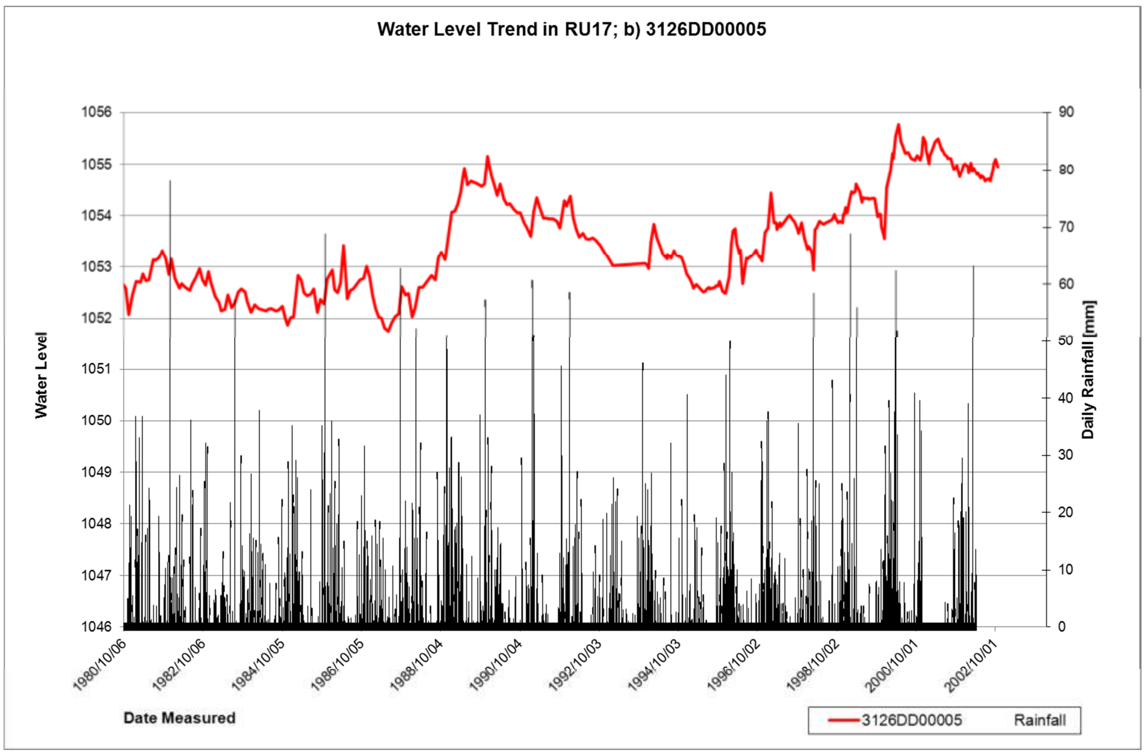


Figure 5-82 Water level trends in selected boreholes from RU17; a) 3126DD00003, b) 3126DD00005

The hydro-census in the area has confirmed that there is significant agricultural usage, but yet the GRAII number is deemed too high. The Lukanji Feasibility Study suggests that the total groundwater abstraction in Resource Units 15, 16, 18 ,19, 20 and 21 is approximately 5.5 million m^3/a. According to the GRAII data this number is already reached by abstraction in Resource Units 15 and 16 alone. Hence, a value equal to half of the GRAII number which represents a value between the GRAII and WARMS is used.

In Resource Unit 18 GRAII data indicates usage of 0.91 million m^3/a which is much higher than the WARMS value. There is no municipal/domestic usage detected by the All Towns Reconciliation Strategy Study or GRIP. Hence the difference is likely to be attributed to unregistered agricultural use. Based on the field visit, the GRAII number is deemed realistic.

In Resource Unit 19 there is no municipal/domestic use detected by the GRIP or All Towns Reconciliation Strategy Study. The area west-northwest of Queenstown is rather characterised by farmland mostly used for livestock (cattle and sheep). The interviews proved that boreholes in this particular area are currently only used for domestic purposes as well as livestock farming. There are boreholes driven with windmills or electric pumps present in the area but farmers report that these usually do not yield enough water to sustain any crop irrigation. Only in one incidence some irrigation was observed at all which was restricted to using river water stored in dams. Reportedly boreholes were used in the past but not at present. In most parts of the catchment groundwater seems to be used strictly for domestic purposes and livestock farming. Since farms in the area are very sparsely distributed this is not likely to account for the high groundwater stress indicated by the GRA II data.

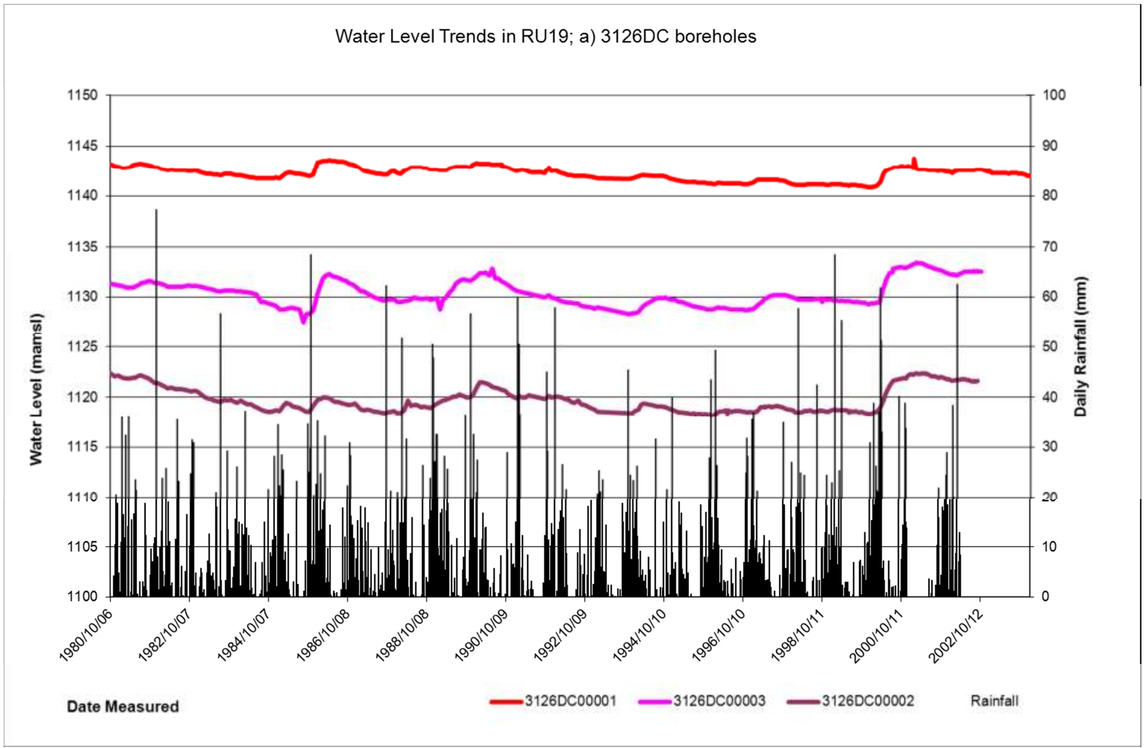
The GRAII value with 5.01 million m^3/a seems to be much too high to be realistic whereas the WARMS registered agricultural use, in contrast, seems to be very low. It has been confirmed by the hydrocensus that there is only very little agricultural and domestic groundwater usage in this area. Therefore a number of one fifth of the GRAII number is used which is still significantly higher than the WARMS registration. This finding is supported by the fact that long-term water level monitoring does not indicate a declining trend in water table (see **Figure 5-83**).

In Resource Unit 20 GRAII data with 2.76 million m^3/a indicates a much higher usage than the WARMS. There is no municipal/domestic usage detected by the All Towns Reconciliation Strategy Study or GRIP. Hence the difference is likely to be attributed to unregistered agricultural use. An abstraction volume equal to half of the GRAII number is deemed realistic.

In Resource Unit 21 GRAII data with 1.08 million m^3/a indicates a much higher usage than the WARMS. There is some municipal/domestic usage detected by the All Towns Reconciliation Strategy Study. Hence the GRAII number is deemed more realistic than the WARMS registration.

In Resource Unit 22 the All Towns Reconciliation Strategy Study suggests a groundwater usage of 1.11 million m^3/a that is much higher than the one indicated by GRAII and WARMS. This number derived for the groundwater dependent communities is increased by the WAMRS registered agricultural usage of 0.15 million m^3/a.

Based on these estimates, Resource Unit 14 is considered minimally modified, with an aquifer stress index of 8%. Resource Units 17 to 22 are considered minimally to moderately modified with aquifer stress indices above 10%, while Resource Units 15 and 16 are considered moderately to heavily modified with aquifer stress indices above 40%.



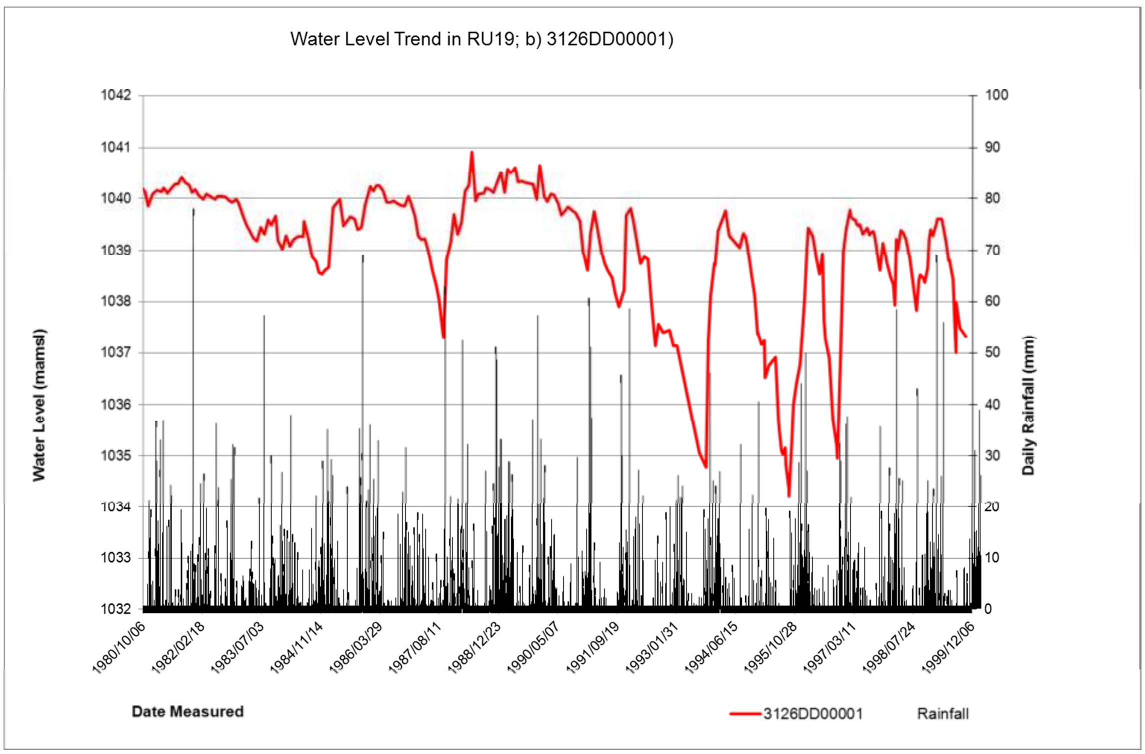


Figure 5-83 **Water level trends in selected boreholes from RU19; a) 3126DC00001, 3126DC00002 & 3126DC00003; b) 3126DD00001**

The hydrochemical characterisation of the aquifers is determined by the geology and catchment signature. In most of the resource units the aquifers show a mixed water composition between Na-Cl and Ca-HCO_3 (see **Figure 5-87** to **Figure 5-87**). However, the northern catchments in Resource Unit 19, 20 and 21 show a more distinct HCO_3 signature, while the southern catchments in Resource Unit 16 and 22 show a wider spread with significant influence of Cl-dominated water.

The water quality is generally good with most boreholes falling in Class 0 or Class I with respect to EC as indicator.

The Class II EC is found in one borehole that is located in the eastern part of Resource Unit 14. High nitrate content that exceeds 20 mg/l is found in one borehole that is situated in eastern part of this region. Class II EC and high nitrate is also found in few boreholes in the southern part of Resource Unit 15. Two boreholes around Resource Unit 16 have EC that falls in Class II, one of which has also high nitrate content.

One borehole in Resource Unit 18 has nitrate concentration that exceeds 20 mg/l. The borehole is situated in the northern part of the resource unit. Resource Unit 19 has only one borehole that has high nitrate, the borehole is located on the southern part of resource unit.

One borehole in the southern part of Resource Unit 21 has EC concentration that falls under Class II. The Class II EC is also found in two boreholes that are located in the southern part of Resource Unit 22. The resource unit has only one borehole that has nitrate content that exceeds 20 mg/l and is also in the southern part.

However, these are considered isolated incidents. Long-term monitoring at a borehole in Resource Unit 19 does not show negative trends in water quality (see **Figure 5-88**).

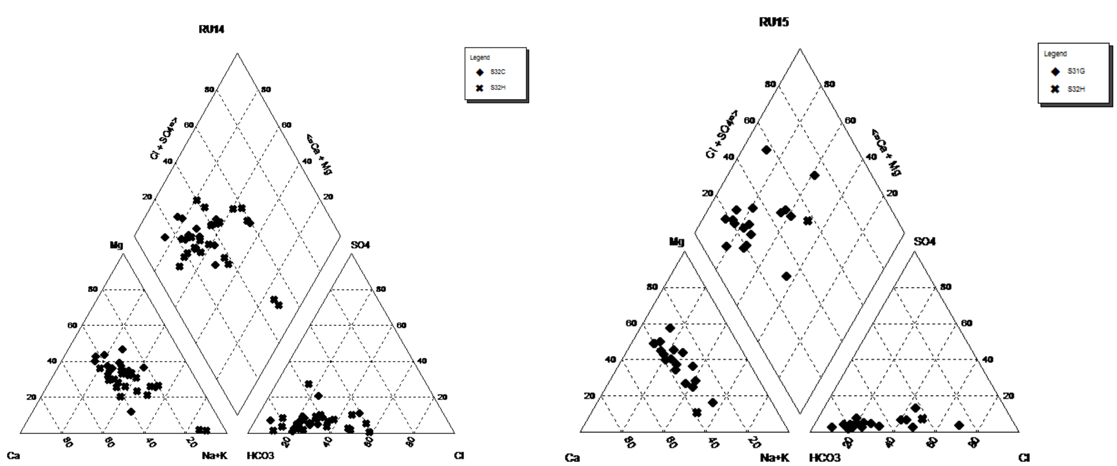


Figure 5-84 Hydrochemical characterisation and groundwater quality in RU14 and 15

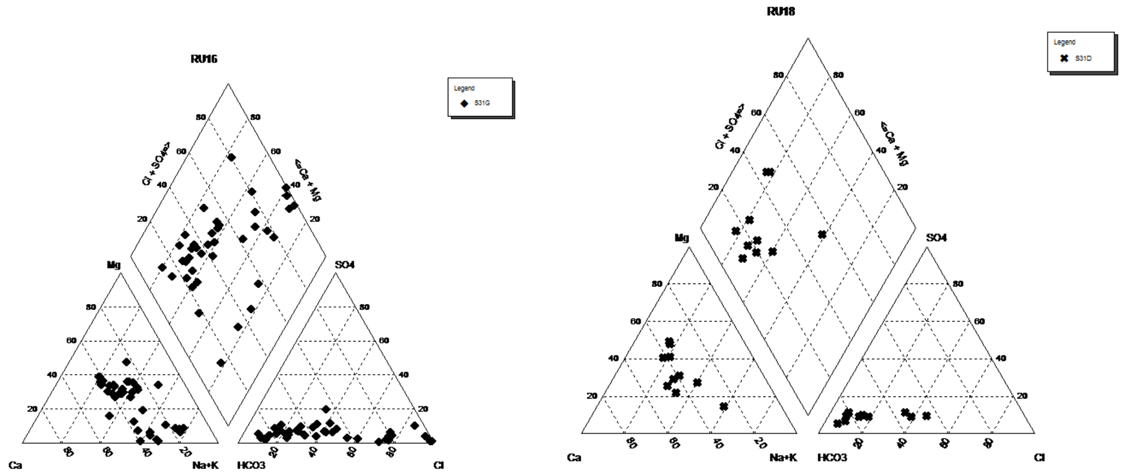


Figure 5-85 Hydrochemical characterisation and groundwater quality in RU16 and 18

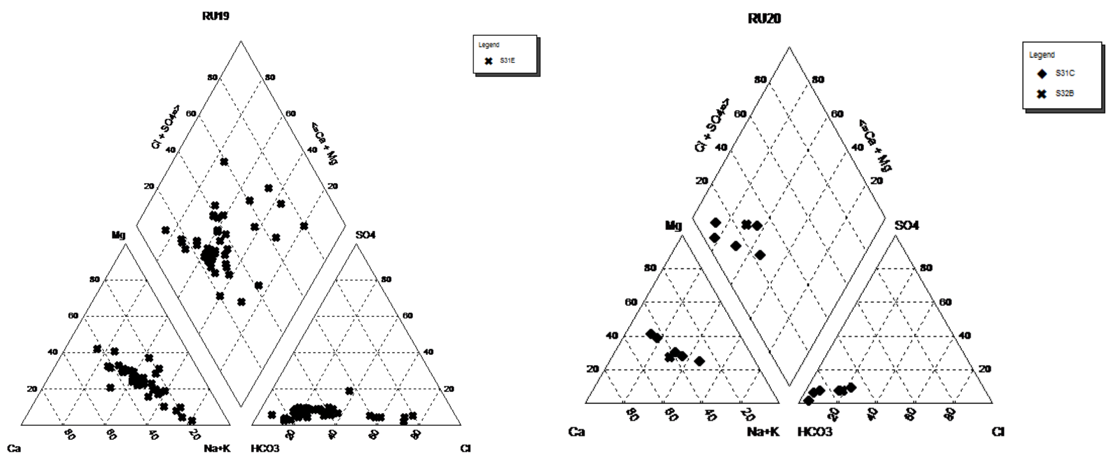


Figure 5-86 Hydrochemical characterisation and groundwater quality in RU19 and 20

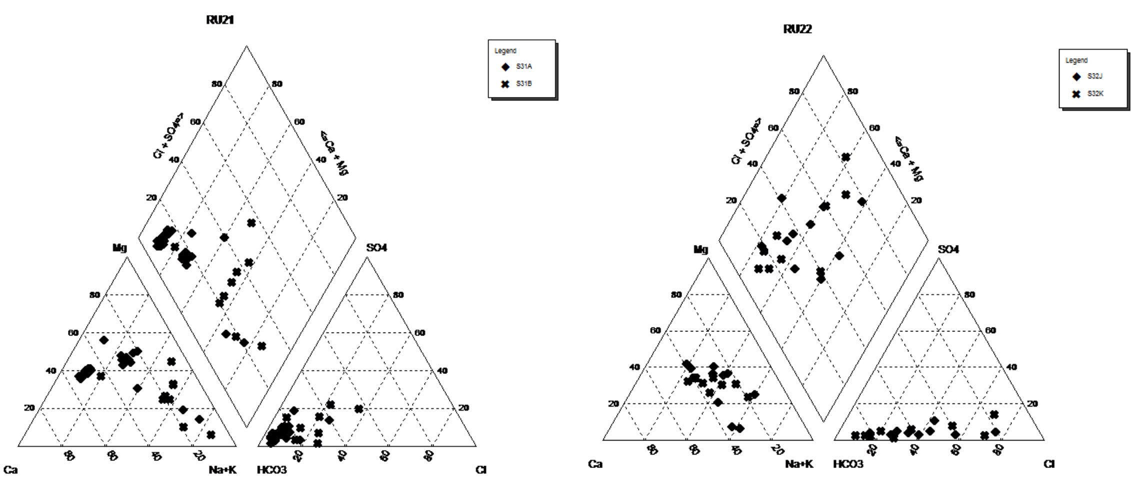


Figure 5-87 Hydrochemical characterisation and groundwater quality in RU21 to 22

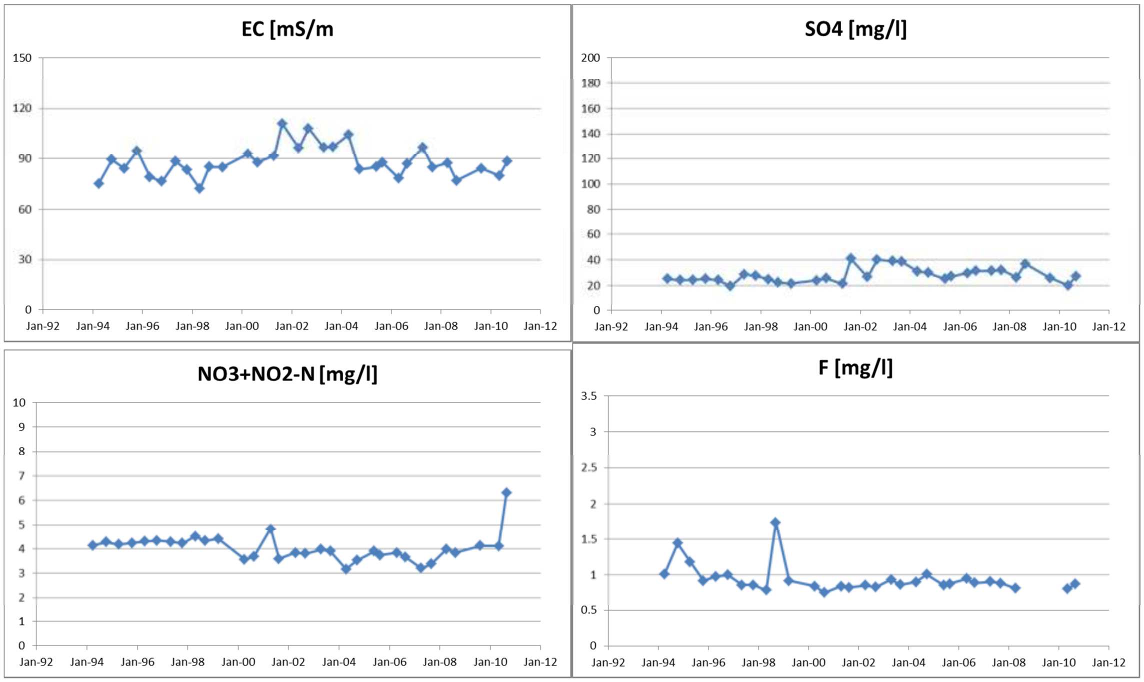


Figure 5-88 Groundwater quality trends in RU19 (Borehole 89695)

6. INTERMEDIATE GRDM ASSESSMENT

6.1 PREAMBLE

Ideally, all water resources in South Africa should be assessed to the same degree and the results of the assessment should be of a high confidence. At present, the country does not have the manpower or financial resources to carry out GRDM assessments countrywide at a high level of confidence in the short term. To overcome this problem, three strategies are followed:

- Priority areas are being identified that require detail investigation;
- Different levels of GRDM assessments are being used; and
- A multi-level approach can be applied in the same Groundwater Resource Unit (RU).

Four levels of GRDM determination are recognised, with each expected to yield a greater level of confidence in the results. However, it must be noted that data availability will dictate the confidence level. The following general features characterise the differences between the four levels:

Desktop: these determinations are done using readily available data and information; extrapolate the results from previous more detailed and localised assessments; have low intensity information requirements; take a matter of days to complete; and yield results of very low confidence; usually the first step in any GRDM process and a useful planning tool.

Rapid: similar to desktop determinations but include a short field trip to assess present conditions; typically used to assess individual licence applications in minor or poor aquifer systems in catchments of low ecological importance and few people dependent on groundwater for basic human needs. It should take less than two weeks to complete.

Intermediate: these determinations yield results of medium confidence; require field investigations by experienced specialists and should take approximately 6 months to complete; used to assess implications of individual licences in sole-source or major aquifer systems.

Comprehensive: comprehensive GRDM determinations aim to produce high confidence results and are based on site-specific data collected by a team of specialists; used for all compulsory licensing exercises, as well as for individual licence applications that could have a large impact in any sole-source or major aquifer systems, that are vulnerable to over-abstraction and/or contamination. It should take less than two years to complete. Due to lack of long-term geohydrological data sets, GRDM assessments will only rarely be done at this level.

In accordance with the **precautionary principle**, lower-confidence assessments need to be more conservative in nature than higher-confidence assessments.

This GRDM assessment was undertaken at an **intermediate level** for resource units, where this was deemed necessary, based on the initial desktop assessment (see Section 4.10).

6.2 PRESENT ECOLOGICAL STATUS

6.2.1 Water Quantity

The recent status of a groundwater resource unit can be assessed in terms of sustainable use, observed ecological impacts or water stress. Since no information about ecological impacts of groundwater abstraction is available at the scale of investigation, the concept of water stress was applied for the classification process.

The concept of stressed water resources is addressed by the National Water Act, but is not defined. Part 8 of the Act gives some guidance by providing the following qualitative examples of 'water stress':

- Where demands for water are approaching or exceed the available supply;
- Where water quality problems are imminent or already exist; or
- Where water resource quality is under threat.

The water quality aspects are dealt with in section 6.2.2 below. To provide a quantitative means of defining stress, a groundwater stress index was developed by dividing the volume of groundwater abstracted from a groundwater unit by the estimated recharge to that unit (Parsons, 2005):

$$\text{Stress Index} = \frac{\text{Groundwater Abstraction}}{\text{Recharge}}$$

The present status category was then assigned according to the classes described in **Table 6-1**.

Table 6-1 Guide for determining the level of stress of a groundwater resource unit, based on abstraction and recharge (modified after Parsons, 2005, and Dennis, 2010)

PRESENT STATUS CATEGORY		DESCRIPTION	STRESS INDEX (groundwater abstraction / recharge)
Minimally used (I)	A	Unstressed or low levels of stress	< 0.05
	B		0.05–0.20
Moderately used (II)	C	Moderate levels of stress	0.20–0.40
	D		0.40–0.65
Heavily used (III)	E	Stressed	0.65–0.95
	F	Critically stressed	> 0.95

Recharge and groundwater abstraction are estimated pre resource unit on an aquifer specific basis, as described in Section 2. Applying this concept, the present status categories in terms of water quantity are estimated and the results per resource unit are listed in **Table 6-2** below.

Table 6-2 Present Status Category for Resource Units, based on Stress Index

	Water Quantity				
	Recharge	MLF	GW-Use	Stress Index	
Resource Unit	Mio m^3/a	Mio m^3/a	Mio m^3/a	%	PS
1	85.89	19.8	0.75	1	A
2	173	15.3	2.15	1	A
3	121	23.7	1.40	1	A
4	122	71.5	2.40	2	A
5	9.17	1.38	0.27	3	A
6	3.02	0.11	0.10	3	A
7	10.5	7.37	0.00	0	A
8	8.16	1.45	0.40	5	A
9	97.9	10.0	1.34	1	A
10	186	14.6	2.64	1	A
11	133	21.2	5.44	4	A
12	51.8	5.56	3.02	6	B
13	54.9	18.5	0.44	1	A
14	14.9	0.83	1.14	8	B
15	3.48	0.25	1.56	45	D
16	2.33	0.20	1.34	57	D
17	5.30	0.52	0.76	14	B
18	7.74	0.25	0.91	12	B
19	8.94	0.29	1.00	11	B
20	12.4	0.68	1.38	11	B
21	8.49	0.32	1.08	13	B
22	7.30	0.58	1.26	17	B
Total	**1129**	**214**	**30.8**	**3**	**A**

However, this concept does not take cognizance of the impact of other land use practices on groundwater and surface water resources. It is therefore proposed to modify the stress index by taking stream flow reduction activities and the groundwater contribution to baseflow, or required Maintenance Low Flow (MLF) into account. However, it is noted that this would not significantly alter the Present Status of the resource units.

6.2.2 Water Quality

The groundwater quality is described in detail in section 5. The categorization is based on

- the level of observed contamination **Table 6-3**, and
- the expected contamination due to land use and vulnerability, see **Table 6-4**.

Table 6-3 Present Status Category based on DWA water quality guidelines for domestic use (from Dennis, 2010)

Present Status	Description	Compliance (spatial/temporal)
I	DWA class 0 or 1 or natural background	95 %
II	DWA class 2 (95 % compliance) or natural background (75 % compliance)	75 %
III	DWA class 3 or 4 or natural background (<75 % compliance)	<75 %

In most resource units the expected land use impact is considered low to moderate due to small to medium waste sites, small sewage sites and the use of irrigation. However, the area of the former Transkei and Ciskei poses a moderate to high land use impact due to the lack of proper sanitation and the practice of cattle kraals. In the Nature Reserves and the mountain peaks the expected impact is negligible.

The conditions in the lowland indicate a medium to high vulnerability of the aquifers to contamination. There are mostly no confining or protecting layers, and any contamination can move directly with the infiltration into the aquifers.

Table 6-4 Present Status Category, based on vulnerability and expected land use impact (after Parsons, 2005)

	VULNERABILITY			
EXPECTED LAND USE IMPACT		Low	Medium	High
	Low Impact	A	B	B
	Moderate Impact	B	C	D
	High Impact	C	D	E

Contamination is defined as concentrations of chemical parameters in groundwater above the natural background concentration that could render the water unfit for human consumption (i.e. domestic use), cattle (i.e. stock watering) or irrigation (i.e. agricultural).

The analysis of the water quality indicates a localized contamination of the regolith aquifers with Nitrates, Chlorides, Sulphates and other chemicals, typical for human settlements. However, there is more widespread contamination with coliform bacteria due to animal and manure.

The assigned PS for water quality is based on the observed data, where sufficiently available, rather than the expected contamination (see **Table 6-5**).

Table 6-5 Present Ecological Status for water quality in the Resource Units, based on observed contamination, expected land use impact and vulnerability

Resource Unit	Contamination	Impact / Vulnerability			Final
	PS	Expected Impact	Vulnerability	PS	PS
1	C	Moderate	Low	B	C
2	C	Moderate	Low	B	C
3	B	Low	Low	A	B
4	D	Moderate	Low	B	D
5	B	Low	Medium	B	B
6	B	Low	Medium	B	B
7	A	Low	Low	A	A
8	A	Low	Low	A	A
9	D	Moderate	Low	B	D
10	B	Low	Medium	B	B
11	C	Moderate	Medium	C	C
12	B	Low	Low	A	B
13	A	Low	Low	A	A
14	D	Moderate	Medium	C	D
15	C	Moderate	Medium	C	C
16	D	Moderate	Medium	C	D
17	B	Moderate	Medium	C	B
18	C	Moderate	Medium	C	C
19	B	Low	High	B	B
20	B	Low	High	B	B
21	B	Low	High	B	B
22	D	Moderate	Medium	C	D

6.2.3 Combined Classification

When taking both the water quantity and the water quality into account, the Present Status Category can be defined for each Resource Unit (see **Table 6-6**). To describe the combined status of the water resource, the worst of both aspects is considered.

The principles for assigning the proposed desired ecological status for the resource units are:

- the present status in terms of water quality should be maintained or approved on, deterioration of water quality needs to be avoided;
- protected areas, such as Nature Reserves, require a category B in water quality to ensure sustainability of protected ecology;

- Resource units containing the headwaters of the main rivers and aquifers require a category B in water quality to protect water resources further downstream;
- Resource units that mainly comprise rural villages and small towns, that are partly or fully dependent on groundwater for stockwatering, small hold agriculture and domestic use, require at least a category C in both water quantity and water quality to protect the livelihood of the rural population;
- a category D for water quantity is acceptable even in protected areas, as long as a comprehensive monitoring network is in place to detect impacts at an early stage;
- Resource units with mainly commercial agriculture and forestry require a category C in water quality to ensure sufficient water quality for irrigation;
- however, a category D can be accepted for water quantity, provided that this does not have a negative impact on the recommended category in downstream resource units.

Table 6-6 Present Status, proposed Recommended Status and proposed Management Category of the Resource Units

Resource Unit	Present Status			Recommended Status		Management
	Quantity	Quality	Combined	Quantity	Quality	Category
1	A	C	C	C	C	II
2	A	D	D	C	C	III
3	A	B	B	C	B	II
4	A	D	D	C	C	I
5	A	B	B	D	B	II
6	A	B	B	D	B	II
7	A	A	A	A	A	III
8	A	A	A	A	A	III
9	A	D	D	C	C	I
10	A	B	B	C	B	I
11	A	C	C	C	C	I
12	B	B	B	B	B	III
13	A	A	A	B	B	III
14	B	D	D	C	C	I
15	D	C	D	D	C	I
16	D	D	D	D	C	I
17	B	B	B	C	B	II
18	B	C	C	C	C	II
19	B	B	B	C	B	II
20	B	B	B	C	B	II
21	B	B	B	C	B	II
22	B	D	D	C	C	II
Total	**A**	**C**	**C**			

The Management Categories are defined by Dennis et al (2010) with respect to monitoring frequency (see **Table 6-7**).

Table 6-7 Definition of Management Options

MANAGEMENT OPTION	RECOMMENDED MONITORING
I	Monthly monitoring of groundwater levels and chemistry
II	Monitoring of groundwater levels and chemistry every 3 months.
III	Monitoring of groundwater levels and chemistry every 6 months

6.3 RESERVE DETERMINATION

Table 6-8 shows the numbers for all parameters of the reserve determination and calculation of the allocable resources. They indicate that, although there is some groundwater usage in the area, there is still potential for further development. The groundwater stress index (allocated amount divided by total recharge) is well below 20% in most of the Resource Units. Only in Resource Units 15 and 16 south of Queenstown an increased stress index of 45% and 57% is found. The potentially high groundwater stress in this area has been pointed out before and is now confirmed especially for these Resource Units. However, water level trends for these two Resource Units do not indicate any declining groundwater tables.

Table 6-8 Calculation of the Groundwater Reserve

RU	Recharge (10^6 m^3/a)	MLF (10^6 m^3/a)	Population	BHN (10^6 m^3/a)	Reserve (10^6 m^3/a)	Allocable (10^6 m^3/a)	Abstraction (10^6 m^3/a)	Available (10^6 m^3/a)	Stress Index (%)
1	85.89	19.79	257550	2.35	22.14	63.75	0.75	63.00	1%
2	173.28	15.29	980991	8.95	24.24	149.04	2.15	146.88	1%
3	121.06	23.69	198738	1.81	25.51	95.55	1.40	94.15	1%
4	122.24	71.50	194343	1.77	73.28	48.97	2.40	46.57	2%
5	9.17	1.38	32159	0.29	1.67	7.50	0.27	7.23	3%
6	3.02	0.11	882	0.01	0.12	2.90	0.10	2.79	3%
7	10.50	7.37	6917	0.06	7.43	3.07	0.00	3.07	0%
8	8.16	1.45	20672	0.19	1.64	6.52	0.40	6.12	5%
9	97.90	10.02	199031	1.82	11.84	86.06	1.34	84.72	1%
10	186.66	14.60	105205	0.96	15.56	171.10	2.64	168.46	1%
11	133.36	21.17	438510	4.00	25.17	108.19	5.44	102.75	4%
12	51.81	5.56	36721	0.34	5.89	45.92	3.02	42.90	6%
13	54.97	18.51	45065	0.41	18.92	36.05	0.44	35.61	1%
14	14.92	0.83	26919	0.25	1.07	13.85	1.14	12.71	8%
15	3.48	0.25	4302	0.04	0.29	3.19	1.56	1.63	45%
16	2.33	0.20	39836	0.36	0.56	1.77	1.34	0.43	57%
17	5.30	0.52	83238	0.76	1.28	4.02	0.76	3.26	14%
18	7.74	0.25	10391	0.09	0.35	7.40	0.91	6.48	12%
19	8.94	0.29	1601	0.01	0.31	8.63	1.00	7.63	11%
20	12.36	0.68	9858	0.09	0.77	11.59	1.38	10.21	11%
21	8.49	0.32	1262	0.01	0.33	8.16	1.08	7.08	13%
22	7.30	0.58	25515	0.23	0.82	6.48	1.26	5.22	17%
Total	**1128.89**	**214.36**	**2719706**	**24.82**	**239.18**	**889.71**	**30.79**	**858.91**	**3%**

6.4 RESOURCE QUALITY OBJECTIVES

6.4.1 General RQOs for Study Area

Resource quality objectives are measurable indicators (e.g. gradients, water levels, quality ranges) set to ensure the sustainable functioning of the groundwater system. **Table 6-9** gives a summary of RQOs and indicators that are applicable in the study area.

Generally two kinds of Resource Quality Objectives can be considered:

1. Restrictions for human activity with potential impact on groundwater resources
2. Specific measurable parameters to be kept below a certain limit

Table 6-9 Resource Quality Objectives and indicators, relevant to the study area

Resource	Resource Quality Objective	Indicator - Measurement
Perennial River	Maintain water level or groundwater gradient	Distance of borehole to river Drawdown in abstraction borehole Water level in monitoring borehole Groundwater gradient
	Maintain water quality	Concentration of selected parameters in groundwater
Riparian Zone	Maintain water level or groundwater gradient	Distance of borehole to river Drawdown in abstraction borehole Water level in monitoring borehole Groundwater gradient
River Pools	Maintain water level or groundwater gradient	Distance of borehole to river Drawdown in abstraction borehole Water level in monitoring borehole Groundwater gradient
Cold Spring	Maintain water level or groundwater gradient	No boreholes within capture zone
Basic Human Needs	Maintain water level or groundwater gradient	No boreholes within protection radius Drawdown in abstraction borehole
	Maintain water quality	Concentration of selected parameters in groundwater
Protected Area	Maintain water level or groundwater gradient	No boreholes within protection radius

RQOs defined in this Reserve study are developed on a scale that does not allow site specific recommendations or restrictions. Using the available data certain areas can be identified which require special treatment and protection. RQOs are established per each of the defined Resource Units. Within one Resource Unit the RQO may vary depending on the location within the Unit and its relevance for its ecological integrity. Within one Resource Unit distinct RQOs are defined for

- Buffer zones around the headwater of rivers;
- Buffer zones around the main stem of rivers;
- Buffer zones around the tributaries;
- Clusters of Springs and seeps;
- Protected areas.

All protected areas are zoned as special areas and assigned special RQOs limiting groundwater abstraction to Schedule 1 use to protect the environment in that specific area.

Other zones with special RQOs per each Resource Unit are indicated below. It is remarked that these do not represent the actual buffer zones (e.g. around a river or spring) but are meant to highlight potential areas where these are to be applied for selected features. Single buffer zones will have to be delineated in a separate study when required for Water Use Licences.

To ensure that any groundwater abstraction does not impact negatively on the Reserve, the environment and existing users, further site specific RQOs and licence conditions might be necessary:

- Development of a numerical aquifer and wellfield model, which can simulate different scenarios and forms the basis for wellfield operation procedures. This needs to be based on a sound conceptual model and the data collected to date.
- The Monitoring Programme needs to be implemented prior to commencing full-scale abstraction from a wellfield.

6.4.2 RQOs for Resource Units 1 and 8

As shown on the piezometric map (**Figure 5-7**), the general groundwater flow direction is from north to south, which roughly follows the rivers draining into the sea. In addition there is usually a flow component from the aquifer into rivers and streams which is indicated by the groundwater contour lines bending towards the river and not running perpendicular to them.

The poor aquifer characteristics of the Adelaide Subgroup in this Resource Unit suggest that groundwater is not very significant to sustain ecological integrity and neither to provide municipal or rural water supply. Since the major river in the area, the Keiskamma River, is regulated throughout a large part of the Resource Unit and seepage from groundwater as a consequence of small hydraulic conductivities is deemed insignificant, there are no special RQOs for the riparian zone around this river.

However, towards the North of the Resource Unit in the area of the southern foothills of the Amathola Mountain Range numerous seeps and springs can be identified that sustain the headwaters of some minor streams such as the Tyume, Amatele, Wolf or Cata Rivers. These form tributaries to the Keiskammahoek River and are understood to be partly groundwater dependent. Hence, in order to protect the ecosystem in and around these streams special zones with distinct RQOs are indicated.

The RQO for these zones is:

- Buffer of 100 m around streams, wetlands and springs, if these are groundwater dependent, with no groundwater abstraction

As discussed in section 5.2.3, groundwater quality in these two RUs is generally good (class I or II). However, there have been cases of high nitrate and fluoride concentrations. High nitrate concentrations can originate from agricultural contamination but since one borehole showed a value lying in class III, no special RQO is required to keep nitrate at an acceptable level. High fluoride is likely to be due to local geology and therefore also does not require any RQO. Both parameters are part of the standard water sampling schedule (SANS 241) and should therefore be monitored automatically.

6.4.3 RQOs for Resource Units 2, 5 and 6

As shown on the piezometric map (**Figure 5-18)**, the general groundwater flow direction is from north to south, which roughly follows the rivers draining into the sea. In addition there is usually a flow component from the aquifer into rivers and streams which is indicated by the groundwater contour lines bending towards the river and not running perpendicular to them.

The poor aquifer characteristics of the Adelaide Subgroup in this Resource Unit highlight that groundwater is not very significant to sustain ecological integrity and neither to provide municipal or rural water supply. Since the major river in the area, the Buffalo River, is completely regulated by dams such as the Bridle Drift and Laing Dams and seepage from groundwater as a consequence of small hydraulic conductivities is deemed insignificant, there are no special RQOs for the riparian zone around this river.

However, towards the North of the Resource Unit south of the main surface water divide between the primary catchments R and S numerous seeps can be identified that sustain the headwaters of some minor streams. These form tributaries to the Buffalo River and are understood to be partly groundwater dependent. Similarly towards the Northeast of the RU seeps around the main divide sustain the headwaters of numerous streams that are tributaries to larger rivers such as the Nahoon, Gqunube and Kwelera Rivers. Hence, in order to protect the ecosystem in and around these streams special zones with distinct RQOs are indicated.

The RQO for these zones is:

- Buffer of 100 m around streams, wetlands and springs, if these are groundwater dependent, with no groundwater abstraction

Some boreholes in the area show EC values in excess of 370 mg/l (class III, not suitable for consumption). It is not known exactly what this high EC value is attributed to but it is likely that it is caused by contamination coming from human settlements and industrial activity in the area. Since groundwater is not being used in the areas of King William's Town and East London, high EC values are not of great concern. However, groundwater is used for public supply in the Great Kei local municipality in the area of Cintsa East. High EC values have been reported from south of Komga which lies upstream of the area of interest. Therefore, for the whole eastern portions of the RU class II drinking water quality (EC < 370 mg/l) is recommended.

6.4.4 RQOs for Resource Unit 3

As shown on the piezometric map (**Figure 5-27**), the general groundwater flow direction is towards the Great Kei River and its tributaries (Kubusi, Tsomo and Gcuwa Rivers) draining into the sea.

The poor aquifer characteristics of the Adelaide Subgroup in this Resource Unit highlight that groundwater is not very significant to sustain ecological integrity. Since the Great Kei River is regulated by dams up-stream of the Resource Unit and seepage from groundwater as a consequence of low hydraulic conductivities is deemed insignificant, there are no special RQOs for the riparian zone around this river.

However, towards the Northwest of the Resource Unit along the geological boundary to the overlying Katberg Formation numerous seeps can be identified that sustain the headwaters of some minor streams. These form tributaries to the Great Kei River and are understood to be partly groundwater dependent. Similarly in the centre of the Resource Unit there is cluster of springs that is likely to be attributed to the occurrence of large dolerite sills. These springs sustain the headwaters of some tributaries draining into the Great Kei and Gcuwa Rivers. Hence, in order to protect the ecosystem in and around these streams special zones with distinct RQOs are indicated.

The RQO for these zones is:

- Buffer of 100 m around streams, wetlands and springs, if these are groundwater dependent, with no groundwater abstraction

Generally the quality of groundwater in RU 3 is in good conditions but there have been incidents with high coliform concentrations causing the water not be suitable for consumption. Although groundwater usage for drinking water supply is not very wide spread in this area, it is recommended that coliform concentrations be according to SANS 241 drinking water standard (total coliform count less than 10 organisms per 100 ml).

6.4.5 RQOs for Resource Units 4 and 7

As shown on the piezometric map (**Figure 5-36)**, the general groundwater flow direction is from north to south, which roughly follows the rivers draining into the sea. In addition there is usually a flow component from the aquifer into rivers and streams.

The poor aquifer characteristics of the Adelaide Subgroup in this Resource Unit highlight that groundwater is not very significant to sustain ecological integrity. Since seepage from groundwater as a consequence of small hydraulic conductivities is deemed insignificant, there are no special RQOs for the riparian zone around rivers.

However, towards the Northwest of the Resource Unit along the main surface water divide between primary catchments S and T numerous seeps can be identified that are likely to sustain the headwaters of the main rivers such as the Quorha, Qwaninga and Shixini Rivers. These are understood to be partly groundwater dependent. In addition, a number of clusters of springs can be identified in RU 4 and 7 that also contribute to sustaining rivers. Hence, in order to protect the ecosystem in and around the rivers special zones with distinct RQOs are indicated.

The RQOs for these zones are:

- Buffer of 100 m around streams, wetlands and springs, if these are groundwater dependent, with no groundwater abstraction

The area of Kentani is partly dependent on groundwater for drinking water supply. GRIP data as well as field sampling indicates that groundwater contamination due to human settlements and livestock farming is a wide spread problem. Nitrate and nitrite concentrations frequently exceed the tolerable value of 20 mg/l. Consequently it is recommended that measures be put in place in order to keep contamination of boreholes at a minimum and reduce the nitrate/nitrite concentrations to below 20 mg/l.

6.4.6 RQOs for Resource Unit 9

The piezometric map (**Figure 5-45**) shows that the general groundwater flow direction is from north to south whereas the impact of drainage towards the major rivers (Great Kei River and Tsomo River) and its tributaries is relatively strong.

The fractured Katberg Formation is rich in sandstone and usually displays a high hydraulic conductivity. In this environment the interaction between surface water and groundwater are much more dominant than in a poor aquifer of e.g. high clay content. Therefore it is proposed to create a buffer zone around the major rivers with special RQOs:

- No groundwater abstraction within the buffer zone of 50 m around the main stems of rivers

In addition, 3 clusters of springs can be identified that sustain the headwaters of some minor streams. These form tributaries to the Great Kei River and Tsomo River and are understood to be partly groundwater dependent. Hence, in order to protect the ecosystem in and around these streams special zones with distinct RQOs are indicated.

The RQOs for these zones are:

- Buffer of 100 m around streams, wetlands and springs, if these are groundwater dependent, with no groundwater abstraction

Generally water quality in RU 9 is good but there has been one case of high nitrate/nitrite concentration which is a health risk originating from contamination by human or animal manure. It is recommended to keep this value under 20 mg/l by introducing or increasing the magnitude of protection areas around boreholes used for drinking water supply.

6.4.7 RQOs for Resource Unit 10

The piezometric map (**Figure 5-54**) shows that the general groundwater flow direction follows the surface water drainage towards the White Kei River and its tributaries. This deviation from normal groundwater drainage towards the sea is mostly due to the Amathola Mountains as well as the Cathcart Dolerite Ring that is drained by the Black Kei River.

The fractured Katberg Formation is rich in sandstone and usually displays a high hydraulic conductivity. In this environment the interaction between surface water and groundwater is much more dominant than in a poor aquifer of e.g. high clay content. Therefore it is proposed to create a buffer zone around the major rivers with special RQOs:

- Buffer zone of 50 m with no groundwater abstraction around all main stems of rivers

Along the southern boundary of the Resource Unit following the Amathola Mountain Range and the Cathcart Dolerite Ring numerous springs and wetlands can be identified that sustain the headwaters of some minor streams. These form tributaries to the Black Kei River and are understood to be partly groundwater dependent. Hence, in order to protect the ecosystem in and around the streams and wetlands special zones with distinct RQOs are indicated.

The RQOs for these zones are:

- Buffer of 100 m around streams, wetlands and springs, if these are groundwater dependent, with no groundwater abstraction

Water quality in RU 10 is generally good. There have been two cases with increased nitrate/nitrite concentrations (>20 mg/l) but long term monitoring has shown that there is no deteriorating trend in water quality and there are no special RQOs regarding water quality recommended for this unit.

6.4.8 RQOs for Resource Unit 11

The piezometric map (**Figure 5-62**) shows that the general groundwater flow direction is from north to south whereas there is a strong impact of surface water drainage. As shown by the piezometric map, in the vicinity of the rivers there is deviation from the larger flow pattern with groundwater flowing from the aquifer into the rivers.

The intergranular / fractured Burgersdorp Formation usually displays a moderate hydraulic conductivity. In this environment the interaction between surface water and groundwater is present to a certain degree but may depend on the local hydrogeology. Therefore it is proposed to create a buffer zone around the major rivers with special RQOs:

- Buffer zone of 50 m with no groundwater abstraction around main stems of rivers

Throughout the Resource Unit various bigger and smaller clusters of springs can be identified. These may form the headwaters for some groundwater dependent tributaries to the White Kei and Tsomo Rivers and may also be used for municipal supply. In order to protect the ecosystem of the rivers and wetlands surrounding the springs, distinct RQOs are defined.

The RQOs for these zones are:

- Buffer of 100 m around streams, wetlands and springs, if these are groundwater dependent, with no groundwater abstraction

Groundwater quality is generally very good in RU 11 and no special RQOs are urgently required. Yet, a nitrate/nitrite concentration in excess of 20 mg/l was found in one borehole and it is recommended that this be kept below this critical value. Since groundwater is used widely for rural supply, it is recommended that protection zones around boreholes used for drinking water are established or increased in order to reduce nitrate/nitrite contamination usually originating from human or animal manure.

6.4.9 RQOs for Resource Units 12 and 13

As confirmed by the piezometric map (**Figure 5-69**) the general direction of groundwater flow in Resource Units 12 and 13 is from north to south. The Northern boundary of these Resource Units also forms the boundary between the primary surface water catchments S (Great Kei River) and D (Orange River) and it is understood that groundwater flow roughly follows the same catchment boundaries.

Along this catchment boundary in the North of the Resource Units a number of seeps and springs can be identified that sustain the headwaters of some minor streams draining mostly into the White Kei and Tsomo Rivers. In order to protect the ecological integrity of wetlands and the headwaters of the streams, a zone with distinct RQOs is proposed for this area.

In addition, towards the South of the RUs three clusters of Springs can be identified which originate from the Molteno Formation wedging out above the underlying Burgersdorp Formation. The high frequency of Springs around the geological boundary is understood to be due to the higher percentage of sandstone and therefore higher hydraulic conductivity of the Molteno Formation compared to the underlying Burgersdorp Formation.

The RQOs for these zones are:

- Buffer zone of 100 m with no groundwater abstraction around wetlands, seeps and springs that are classified as groundwater dependent

Groundwater quality in RUs 12 and 13 is generally good and no special RQOs are required.

6.4.10 RQOs for Resource Units 14 to 22

The high groundwater stress in Resource Units 14 to 22 (see Table 6-8) calls for specific Resource Quality Objectives. In order to limit groundwater usage and its detrimental impacts it is proposed to put in place certain restrictions.

The special environment comprising large alluvial plains with quaternary aquifers of high hydraulic conductivity suggest shallow gradients towards the rivers. The Klaas Smits and Black Kei River down to their confluence with the White Kei River are not regulated and depend partly on seepage from the surrounding aquifers. Therefore strict adherence to prescribed water levels is imperative in order prevent the inversion of flow from rivers into the aquifer. The proposed restrictions are:

- Buffer zone of 50 m around rivers with no groundwater abstraction
- Buffer zone of 200 m around rivers where groundwater abstraction is restricted to a drawdown of not more than 2 m.

Due to the relatively flat topography of the area springs and wetlands are very rare and groundwater mostly drains directly into the rivers. Some minor clusters of wetlands can be identified in Resource Units 17, 18 and 19.

The western to north-western boundary of the area (RUs 20 and 21) also forms the boundary to the primary surface water catchments D (Orange River) to the north-west and Q (Fish River) to the west and it is understood that groundwater flow roughly follows the same catchment boundaries. Along this primary catchment boundary a number of seeps can be identified in the headwaters of some tributaries to the Klaas Smits River that drains into the Black Kei River. All wetlands and springs need to be protected by restrictions such as:

- Buffer zone of 100 m with no groundwater abstraction around wetlands, seeps and springs that are classified as groundwater dependent

Groundwater quality in RUs 14 to 22 can be described as good but the tolerable nitrate/nitrite concentration is frequently exceeded. Therefore, although groundwater us rarely used for drinking water supply, the RQO of keeping this value at a maximum of 20 mg/l is recommended.

These RQOs are considered general guidelines that need to be specified further for water use licences on a site and case specific basis.

7. MONITORING PROGRAMME

The selection and delineation of monitoring sites in the study area will assist in the assessment and management of groundwater resources (including water quantity and quality) which relates to the sustainable development and use of the resource. The monitoring programme for the study area is specified on a regional scale that is appropriate in order to be implemented by the DWA. The large scale of this study does not allow specifications on a local scale and rather recommends a regional network that is able to monitor the general status of groundwater resources as well as the above defined Resource Quality Objectives, one of them being the Reserve.

Since the RQOs are also not specified locally and rather prescribe general buffer zones around rivers, springs and wetlands, the compliance with these rather requires administrative tasks than fieldwork and actual measurements. The crucial task is therefore to enforce the strict adherence to the RQOs by making sure the buffer zones are respected.

Table 7-1 indicates the present and recent groundwater and surface water monitoring network by the DWA. Some of the rainfall stations and flow gauges are out of commission, while other flow gauges are not suitable for monitoring of groundwater discharge due to their positions at or downstreams of dams. The network of boreholes for water quality monitoring (WMS) is much wider, but not used regularly over an extended time period. It is not known, which of the NGDB boreholes is still monitored and whether the data are available to the DWA.

Table 7-1 Current or recent Monitoring Network, relevant to GRDM assessment

RU	Rainfall Station	Flow Gauges	WMS Borehole	NGDB Borehole
1, 8	R1E001, 002, 003	R1H014, 015, 017	90144	
2, 5, 6	R2E001, 002, 003, 004, R3E001, R4E001	R2H001, 005, 006, 008, 009, 010, 027 R3H001	90061 (RU 5)	3228CC00005, 3228CC00041, 3228CC00040
3	S6E001, 002, 003, S7E001, 002	S6H001, 003, S7H001, 004	89741, 90050	3225DD00001
4, 7			1-56	
9	S7E001, 002, S5E003	S5H002		
10	S3E001, S6E001	S3H003, 010, 013		3226BB00001
11	S1E001, S2E001, 002, S5E003	S5H002		
12, 13	S2E002		89738, 89739, 183491	
14		S3H004, 010		3126DC00005,
15 – 17	S3E002, 003, 004			3126DD00002, 3126DD00004, 3126DD00003, 3126DD00005,
19 – 21		S3H002, 006,	89695, 89739, 183491	3126DC00001, 3126DC00002, 3126DC00003, 3126DD00001
18 / 22				

The minimum requirement for a regional monitoring network of groundwater resources and RQO compliance comprise the following criteria and parameters:

- Weather stations need to spread over each resource unit to cover areas of similar climatic conditions. Depending upon the size of the resource unit and variation of climatic conditions, 2 or 3 stations should be sufficient, measuring:
    - Daily rainfall, to assess water level fluctuations and responses;
    - Daily temperature.
- Flow gauging stations are required to measure the groundwater contribution to river flow, especially during low flows. The network should cater for the upper, mostly natural reaches and the lower reaches, but far from any direct impact by dams. Parameters should include
    - Hourly or daily discharge;
    - Water level at stage.
- Monitoring boreholes need to be dedicated boreholes and situated across the resource unit in both unimpacted and possibly impacted areas, for
    - Water level, measured continuously with data loggers;
    - Water quality, based on bi-annual sampling and chemical analysis.
- Selected springs in the defined zones for special RQOs (see section 6.4) for measuring
    - Discharge, measured continuously with data loggers;
    - Water quality, based on bi-annual sampling and chemical analysis.

To successfully allocate monitoring sites is it important to look at the different characteristics of the area from the natural features/events (geology, aquifer type, weather patterns, climate, etc) to man-made (agriculture, water use/abstraction, farming) which can influence ecological, environmental and hydrogeological changes.

The monitoring network will be based on the existing monitoring sites. However, additional regional monitoring sites are required in some resource units (see **Table 7-2**). In instances where further on the ground monitoring is needed in order to enforce the RQOs it is recommended to supplement the monitoring infrastructure on a site specific basis.

Table 7-2 Present and recommended groundwater and surface water monitoring network per Resource Unit

	Groundwater				Surface water flow gauges, suitable for GRDM assessment		Climate	
	Water level measurement (NGDB Boreholes		Chemical sampling (WMS Boreholes)				Rainfall	
RU	present	additional	present	additional	present	additional	present	additional
1, 8	-	3	1	2	2		3	
2, 5, 6	3	2	1	2	4		6	
3	1	3	2	2	2		5	
4, 7	-	3	1	4	-	1	2	
9	-	3		3	1		2	
10	1	3		3	4	1	1	
11	-	4		4	-	3	4	
12, 13	-	3	1	2	-	2	-	1
14		2		1	1			
15, 16	2	1		2		1	1	
17, 18	2	1		2			2	
19 – 21	4	2	3	1	2			1
22		1		1				

8. RECOMMENDATIONS

8.1 CONCLUSIONS

The groundwater Reserve determination and GRDM assessment for the Mzimvubu to Keiskamma WMA was undertaken at an intermediate level, as the spatial scale does not allow for a comprehensive level. Most of the delineated resource units comprise several catchments of similar geological / hydrogeological and land use characteristics. Hence, the results of this Reserve determination provide a guideline for groundwater management on a regional scale, but do not allow for local and site specific differences.

The Reserve determination with respect to the groundwater component of the ecological Reserve and Basic Human Needs Reserve is based on the maintenance low flow requirements per quaternary catchment, as per available surface water Reserves, and the total population living in the area. The estimation for the groundwater component of the Reserve for the study area amounts to 214 million m^3/a for the ecological Reserve component and 24.8 million m^3/a for the BHN component. This results in a range of the Reserve requirements between 3% and 71% of recharge for the different resource units with an average of 21% of recharge for the study area. The highest requirements of 60% and 71% are estimated for Resource Unit 4 and 7, respectively, in the T90 catchments. The lowest requirements between 3% and 8% are estimated for resource units in the north-western part of the study area.

However, the major input parameters for the GRDM assessment; i.e. recharge and current groundwater use; show a larger degree of uncertainty that need to be taken into account in further allocations.

Except for the area south of Queenstown, which is already highly stressed with respect to groundwater use (i.e. Resource Unit 15 and 16), the major part of the Mzimvubu to Keiskamma WMA is currently under developed and shows significant potential for further groundwater abstraction to meet the growing water requirements, especially for the vast amount of villages across the former Transkei and Ciskei areas.

The water quality of the groundwater in some areas is of concern, as local contamination with faecal coliform bacteria and Nitrate was detected in several resource units (e.g. Resource Unit 4, 9, 11, 14, 15, 16, 22), mainly linked to the handling of animal manure and the lack of proper sanitation in the rural areas.

High concentrations of Fluoride were detected in some isolated boreholes in some of the resource units, which renders the water unfit for human consumption. However, these are single incidents and most probably of geological origin.

8.2 RECOMMENDATIONS

Based on the findings of the Reserve determination and GRDM assessment, the following is recommended:

- The groundwater use in the highly stressed catchments of Resource Unit 14 to 22 needs to be verified, including a validation and verification of existing lawful use and verification of actual use vs. WARMS registrations.
- Licence conditions pertaining to limiting drawdown or abstraction volumes should be derived and implemented for the currently authorised usage in the highly stressed Resource Units 15 and 16, if legally possible.
- Compulsory licensing should be considered for Resource Unit 15 and 16.
- A site specific, comprehensive groundwater Reserve determination should be undertaken, if
    - the groundwater use exceeds 50% of the estimated allocable amount for a resource unit, or
    - groundwater abstraction of more than 10% of the allocable volume is concentrated within one catchment of the resource unit.
- Measures to reduce the contamination with coliform bacteria and Nitrate need to be put in place in all effected resource units. This should include:
    - Appropriate sanitation for the rural areas;
    - Improved handling of animal manure;
    - Protection zones for springs and boreholes.

9. REFERENCES

[1] Chevallier, L., Donde, C., Nhlenko, L., Nomnganga, A., Woodford, A.C., Murray, R. and Gqoiba, D. (2009) Flow Conceptualisation, Recharge and Storativity Determination in Karoo Aquifers, with special emphasis on Myimvubu – Keiskamma and Mvoti – Umzimkulu Water Management Areas in the Eastern Cape and KwaZulu-Natal Provinces of South Africa

[2] Colvin et al. (2003) A Functional Approach to Setting Resource Quality Objectives for Groundwater, WRC Report No. 1235/1/04

[3] Dennis, I. and Witthüser, K. (2010) Groundwater Resource Directed Measures (Draft), Institute for Groundwater Studies, University of the Free State, Bloemfontein

[4] Department of Water Affairs and Forestry (1998). Hydrogeological Map Series 1:500 000 – Map 3126: Queenstown

[5] Department of Water Affairs and Forestry (1998). Hydrogeological Map Series 1:500 000 – Map 3324: Port Elizabeth

[6] Department of Water Affairs and Forestry (2004). Development of an Internal Strategic Perspective for the Amatole-Kei Area of the Mzimbvubu to Keiskamma Water Management Area (WMA No. 12). Prepared by FST Consulting Engineers (Pty) Ltd in association with Tlou and Matji and Umvoto Africa, on behalf of the Directorate: National Water Resource Planning.

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

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

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

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

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

[12] Department of Water Affairs and Forestry (2005). Mzimvubu to Keiskamma Water Management Area – Mzimvubu-Mbashe ISP Area: Internal Strategic Perspective. Prepared by Tlou and Matji Engineering and Management Services (Pty) Ltd in association with Ninham Shand, FST and Umvoto Africa, on behalf of the Directorate: National Water Resource Planning.

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

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

[15] Department of Water Affairs and Forestry (2006). Groundwater Reserve Determination Studies in the Letaba Catchment. Prepared by Africon Engineering International (Pty) Ltd in association with Umvoto Africa (Pty) Ltd on behalf of the Directorate : Resource Directed Measures.

[16] Department of Water Affairs, South Africa (2010). Development of Reconciliation Strategies for all Towns in the Southern Planning Region: Summary Report – Amathole District Municipality. Prepared by Umvoto Africa (Pty) Ltd in association with Aurecon (Pty) Ltd on behalf of the Directorate : National Water Resource Planning. DWA Report No.

[17] Department of Water Affairs, South Africa (in prep.). Development of Reconciliation Strategies for all Towns in the Southern Planning Region: Summary Report – Chris Hani District

Municipality. Prepared by Umvoto Africa (Pty) Ltd in association with Aurecon (Pty) Ltd on behalf of the Directorate : National Water Resource Planning. DWA Report No.

[18] Momba M, Makala, N. and Brouckeart, B. (2004) Strategies to ensure sustainable effective disinfection in small municipal water distribution systems, WRC Report No. 1391

[19] Parsons, R. and Wentzel, J. (2004). Groundwater Resource Directed Measures Manual – Setting Resource Directed Measures (RDM) for Groundwater: Pilot Study, WRC Report No 299/07, April 2007

[20] Smart, M.C. (1998) An Explanation of the 1:5000 000 General Hydrological Map, Queenstown 3126, Department of Water Affairs, Pretoria

[21] Umvoto Africa (2009) Proposal for the Groundwater Reserve Determination Study in the Mzimvubu to Keiskamma WMA, Project No. WP10261

[22] Umvoto Africa (2009). Groundwater Reserve Determination for current and potential Wellfield Development of TMG Aquifers. Deep Artesian Groundwater Exploration for Oudtshoorn Municipal Supply. Prepared for the Water Research Commission

[23] Vegter, J.R. (1995a). An Explanation of a set of National Groundwater Maps. Prepared for Water Research Commission report TT 74/95. p82. Water Research Commission, Pretoria.

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

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

[26] Xu et al (2002) Towards the Resource Directed Measures: Groundwater Component, WRC Report No. 1090-2/1/03

10. APPENDICES

Appendix A Chemical Analysis Report

Annexure

Honours Thesis by S.O. Jack