

**WATER RESEARCH COMMISSION**  
**Report No. K8/970**

# **Groundwater Resource Directed Measures for Maloney's Eye Catchment**



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# 1 INTRODUCTION

## 1.1 Preamble

The Department of Water Affairs (DWA) is mandated through the National Water Act (NWA; Act 36 of 1998) to ensure that the nation's water resources are protected; used; developed; conserved; managed and controlled in a sustainable manner for the benefit of all persons. The act states "*the quantity, quality and reliability of water, required to maintain the ecological functions of which humans depend, shall be reserved so that human use does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems*". This amount and quality of water that must remain for ecosystem to remain healthy and to be able to provide for the basic needs is called the Reserve.

It is currently the responsibility of the Chief Directorate: Resource Directed measures within DWA to determine the Reserves of the country's water resources such as rivers, groundwater, wetlands and estuaries. Methods for GRDM assessments are new and still under development and review. As a general principle, an effort has to be made to keep methods simple and efficient, while clear and accepted terminology needs to be used. In developing and refining the GRDM methods, cognisance needs to be taken of the outcomes of GRDM assessments:

- How much groundwater can be abstracted without impacting the Reserve and resource Classification requirements?
- How should the groundwater resource be managed to ensure the resource is used sustainably?

Water management in South Africa is based on three key principles:

- Sustainability – water use must promote social and economic development, but not at the expense of sustaining the environment (technical component)
- Equity – every citizen of the country must have access to water and the benefit of using water (social component)
- Efficiency – water must not be wasted and must be used to the best possible social and economic advantage (economic component)

The DWA has entered into a memorandum of understanding (MoA) with the Water Research Commission (WRC) to conduct research programs on behalf of the Chief Directorate: Resource Directed Measures. The agreement is to cease on 31<sup>st</sup> March 2012.

The groundwater component of the Reserve was done on a rapid (quaternary catchment) level for the Crocodile (West) and Marico WMA. The PSC classification of the groundwater resource in catchment A21F is E with a resource category being Poor.

In view of the very high water use / demand for agricultural irrigation in the **Steenkoppies Dolomite Compartment, a sub-portion of the quaternary catchment A21F** and currently with reduced flows discharging from the Maloney's Eye, there is a need to carry out an intermediate / comprehensive level of the groundwater Reserve. The latter will depend on the geohydrological data available.

Increasing quantities of effluent return flow from urban and industrial areas offer considerable potential for re-use, but at the same time a major concern of pollution in some areas. Return flows also originate from irrigation, estimated at 10% of annual water use.

As the implementing agent the WRC is required to engage groundwater specialists who have worked on the Crocodile (West) and Marico WMA, so that they are able to use the data at their disposal efficiently and effectively. Golder Associates Africa (Pty) Ltd was appointed by the WRC as Professional Service Provider (PSP) to conduct a comprehensive groundwater Reserve determination of the Steenkoppies Dolomite Compartment (DC) (Figure 1-1).

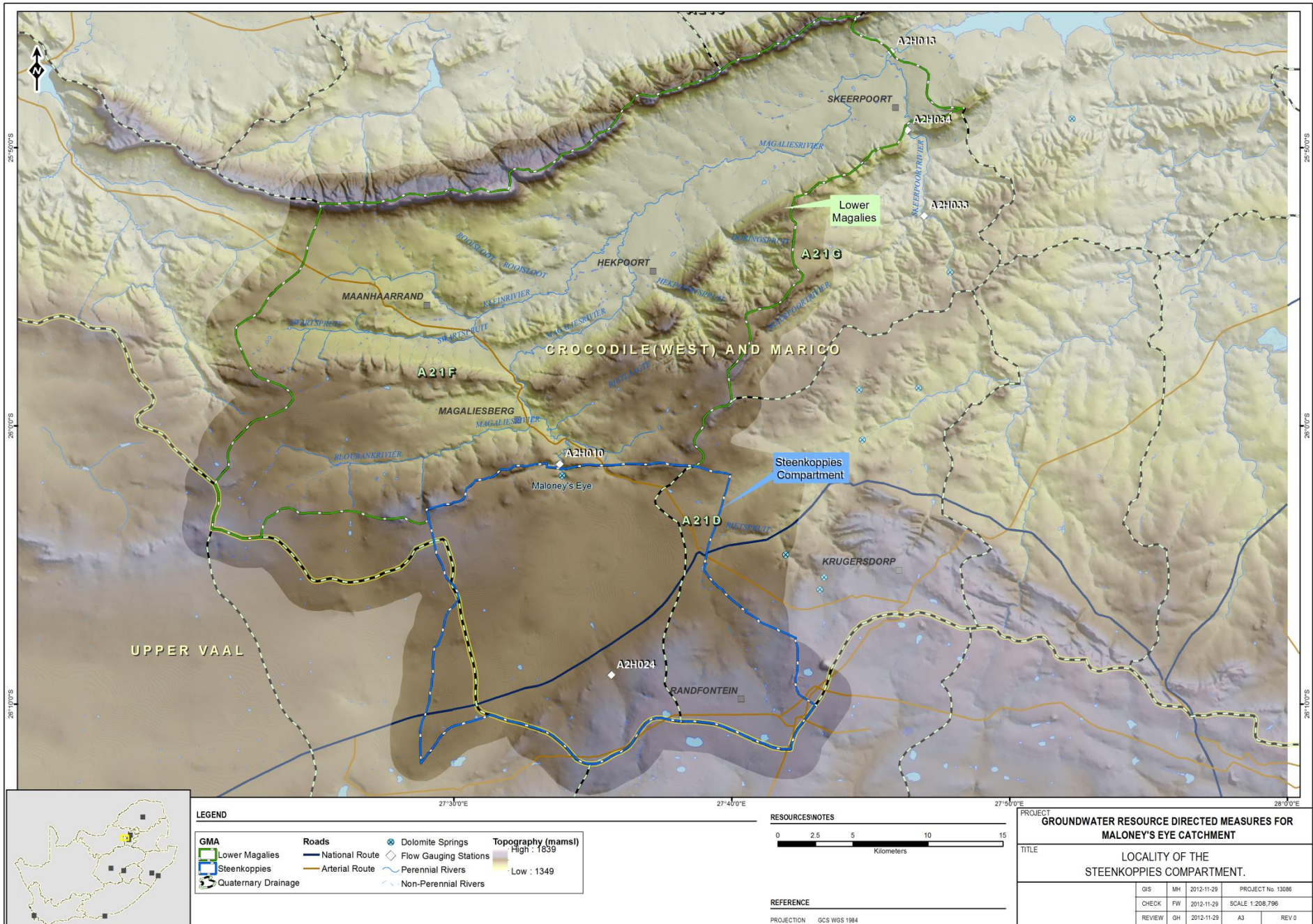


Figure 1-1. Location of the study area.

## 1.2 Implementation (GRDM Assessment)

To date the most commonly applied manual to address the methods and procedures needed to implement the Groundwater Resource Directed Measures (GRDM) was based on Parsons and Wentzel (2007). This manual was updated in 2011 by the Institute for Groundwater Studies, University of the Free State, which included some new methods which can be applied to assess Groundwater Resource Directed Measures. More importantly the GRDM manual is aligned to that of the gazetted Regulations for the Establishment of the Classification System (2010) (Dennis, 2011). As a result, it is important to incorporate the updated methodology (and more specifically the classification (categorisation) of water resources) as outlined by the 2011 manual.

In addition, for the high level (Intermediate/comprehensive) GRDM assessment of the Maloney's Eye certain data gaps identified by recent studies (e.g. Barnard, 1997; Holland et al., 2009), will be fulfilled through a number of site investigations. The identified data gaps will largely be addressed by the following pre-required site investigations:

- Additional gravity surveys. Extension of existing gravity coverage in the direction to Maloney's Eye, to map high transmissivity zones that act as conduits for preferential groundwater flow. Provision for nine hundred gravity stations (300 by 100 metre grid spacing) is made. Approximate 1400 existing gravity data along roads and fences at 100 meter intervals also exist in the compartment area which needs to be captured electronically and incorporated in a common gravity data set.
- Tarlton water use borehole information. Collation of production boreholes and water use information from the Tarlton Users Association's data base.
- Steenkoppies DC hydrocensus survey. Survey is aimed at ground truthing production boreholes, measuring water levels in all accessible boreholes with previous water level measurements to obtain a snapshot of current water levels (April 2011). Water level measurements will also be focussed at boreholes located close to possible compartment sub-boundaries. The survey will include water sampling from higher yielding boreholes and Maloney's Eye for chemical analysis of macro elements (especially aimed at obtaining reliable chloride concentrations in groundwater). Historic chloride values are very low (1 to 2 mg/l) of which the reliability is uncertain.
- Magalies River hydrocensus survey. Survey of boreholes in proximity of the Magalies River, down-stream of Maloney's Eye, to obtain information to assist in assessing the interaction between surface and groundwater source. Boreholes in use currently registered on WARMS and located along the Magalies River will be ground truthed, where possible.

In correspondence with the proposal submitted to the WRC and in terms of the appointment. The GRDM assessment entails three main phases (Initiation, Implementation and Termination), each phase comprising a number of tasks.

### 1.2.1 Phase 1: Project Inception

This phase comprises five tasks:

- Task 1.1. Literature review
- Task 1.2. Collate project borehole database (spatial, depth and time dependant) and GIS information layers.
- Task 1.3. Initiation workshop to identify draft approaches to conduct GRDM on the delineation of various aquifer units (quantity and quality considerations) taking cognisance of Integrated Unit of Analysis (IUA) as per the National Water Resource Classification regulations.
- Task 1.4. Approach / methodology to be used in delineation and quantification of groundwater and surface water interactions, occurring near rivers and wetlands.
- Task 1.5. Compile inception report detailing preliminary methods statement for iterative GRDM study and update costing of study.

### 1.2.2 Phase 2: Study Implementation

This phase forms the essence of the study, comprises of discrete tasks (each with defined deliverables according to the GRDM methodology) as listed below:

- Task 2.1: Preparation and Pre-required Site Investigations. This task overlaps with Phase 1, details the ToR, set required level of GRDM confidence, capture and incorporate existing data into study, define study area. Conduct pre-required site investigations (includes verification of existing data) and incorporate data into study. The pre-required site investigations include:
  - Additional gravity surveys
  - Tarlton water use borehole information
  - Steenkoppies DC hydrocensus survey
  - Magalies River hydrocensus survey
- Task 2.2. Description of Study Area. This task entails the physical and geohydrological description of the study area to required GRDM level. Deliverables are:
  - Geohydrological description of aquifer systems, recharge sources and conceptual model. This will include preliminary/existing delineation of aquifer systems up to secondary delineation (Refer Task 2.3 below)
  - Description of the status of identified water resources with reference to:
    - Identifying ambient/reference conditions
    - Observed impacts (quantity and quality)

Technical workshop with steering committee required to obtain consensus on conceptual model before commencing with 3D numerical modelling using FEFLOW.

- Task 2.3. Delineation of Resource Units (Groundwater Unit of Analysis). A three-tier system of delineation from primary delineation (quaternary catchment level), then secondary delineation (based on aquifer type and significant eco region) and last tertiary delineation (based on

conceptual model with delineations of single sub-dolomite compartments or sub-aquifer units) will be used. Deliverables are:

- Delineation and description of Groundwater Unit of Analysis (GUA).
- Map showing extent of delineated units.

Delineations to tertiary level are required prior to commencement of 3D numerical modelling to firstly quantify and simulate natural conditions.

- Consideration of groundwater interaction with wetlands, rivers, etc.
- GRDM determinations for each GUA to include:
  - Resource Classification
  - Preliminary Reserve Quantification
  - Preliminary RQO's
- Task 2.4. Water Resource Classification. This task entails defining the current impact (quantity and quality) on the resource for each GUA, and will be informed by numerical modelling. Deliverables are:
  - Assigned Water Resource Category
  - GRDM assessment data sheet for all GUA
- Task 2.5. Quantification of the Groundwater Reserve. This task quantifies the groundwater volume (both quantity and quality) that can be abstracted from a water resource (Allocation) without impacting the ability to contribute to the Reserve (BHN and Ecological Reserve), and will be informed by numerical modelling.
- Deliverables for all GUA are:
  - Quantification of recharge.
  - Quantification of groundwater contribution to base-flow and groundwater dependant ecosystems
  - Quantification of the groundwater basic Human Needs (BHN)
  - Quantification of groundwater allocation
  - Compile standard GRDM assessment sheet
  - Scale results to appropriate units according to the management and administrative needs of DWA.
  - Compile list of proposed groundwater utilization licence conditions to assist DWA to list licence conditions. This also includes delineation of aquifer protection zones from which groundwater use is limited or not allowed.
- Task 2.6. Setting of Preliminary Resource Quality Objectives (RQO's) This task deals with technical considerations to preliminary set practical, implementable and measurable goals that balance the need to protect and sustain a water resource with the need to develop and use the resource. This task will be informed by transient aquifer modelling. Deliverables are:

- List of preliminary RQO's, either numeric or descriptive, to set aquifer management criteria and/or limits of acceptable impact to protect groundwater dependant ecosystems, etc.
- Task 2.7. Monitoring Programme for post GRDM. Task entails defining monitoring protocols to generate data to assess whether the RQO's are being met for each RU's.
  - The design of the monitoring programme is guided by information requirements related to resource management and protection as specified for the GRDM determination process. The established 3D numerical aquifer model will be available as a reliable tool for future aquifer management and will be used to inform this task.

On completion of tasks 1 to 7 of the phase 2 study component a comprehensive draft technical report will be compiled and presented to the steering committee for approval and external review. The report will include recommendations on improving future Reserve determination studies and report back on capacity building of HDI's during the current study.

### 1.2.3 Phase 3: Project Termination

Once all objectives have been achieved and upon recommendation of the Project Management PSP (WRC), the Client will issue instructions to the PSP to terminate the study. This is required to analyse the experience of the PSP in executing the project, and to translate this knowledge into a report which contributes to and builds on the evolving practice of GRDM assessment studies. The PSP shall produce a comprehensive final technical report, including recommendations on improving future Reserve determination studies and capacity building of HDI's during the technical studies

## 1.3 Assumptions related to GRDM assessments

To be able to undertake GRDM assessments and quantify the volume of groundwater required to meet Classification requirements and sustain the Reserve, a number of assumptions are made:

- Groundwater systems are generally resilient and can normally recover from most perturbations. However, it is accepted that groundwater contamination can persist over decades and centuries.
- Groundwater resources can be developed and used up to a point without significantly impacting the ability of groundwater resources to sustain the Reserve or meet the RQOs.
- The ability of a geohydrological system to satisfy basic human needs, RQOs and the ecological Reserve is not impacted if regional groundwater levels do not decline significantly over the long term, and ambient groundwater quality remains within natural limits.
- The sustainable rate at which groundwater can be abstracted is a function of the average long-term annual recharge, while the volume of groundwater held in storage acts as a buffer during dry periods.

- It is assumed that recharge and groundwater abstraction are distributed relatively evenly throughout significant water resources.
- The validity of each GRDM assessment will be reviewed at least every five years using monitored data from the study area.

#### **1.4 Sources of Information**

The following datasets were collated as part of the inception phase:

- The 1:250 000 scale geological maps 2526 Rustenburg and 2626 West Rand.
- Water level monitoring data (HYDSTRA) extracted from the National Groundwater Database (NGDB) managed by DWA.
- Water level logger data (part of the SAMA WUA monitoring programme).
- Groundwater quality data extracted from the NGDB and relevant reports.
- Effluent discharge volumes from the Randfontein WWTW.
- Long term monthly rainfall records for all stations within the study area.
  - Numerous rainfall station data (part of the SAMA WUA monitoring programme).
- Long term flow records of the Maloney's Eye (A2H010) in addition to the Brandvlei (A2H024) and Magalies River at Scheerpoort (A2H013).
- Water level measurements from Greenway farms (since 2004).
- Aeromagnetic data for the dolomite outcrop and map sheet 2527DD.
- Gravity survey data conducted in 1985 (digital).
- Water use validation data and registered water use as per WARMS dataset.
  - Validation data obtained from Schoeman & Associates aimed to determine existing lawful water use in the area prior to 1998 was conducted in the late 2000s.

## **2 LITERATURE REVIEW (THE MALONEY'S EYE CONCERN)**

### **2.1 Setting**

The Steenkoppies DC is located in the upper reaches of the Magalies River catchment (A21F) which comprises a total drainage area of approximately 1 000 km<sup>2</sup>. The Maloney's Eye catchment (the Steenkoppies DC) comprises an area of approximately 332 km<sup>2</sup> and is underlain by the Malmani dolomite formations of the Chuniespoort Group. It is within this Group that karst formation has occurred. Dykes that form boundaries to groundwater flow cross the dolomites, creating isolated hydrogeological compartments.

### **2.2 Reduction of spring discharge**

The Steenkoppies DC has received great attention since the naturally discharging spring of the Steenkoppies DC (known as "Maloney's Eye") reached the lowest flow on record. During March 2007 eight of the nine springs constituting the Maloney's Eye stopped flowing and flow was measured at 0.05 m<sup>3</sup>/s (or 1.58 Mm<sup>3</sup>/a). This had major consequences for downstream water users as flow from the spring forms a portion of the flow of the Magalies River. At the time of this study, flow measured at the Maloney's Eye gauging station was 0.338 m<sup>3</sup>/s (or 10.66 Mm<sup>3</sup>/a) compared to a long term average of 14.13 Mm<sup>3</sup>/a (since 1908). The Steenkoppies DC has been exploited through the abstraction of groundwater primarily for agricultural irrigation since the early 1980's and recent studies have indicated declines in groundwater levels in the Steenkoppies DC, suggesting over abstraction which could lead to a decline in discharges to the Eye (Barnard, 1997; Holland et al., 2009). In 2007 the Magalies River Crisis Committee (MRCC) made a submission to the South African Presidency regarding the low flows at Maloney's Eye and the possible impact on the Magalies River, seeking amongst other things a temporary cessation of all groundwater abstractions from the Steenkoppies DC to allow the flow at the eye to recover (MRCC, 2007). However, the value of agricultural activities in the Steenkoppies DC is very large, both in terms of money flowing into the area and in terms of employment. The Tarlton Farmers estimate that the activities are worth more than three quarters of a billion rand and employ 3500 people directly, as well as supporting large numbers of people and economic activities indirectly (Tarlton, 2007). Obviously any major reduction in farming activities could have severe economic and social consequences for the area. In 2007 the 'Tarlton' farmers started negotiations aimed at the establishment of a Water User Association (WUA) for the area, to be known as the Steenkoppies Aquifer Management Association (SAMA), with the assistance of the Danish government aid organisation DANIDA. The WUA is essentially aimed at furthering the joint interests of users of groundwater from the Steenkoppies DC, and a constitution for the WUA has been submitted and awaits final response from DWA.

### **2.3 Hydrogeological studies**

Hydrogeological investigations conducted on the Steenkoppies DC in the early 1980s, were mainly to determine the groundwater supply potential for emergency utilisation (Foster, 1984; Kuhn, 1986; Bredenkamp et al., 1986). During the late 1990s a decrease in the flow of the Maloney's Eye caused great concern amongst downstream users who blamed irrigation activities and the sub-sequent over exploitation of the groundwater resources in the Steenkoppies DC, for the decrease in flow. Barnard's (1997) investigation focussed firstly to determine the catchment boundaries for Maloney's Eye, and secondly to draw up a water balance for the catchment with special reference for reasons for the reduced flow. This study included a simulation of the Steenkoppies DC by means of a numerical flow model mainly to quantify hydraulic parameters and establish a balance between them. Barnard (1997) concluded that a general decline in water levels will occur over the aquifer resulting in a decline the flow of the Maloney's Eye for below average or average rainfall seasons.

During the mid-2000s the Tarlton farmers dispute that irrigation is to blame for the low flows at Maloney's Eye, although they agree that water resources in the greater Magalies area are under stress. They state that "No credible evidence has been put forward to show that the water difficulties in the Tarlton and Magalies River area is attributable to the existing lawful use of water by the Tarlton Farmers" (Tarlton, 2007). As a result, the Tarlton farmers commissioned and paid for a groundwater study by the environmental consultancy ERM (Pty) Ltd which supports their views (ERM, 2007). In particular, the ERM report states that changing rainfall patterns, changing sewage inputs to the compartment, changing water uses downstream of Maloney's Eye, alien vegetation along the banks of the Magalies River, mining activities and other factors are also to blame for the decline in flow at the eye and in the Magalies River (ERM, 2007).

Under increasing pressure from both the Tarlton farmers and downstream users, the DWA Water Resource Planning directorate initiated a study as part of the Dolomitic Guideline Development in 2009. During this investigation carried out by Holland et al. (2009), the conceptual understanding of the Steenkoppies DC was reviewed and updated. The study also proposed specific interventions with regard to management and concluded that the flow at Maloney's Eye correlates very well with rainfall over most of the record length, but that in the last fifteen or so years, the flow has declined further than rainfall records would suggest. Further, the groundwater levels in the compartment have declined in recent years, to levels below what would be expected from rainfall decreases alone. Despite these resulting conclusions, the interaction of the Maloney's Eye with the larger Magalies River catchment wasn't assessed. The need for an intermediate / comprehensive level of the groundwater Reserve was proposed by a number of investigations and should provide insight into the relationship between declining flows at the eye and declining flows further downstream in the Magalies River.

### 3 DESCRIPTION OF STUDY AREA

#### 3.1 Drainage region

The Steenkoppies DC drains towards the north and forms part of the upper catchment of the Magalies river (quaternary catchment A21F) (Figure 1-1). This Magalies River catchment is part of the upper Crocodile River sub-system and are located within the Crocodile (West) and Marico Water Management Area as described by the DWA. These surface catchments are immediately north of the sub-continental surface water divide (Witwatersrand watershed) between the Vaal River basin to the south and the Limpopo River basin to the north. Believe is that the perennial Maloney's Eye forms a large portion of the flow contributing to the Magalies River system which sustains irrigation activities along the river.

##### 3.1.1 Surface water flows

The low density of runoff drainage over the Steenkoppies DC suggests high recharge and a predominance of water flow underground, which eventually drains into surface streams at topographic lows or emanates as springs next to diabase dykes or formation contacts (e.g. Maloney's Eye). Although the Upper Rietspruit forms part of the adjacent quaternary catchment it does form a vital part of the Steenkoppies DC groundwater system. The Upper Reitspruit drains storm water and surface runoff from the town of Randfontein in addition to treated sewage effluent from the Randfontein Sewage Works facility. For some distance, stream flow remains constant, but irrigation dams and the leakage from the river bed into the underground network reduces the flow to virtually zero at the Tarlton intersection<sup>1</sup>. A summary of the effluent inflows and discharges of the Randfontein WWTW is given in Table 3.1.

**Table 3.1. Randfontein effluent inflows and discharges into the Upper Rietspruit.**

| Year | Raw Inflows<br>Mm <sup>3</sup> /a | Effluent outflow Mm <sup>3</sup> /a |            |             |
|------|-----------------------------------|-------------------------------------|------------|-------------|
|      |                                   | River                               | Irrigation | TOTAL:      |
| 2004 | <b>3.60</b>                       | 1.34                                | 0.94       | <b>2.28</b> |
| 2005 | <b>3.45</b>                       | 1.48                                | 1.34       | <b>2.82</b> |
| 2006 | <b>4.75</b>                       | 1.52                                | 1.45       | <b>2.97</b> |
| 2007 | <b>4.95</b>                       | 0.84                                | 2.07       | <b>2.91</b> |
| 2008 | <b>5.19</b>                       | 0.54                                | 2.73       | <b>3.28</b> |
| 2009 | <b>2.7*</b>                       | 0.5                                 | 1.7        | <b>2.2</b>  |
| 2010 | <b>5.4</b>                        | 1.59                                | 2.7        | <b>4.29</b> |

\* - Data incomplete

<sup>1</sup> E-mail Communication (7 September 2011). Mr. Richard Magwanya of the Randfontein Municipality.

Based on the information obtained from the Randfontein WWTW average effluent discharge for the past five years amount to 2.95 Mm<sup>3</sup>/a of which approximately 1.15 Mm<sup>3</sup>/a is discharged into the Upper Rietspruit and 1.8 Mm<sup>3</sup>/a is used for irrigation purposes. A small component is also used by the adjoining mine dumps for dust suppression and also for irrigation of newly planted vegetation for rehabilitation. Therefore it is fair to assume that very little or any of these effluent discharge components reaches the Steenkoppies DC.

The monthly discharge values are plotted in Figure 3-1 together with monthly rainfall data from the Randfontein rainfall station. Although, no relationship between rainfall and effluent inflow or discharges is evident, an increase in the effluent discharge for irrigation purposes is seen from January 2007 with a slight decrease in discharges to the Rietspruit.

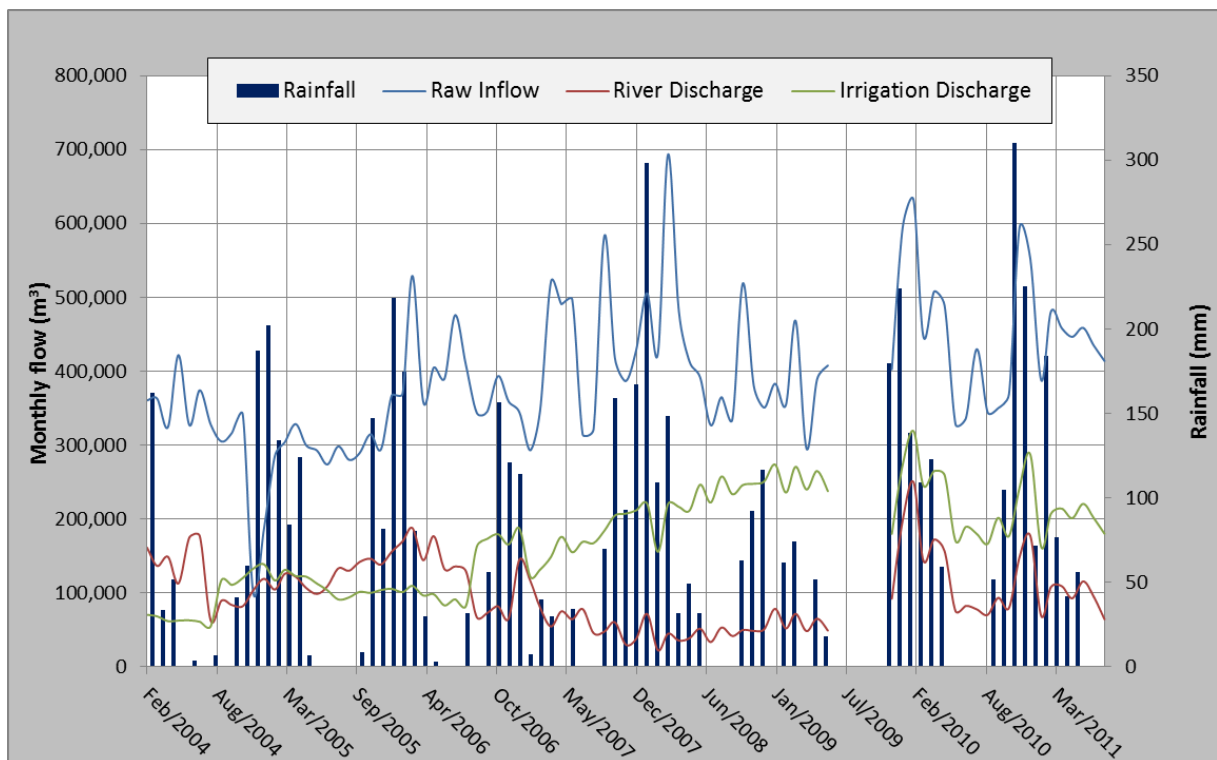


Figure 3-1. Randfontein effluent discharges and raw inflows.

#### Gauging stations

The most important DWA hydrological gauging stations near the Steenkoppies DC are the Maloney's Eye (A2H010) and Brandvlei (A2H024) stations. The Magalies River gauging station (A2H013) is approximately 34km downstream of the Maloney's Eye. The monthly flow hydrograph of both A2H010 and A2H024 are illustrated in Figure 3-2. The peaks of the surface run-off hydrograph correspond well with the peaks of the Maloney's Eye flow. The extend run-off recession period is also substantially longer compared to the river system. The information illustrated in Table 3.2 was obtained from the 100-year flow record of the downstream weir of the Maloney's Eye (A2H010).

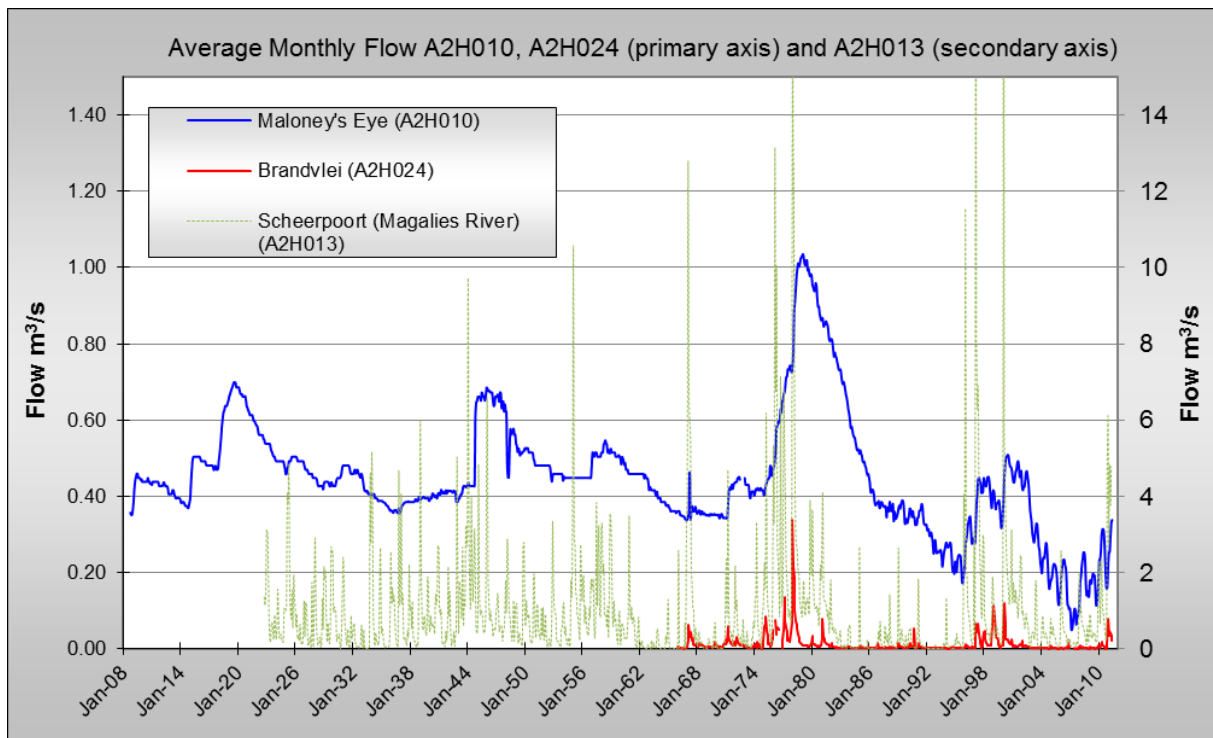


Figure 3-2. Flow hydrograph's of DWAf gauging stations A2H010, A2H024 and A2H013.

Table 3.2. Maloney's Eye flow summary table (October 1908 to June 2010).

| Year (Record)   | Min (Mm <sup>3</sup> /a) | Max (Mm <sup>3</sup> /a) | 10 Percentile (Mm <sup>3</sup> /a) | 90 Percentile (Mm <sup>3</sup> /a) | Median (Mm <sup>3</sup> /a) | Average (Mm <sup>3</sup> /a) |
|-----------------|--------------------------|--------------------------|------------------------------------|------------------------------------|-----------------------------|------------------------------|
| Pre 1985        | 10.63                    | 32.64                    | 11.67                              | 21.26                              | 14.48                       | 15.72                        |
| Post 1985       | 1.58                     | 16.43                    | 5.32                               | 14.22                              | 10.25                       | 9.79                         |
| Last Decade     | 1.58                     | 15.52                    | 3.47                               | 14.03                              | 7.08                        | 7.76                         |
| Complete Record | 1.58                     | 32.64                    | 8.68                               | 20.76                              | 13.78                       | 14.19                        |

Over the last decade the average flow of the Maloney's Eye is significant less compared to the long term and pre-1985 flow records. It is also evident that short term flow fluctuations (variations) have increased over the last few years.

### 3.2 Topography

The Steenkoppies DC is typified by an almost flat undulating plain bounded by between the scarp slopes of the Witwatersrand Supergroup to the south and the Pretoria Group in the north. The altitude along the Witwatersrand watershed and the Magaliesberg mountain range is approximately 1700 metres above mean sea level (mamsl), while the flood plain of the Magalies River ranges between 1400 mamsl to 1200 mamsl from west to east (Figure 1-1).



**Photo 1. Looking north towards the Magalies River (south of Magaliesburg) (Photo; Martin Holland).**

### **3.3 Climate and rainfall**

The climate in the area is typical of the South African “Highveld”, characterised by warm summers, while 80 % of the rainfall is experienced as thunderstorms, and cool dry winters with cold nights. Climatic data of six meteorological stations closest to the study area is summarised in Table 3.3 and spatially presented in Figure 3-4 **Error! Reference source not found..**

**Table 3.3. Meteorological stations in the study area.**

| Station Name              | Station ID | Rainfall Record |             | Elevation (mamsl) | Mean Annual Rainfall MAP (mm) | Distance from Maloney’s Eye (Km) |
|---------------------------|------------|-----------------|-------------|-------------------|-------------------------------|----------------------------------|
|                           |            | Start           | End/Current |                   |                               |                                  |
| Vlakfontein*              | 474751     | 1934            | 1989        | 1,531             | 693.4                         | 13.5                             |
| Steenkoppies*             | 475121     | 1907            | 1952        | 1,502             | 664.4                         | 3.7                              |
| Randfontein*              | 475338     | 1954            | 2009        | 1,705             | 662.0                         | 19.3                             |
| Randfornein GM*           | 475370     | 1914            | 1995        | 1,722             | 708.5                         | 22.7                             |
| Randfontein Jamespark*    | 475370     | 1980            | 2000        | 1,722             | 709.1                         | 22.7                             |
| Krugersdorp Kroningspark* | 475456     | 1965            | 2011        | 1,695             | 716.5                         | 23.1                             |
| Magaliesburg*             | 512090     | 1969            | 2011        | 1,429             | 613.8                         | 3.2                              |
| Deodar <sup>#</sup>       | 30619      | 1982            | 2011        | 1,625             | 639.9                         | 12.9                             |

\*- Data obtained from the South African Weather Services (Pretoria)

<sup>#</sup> - Data obtained from the Agricultural Research Council (Pretoria).

The monthly rainfall time series of different meteorological stations in the wider area of interest were screened with regard to their recorded mean annual precipitation. Only four stations (Vlakfontein, Steenkoppies, Randfontein and Deodar) showed a similar mean annual precipitation (MAP), where, the maximum deviation of mean annual precipitation was below 10 %. These stations were considered for the compilation of a single, representative time series from 1908 to 2011. The time series was compiled by calculating a weighting average (using a squared inverse distance weighting method) of all monthly rainfall records available for a given time period:

$$h_{n,x} = \frac{\left( \sum_{i=1}^4 h_{n,i} \frac{1}{d_i^2} \right)}{\left( \sum_{i=1}^4 \frac{1}{d_i} \right)}$$

Where,

- $h_{n,x}$  estimated representative monthly precipitation for area of interest
- $h_{n,i}$  monthly precipitation of neighbouring stations
- $d_i$  distance of stations to area of interest (Maloney’s Eye)

If a rainfall station did not have any records for a given time period, the station was omitted from the calculations above. The chosen approach ensured the compilation of a continuous 100 year time series of rainfall records; though several time periods rely solely on a single operational station (e.g. only Steenkoppies (475121) was operational prior to 1934).

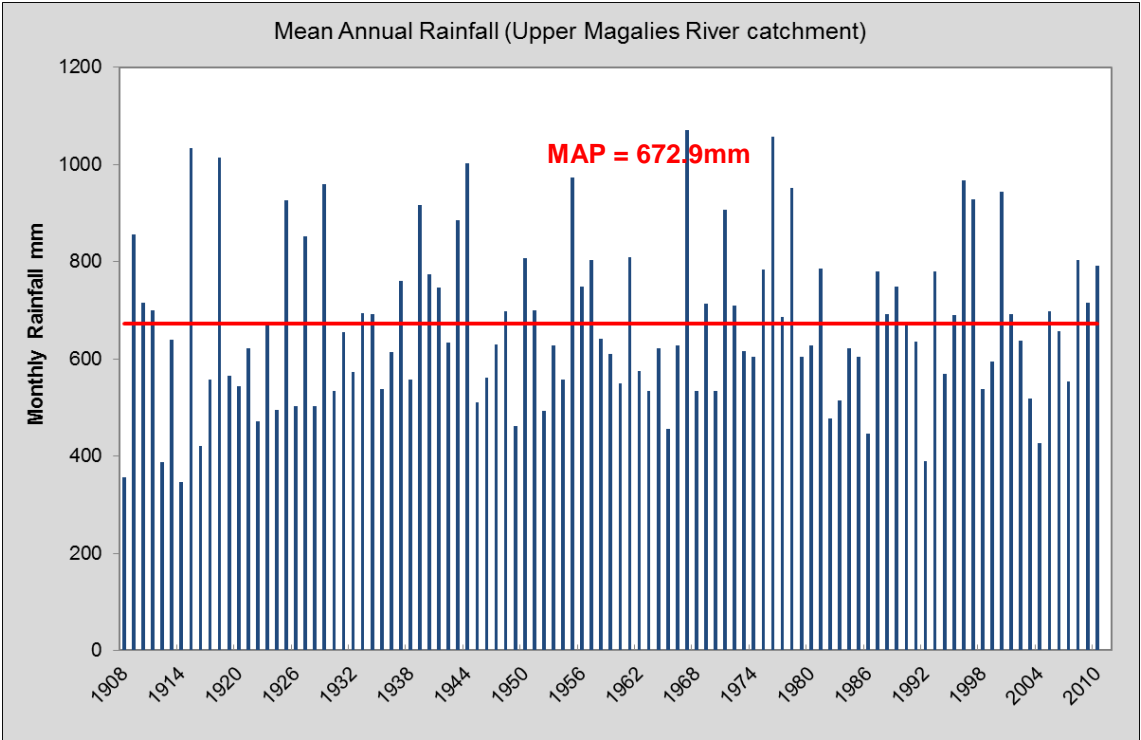


Figure 3-3. Mean annual precipitation for the upper Magalies River catchment.

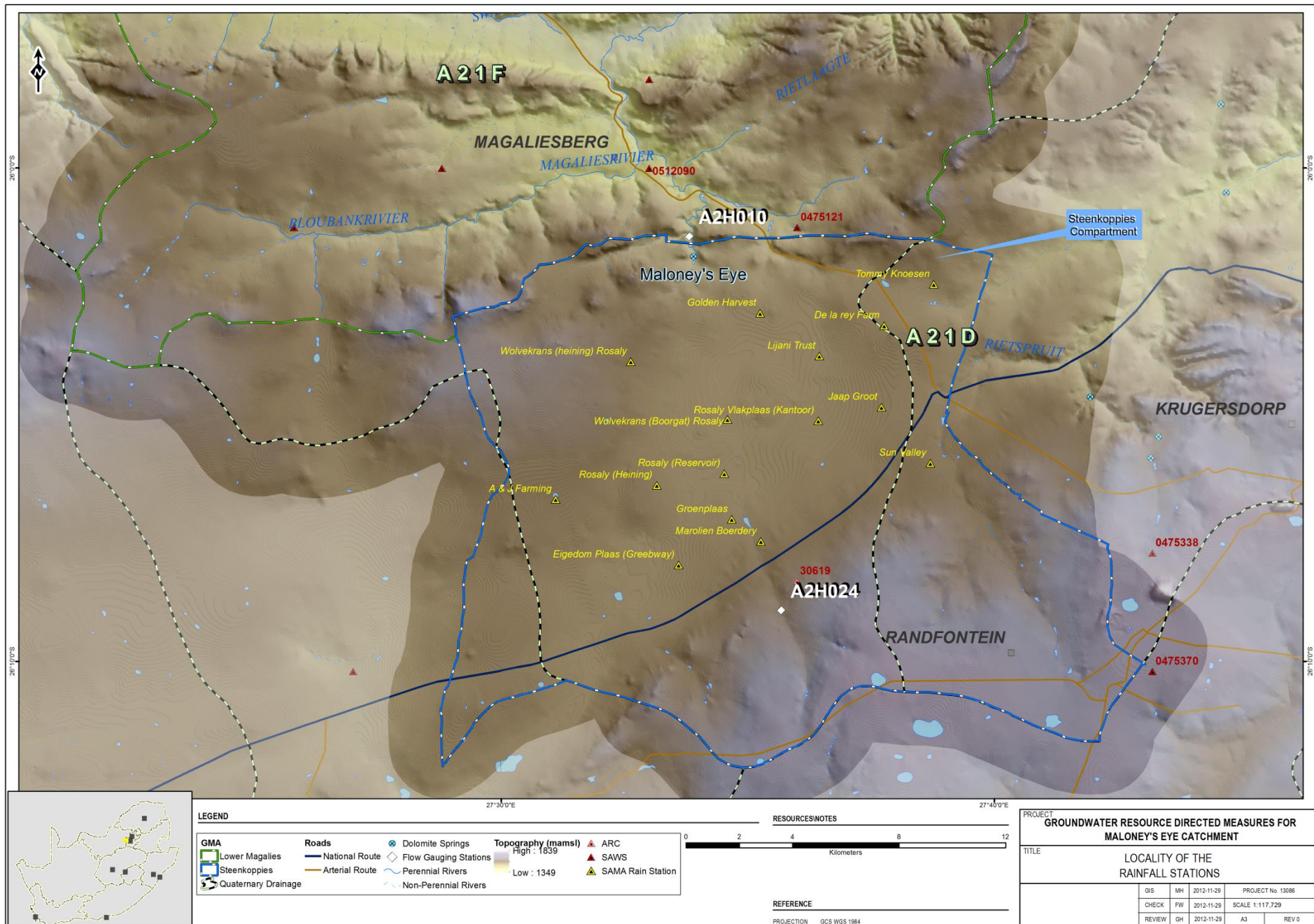


Figure 3-4. Locality of rainfall stations.

### 3.4 Geology

The northern boundary of the Steenkoppies DC runs along the base of the up-tilted Pretoria Group strata, comprising of the Timeball Hill and Rooihoogte Formations (Table 3.4). The strata dip northwards 20-30°. The southern boundary along a number of rock types ranging from igneous basement rocks to the sedimentary succession of the gold bearing Witwatersrand formations forming the faulted rim of the Witwatersrand basin. Dipping off the western flank of the Johannesburg Dome with a disconformable contact is the basal formation of the Transvaal Supergroup consisting of the Black Reef Quartzite Formation underlying the Malmani subgroup dolomites of the Chuniespoort Group Steenkoppies DC. Based on the abundance of chert, the Malmani subgroup has been subdivided into five dolomitic formations (table), however due to the geological complexity and lack of outcrop, the Steenkoppies DC is undifferentiated (Figure 3-5).

**Table 3.4. General stratigraphy of the study area. (SACS, 1980:205; Foster, 1984; Obbes, 2001).**

| Super Group             | Group        | Formation     | Thickness (in m)                  | Lithology   |
|-------------------------|--------------|---------------|-----------------------------------|---|
| TRANSVAAL               | PRETORIA     | Rayton        | 120                               | Shale, quartzite.   |
|                         |              | Magaliesburg  | 300                               | Quartzite.  |
|                         |              | Silverton     | 600                               | Shale.  |
|                         |              | Daspoort      | 80-95                             | Quartzite.  |
|                         |              | Strubenkop    | 105-120                           | Slate.  |
|                         |              | Hekpoort      | 340-550                           | Andesite.   |
|                         |              | Timeball Hill | 270-660                           | Shale, Diamictite, Klapperkop Quartzite and ferruginous quartzite.                                    |
|                         |              | Rooihoogte    | 10-150                            | Quartzite, Shale, Bevets Conglomerate Member and Breccia.   |
|                         | CHUNIESPOORT | Frisco        | 30-158                            | Chert-free dolomite with some primary limestone and carbonaceous shale at the base.                   |
|                         |              | Eccles        | 490                               | Chert-rich dark dolomite with stromatolitic and oolitic bands. Chert increases to the top.            |
|                         |              | Lyttelton     | 220-290                           | Chert-free dark dolomite with large stromatolites and sometimes with wad.                             |
|                         |              | Monte Christo | 740                               | Alternate layers of chert-rich and chert-poor light coloured dolomite with stromatolites and oolites. |
|                         |              | Oaktree       | 190-330                           | Chert-poor dark dolomite with interbedded layers of carbonaceous shale at the base                    |
|                         | Black Reef   | 11-30         | Shale and Quartzite. Arkosic Grit |   |
| WITWATERS RAND          | CENTRAL RAND | -             | 2 880                             | Aranaceous, rudaceous rocks.  |
|                         | WEST RAND    | -             | 5 150                             | Quartzite, reddish and ferruginous magnetic shales.   |
|                         | DOMINION     | -             | ?                                 | Quartzite, conglomerate, shale, interbedded lava.   |
| <b>BASEMENT COMPLEX</b> |              |               |                                   |   |

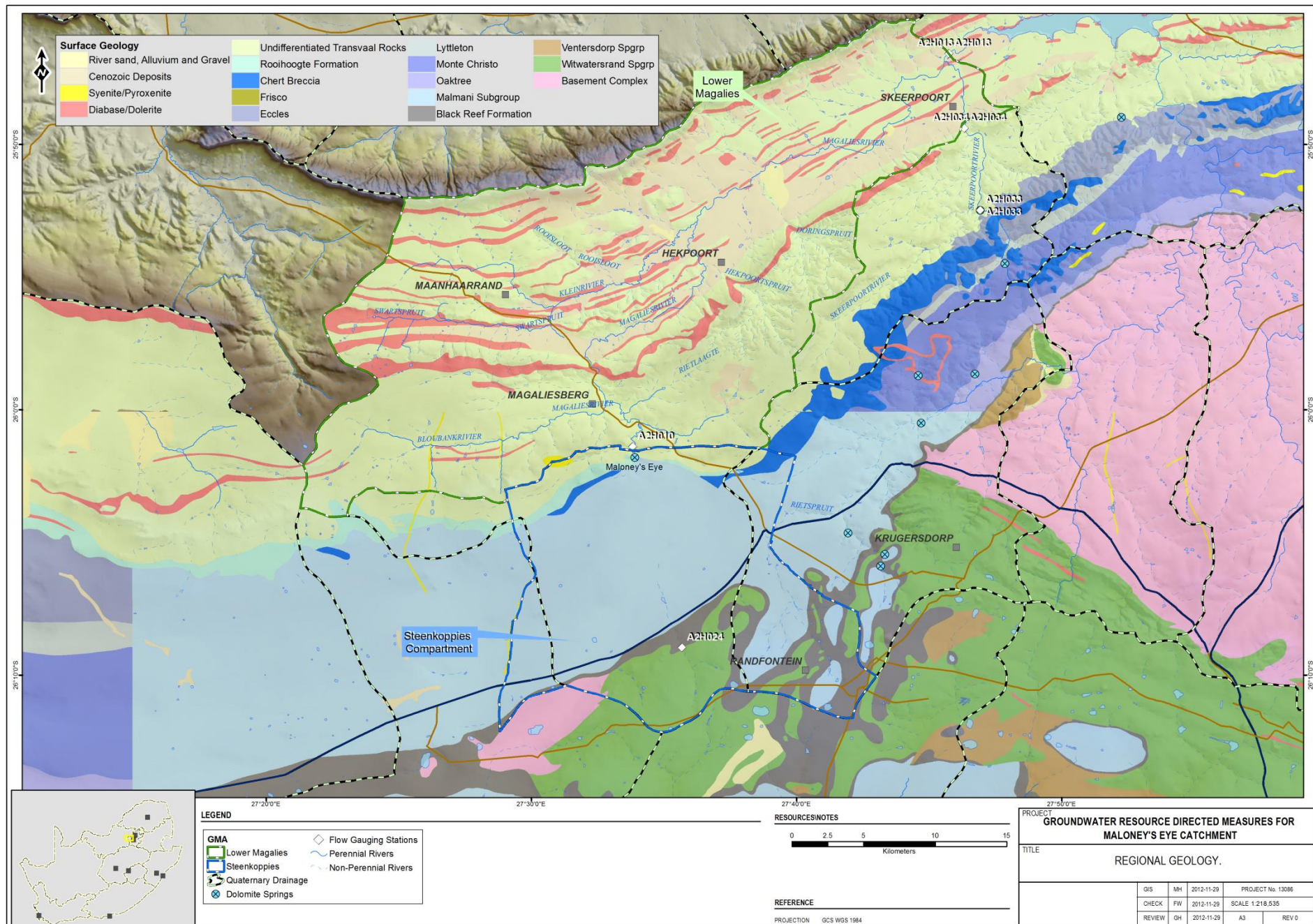
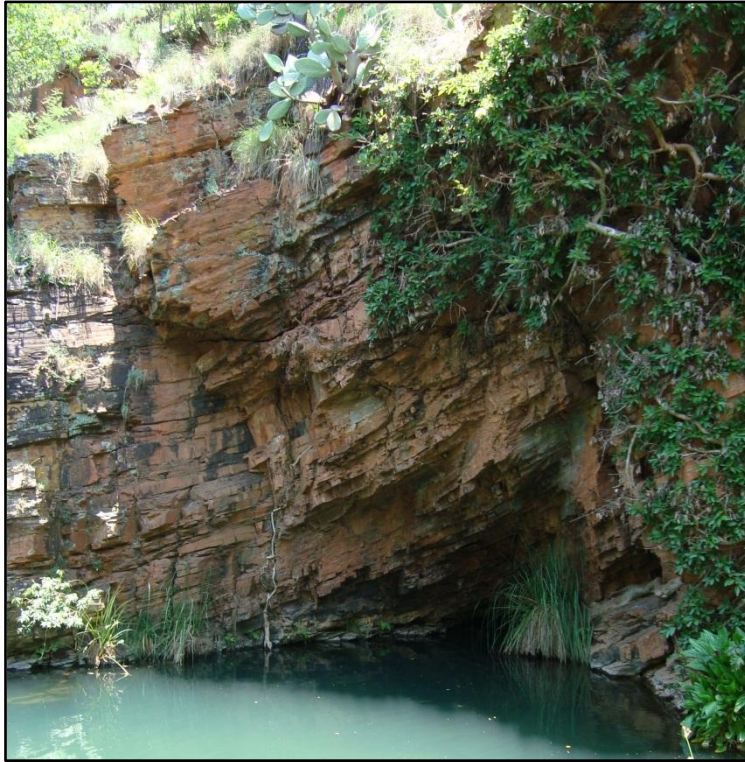


Figure 3-5. Geology of the study area.



**Photo 2. Pretoria Group outcrop downstream of the Maloney’s Eye (Photo; Martin Holland).**

#### 3.4.1 Karstification

The present karst forms and geomorphology have been created by the interplay of ancient and recent erosion cycles on lithologies that have undergone many episodes of deformation. The dolomite is frequently concealed under a thick blanket of residual material that is derived from recent dolomite dissolution and the weathering of older karst regoliths.

#### 3.4.2 Dykes and lineaments

A number of intrusive dykes occur in the area, subdividing the dolomite into compartments and smaller sub-units. The magnetic nature of the dykes makes aeromagnetic data ideal for mapping these features. The total magnetic field (TMF) map together with interpreted linear anomalies is presented in Figure 3-6. These linear anomalies interpreted as dykes’ forms the basis for the delineation of compartments and groundwater management and hydrogeological response units.

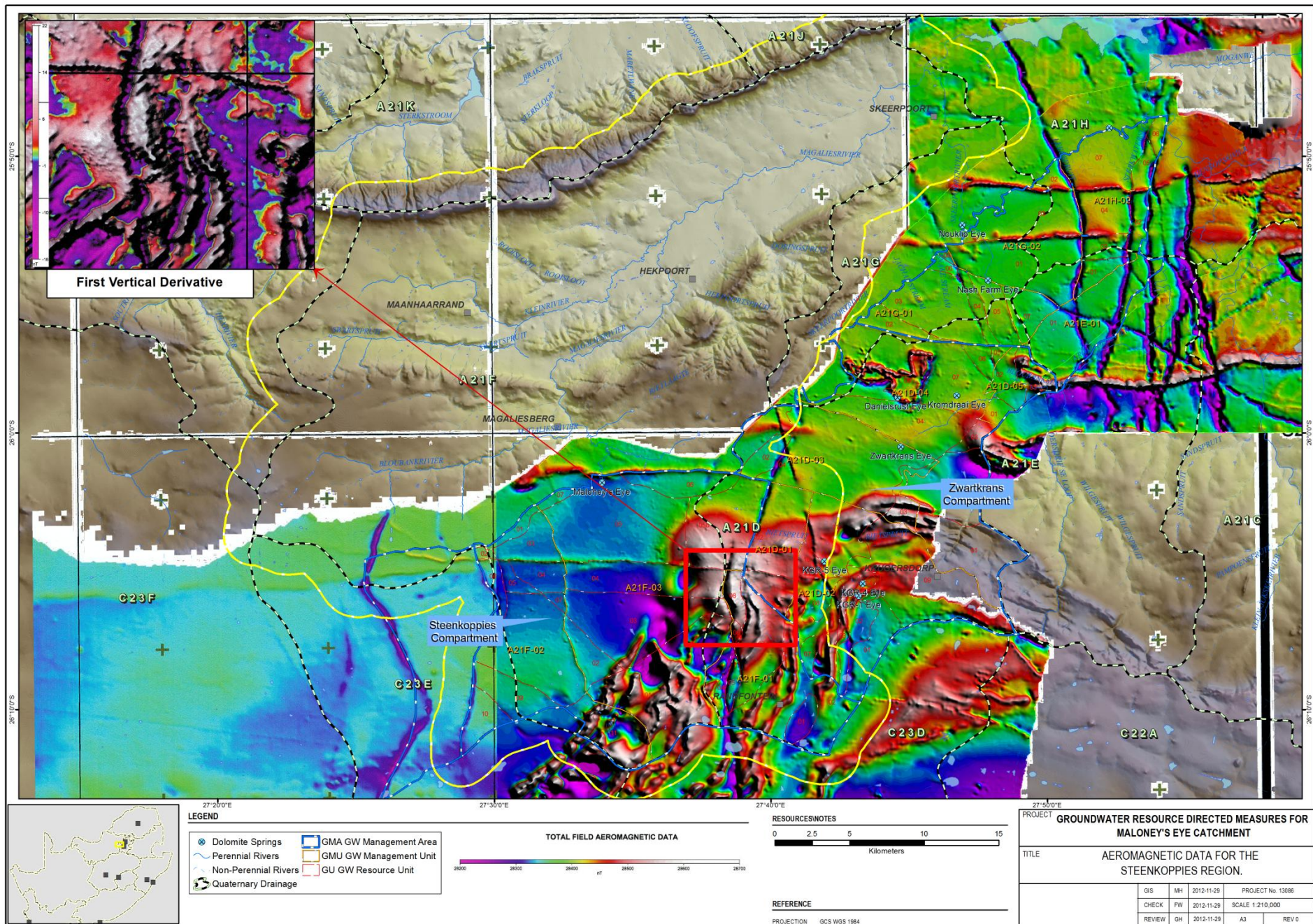


Figure 3-6. Aeromagnetic data for the study area.

## 4 Hydrogeological setting

The data gathered during the desk study and data evaluation phase of the study has been used to develop a hydrogeological conceptual model for the area, which forms the basis for the numerical modelling. In a typical hydrogeological setting groundwater flow and aquifer development are closely linked to the geology and structural geology of an area. There is no reason to believe that the area under investigation will not conform to this assumption and therefore the surface geology as depicted in Figure 3-5 **Error! Reference source not found.** forms the basis on which the conceptual hydrogeological model is based spatially. The nature and distribution of the geological units, and possibly geological structures and dykes control the hydrogeology of the study area.

The aquifer(s) underlying the study area consist(s) mainly of hard rock aquifers associated with the Witwatersrand Supergroup (quartzite), the Ventersdorp Supergroup (Lava), Chuniespoort Group (dolomite) and the Pretoria Group (quartzite and shale) and Karoo Sequence (Ecca Group) sandstone and shale. Post-Karoo dolerite dykes and diabase dykes traverses the study area to divide the dolomite into “compartments”. Historical aquifer test results obtained for these dolomitic “compartments” revealed that very large transmissivities and storativities are associated with the Steenkoppies dolomites (especially within the Monte Christo and Eccles Formations) (Bredenkamp et al., 1986). The dolomites are therefore capable to hold and transmit vast quantities of groundwater.

The overlying Pretoria group reveals very low primary permeabilities and signifies weakly developed secondary permeabilities along faults and fractures. Once the dolomite is exploited excessively it is expected that the Pretoria Group will contribute groundwater to the dolomite (Kuhn, 1989). The hydraulic connection between the dolomites and the underlying Witwatersrand and Basement rocks is considered poor due to the low permeability values of these rocks. Drilling and aquifer testing results obtained elsewhere have indicated that the quartzite and lava formations are very low yielding and very low in permeability (calculated transmissivity values vary between  $10^{-2}m^2/d$  and  $10^{-1}m^2/d$  as found on the MMC Krugersdorp and the Doornkop TSF Sites to the south of the study area. Karstified dolomites in contrast have orders of magnitude higher permeability and transmissivity values in the order  $1-20 \times 10^3 m^2/d$  are not uncommon. Drilling in the area also indicated to a weathered profile down to 35-60m and fractured to 140m below surface. The permeability in the dolomitic aquifer is largely the result of extensive weathering and karstification (leaching) of the dolomite. The weathered part of the dolomite underlain with fractures and fissures is highly heterogeneous. These karst aquifers are often characterised by a dual or triple porosity, comprising of solutional voids, fractures and the rock matrix (intergranular pores). While the fractures and the rock matrix provides most of the storage potential (low permeability), the conduits act additionally as drains (high permeability).

## 4.1 Aquifers

The aquifers identified in the study area can be summarised as follows:

- Karst aquifer
  - Steenkoppies karst aquifer has exceptional groundwater potential with borehole yields often exceeding 5 l/s. Groundwater generally occurs along fault and shear zones associated with intense deformation resulting in the occurrence of fractures, joints and cavities subsequently enlarged by dissolution processes in the dolomites. Large quantities of groundwater can be stored in these dissolution channels and cavities.
- Fractured aquifers
  - Of the Pretoria Group strata the formations comprising of predominantly quartzite (e.g. Klapperkop quartzites, Daspoort Formation) are regarded as fractured aquifers and owe its groundwater potential largely to fracturing. Expected borehole yields are low to moderate with expected yields ranging from 0.5 to 5 l/s.
  - The fractured aquifers associated with the Witwatersrand Supergroup rocks comprise of the quartzite, shales and conglomerate of the Hospital Hill and Government subgroups. Groundwater potential is generally low however, faulting and fracturing can enhance groundwater storage capacity considerably.
  - The groundwater potential of the Black Reef quartzites is regarded insignificant and in instances where the groundwater flow direction is towards the dolomite (such as the Steenkoppies DC), steep groundwater gradients are expected due to the poorer transmissive properties of the quartzite compared to those of the dolomite (Barnard, 2000).
- Intergranular and fractured aquifers
  - Of the Pretoria Group sediments the shale bearing formations (e.g. Timeball Hill) can be regarded as aquifers that develop weathering zones which are associated with fracturing. Shales are more susceptible to weathering than quartzites or chert, the weathered material providing intergranular space for water accumulation. Borehole yields are typically below 2 l/s.
  - The Basement complex towards the southeast of the Steenkoppies DC comprise of a deeper fractured (i.e. secondary) aquifer overlain by a weathered horizon of variable thickness. The groundwater yield potential is regarded as moderate with yields often exceeding 2 l/s.
- Intergranular alluvial aquifers (limited to the main Magalies River stem)
  - Alluvial sediments along drainage channels form elongated aquifers (so called valley trains) with limited width and depth. Alluvial aquifers are recharged during periods of high stream-flows as well as during the rainfall season. It is an important local major aquifer and borehole yields are seldom less than 5 l/s.

## 4.2 Gravity survey and Dolomite Aquifer Zones

Gravity surveys are effectively used for delineating potential zones of leaching (karstification) and/or infilling by residual debris of cavities in dolomite strata.

This method is based on measuring minute variations in gravity, which relate to differences in the sub-surface distribution of mass of soil or rock. These density variations are usually produced by changes in rock type which are characterised by changes in porosity or grain density changes, varying thicknesses of unconsolidated deposits over bedrock, and solution cavities in dolomite bedrock.

Weathered or leached dolomite has a lower density (1.85 mg/cm<sup>3</sup>) than dolomite bedrock (2.85 mg/cm<sup>3</sup>) and this negative density contrast result in negative residual gravity anomalies. A water saturated cavity has a density of only 1.0 mg/cm<sup>3</sup>. A gravity low anomaly represents low density bedrock and cannot distinguish between leached/weathered dolomite and a cavity.

In the 1980s the Department of Water Affairs and Forestry conducted an gravity survey on a 100m grid spacing, known as the Tarlton gravity survey which covered an area of 90 km<sup>2</sup>. The Tarlton extension surveys in 1985, conducted by Southern Geophysical Exploration, covered large portions of both the Steenkoppies and Zwartkrans Dolomite Compartments at 100 m station intervals along 250 m spaced traverses. The original gravity data from the 1980's was available as Bouguer anomalies (both absolute and relative) in the form of hard copy maps, with labelled data points. During the 2009 Steenkoppies groundwater assessment these map plots were used to collate an electronic Bouguer gravity data set, totalling 9910 data points. (Holland et al, 2009).

As part of this groundwater reserve study the existing gravity survey was augmented by additional gravity surveys (totalling 1067 gravity stations) towards the Maloney's Eye to assist in delineating major karst features within the highly heterogeneous dolomite aquifer. In addition to this regional DWA gravity survey data (2058 gravity stations) was located in hard copy format and captured electronically to compile a comprehensive data set for the Steenkoppies DC totalling 13,035 gravity stations.

The relative Bouguer gravity data was formerly compiled by DWAF applying standard gravity data corrections. A density factor of 2.67 g/cc was used for the surface elevation corrections. The relative Bouguer gravity data was tied into the national network and a constant value of -148.19 mgal should be added to obtain absolute gravity values based on the IGSN71 gravity base system.

### *Reduction of Bouguer to residual gravity*

The relative Bouguer gravity data (anomalies) contains information of two gravity components:

- A regional gravity field reflecting deep density variations of the underlying bedrock, and

- Residual gravity anomalies reflecting near surface (<200 m) and local density differences as a result of leached dolomites or overburden (e.g. Karoo sediments)

In the study of dolomite aquifers we need to remove the deep seated gravity effects. This is done by compiling a regular/smooth regional gravity field and subtracting it from the Bouguer data in such a way that zero gravity values represent solid dolomite at surface. The subsequent compiled residual gravity data represents only near surface density variations. Zero or slightly positive gravity values represent outcropping dolomite bedrock, and negative values leached dolomite zones. Pending the configuration of the underlying leached dolomite and fill material of paleo-channels a 40 to 50 meter factor per -1mgal residual gravity value can be used to estimate the depth to bedrock.

The relative Bouguer anomaly map together with the regional gravity field, surface elevation and residual gravity map are presented as a mosaic in Appendix A.

A conceptual bedrock elevation map was compiled by multiplying negative residual gravity values by 50 to obtain a bedrock depth estimate. A zero depth to bedrock value was used for positive residual values. These depth estimates were subtracted from the surface altitudes at each gravity station to obtain conceptual bedrock elevations. The bedrock elevations were combined with water level data to delineate zones of karst dolomite below the water table. The saturated leached dolomite zones represent highly transmissive aquifers and groundwater conduits feeding the Maloney's Eye (Figure 4-1).

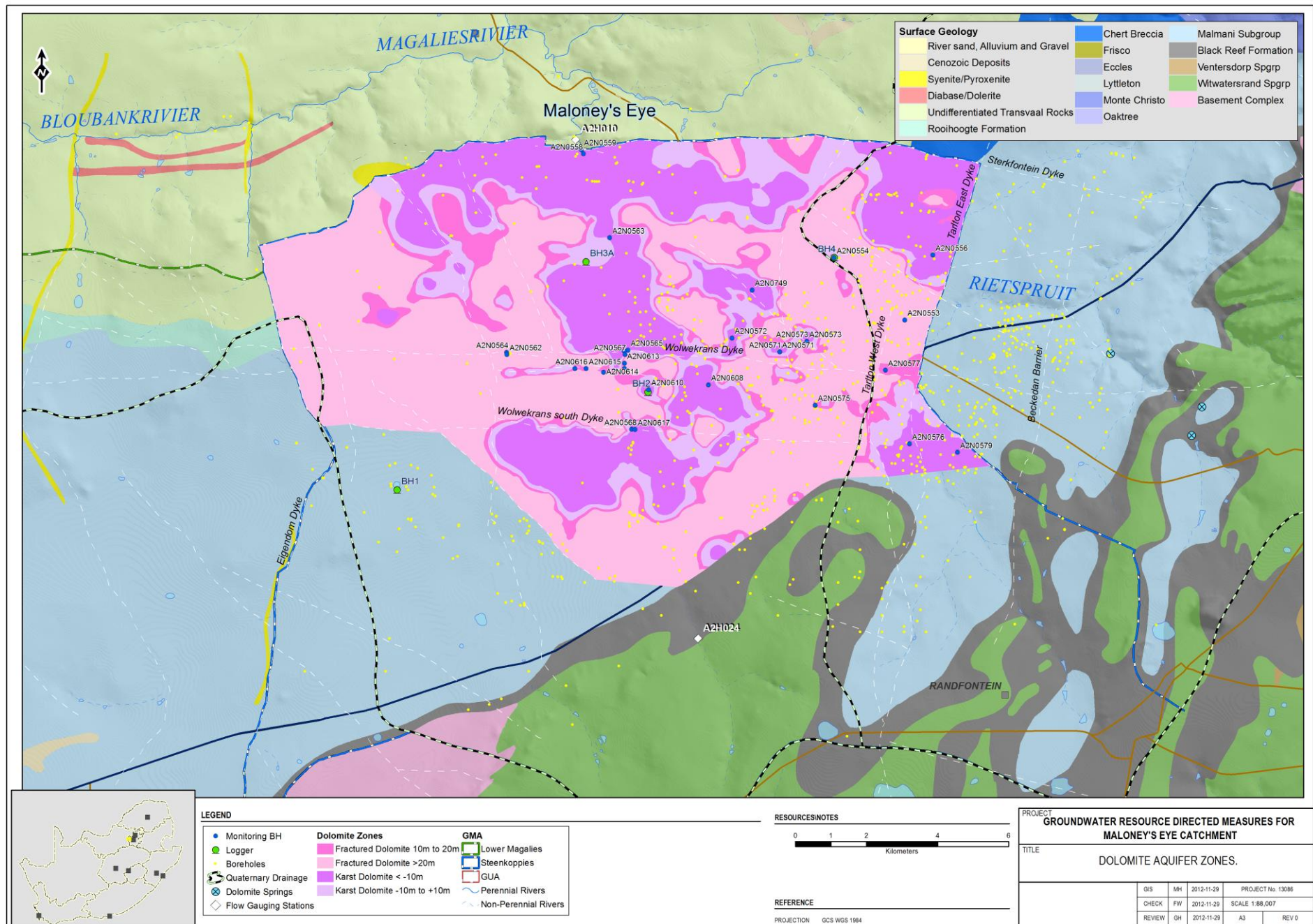


Figure 4-1. Delineated dolomite aquifer zones based on the interpreted gravity survey data .

### 4.3 Delineation of groundwater units

The first step in the RDM Classification process as outlined under Chapter 3 of the NWA, is the demarcation of the units of analysis (UA), of which is to be classified, a Reserve assessment undertaken and Resource Quality Objectives (RQOs) set.

#### ***Groundwater Units of Analysis (GUA)***

By definition, quaternary catchments are used as the primary delineation of water resource units in RDM assessments. When delineating a groundwater unit, it is worth remembering that a Class, Reserve and RQOs have to be set for each unit; linkages with other components have to be considered; and each unit will have to be managed. As a result setting resource unit boundaries will probably be an iterative process requiring modification until all component requirements have been accommodated. However, due to the nature of groundwater the resource units are often completely different to that of surface water systems. In addition many GRDM assessments precede surface water RDM assessments. In this regard the delineation of groundwater is preliminary and provides valuable input towards the final classification of the integrated water resource. Accordingly to align more closely to the gazette approach for classifying water resources, the term Groundwater Unit of Analysis (GUA) will be used. Similarly to Groundwater Resource Units (GRUs) the GUAs are decided based on geohydrological, hydrological and ecological criteria, while taking into consideration the significance of groundwater (Dennis, 2011). In most instances, it is assumed that the GUA is the quaternary catchment; however, this might not always be the case. In this case a second level of delineation is based on aquifer (e.g. primary aquifer, secondary aquifer, dolomitic aquifer). Though these aquifers may be linked, the nature of subsurface flow in them is so different that they warrant obvious delineation. In some cases, it may be desirable to regroup these aquifer types into a single GUA. This is considered and motivated during the third level of delineation. Although no formal methodology exists for delineating groundwater resource units beyond the second level of delineation, three criteria namely physical, management and functional, could be used as the basis for delineation.

It is a well-known fact that dolomites are effectively divided into “compartments” by dolerite or syenite dykes (Vegter, 1986). Other features such as brecciated faults and topographic divides may also form compartment boundaries. Groundwater conditions in each compartment may be relatively uniform and the water table surface fairly flat, whilst large differences in water level between compartments may be found. Flow does occur between compartments, but usually on a smaller scale compared to flow within a compartment. Compartment boundaries are also often associated with spring lines and seepages, as groundwater is forced to the surface (such as the Maloney’s Eye). Based on the high level delineation of the groundwater resources within the larger A21F quaternary catchment and the Steenkoppies DC, 14 groundwater management units (GMU) have been delineated (Figure 4-2). The Steenkoppies DC (the Maloney’s Eye catchment) consists of 6 GUA’s and represents an area of 332 km<sup>2</sup>, while the lower Magalies river catchment have been delineated in 8 GUA’s totalling an area of 740 km<sup>2</sup>.

#### 4.4 Groundwater recharge

Groundwater recharge are normally also orders of magnitudes higher than on other hardrock aquifers as a result of the large permeability that the dolomites exhibit. The groundwater system within the study area is largely recharged via infiltration of precipitation. It is thought that most of the groundwater recharge occurring within the study area discharges via the Maloney's Eye (Photo 3) and discharge to the base of river drainage systems in the lower Magalies area.



**Photo 3. Maloney's Eye (Photo; Martin Holland).**

The annual recharge is estimated to be in the order of 2-4 % of MAP across the hard rock aquifers. Across the dolomitic areas the recharge is significantly higher (in the order of 84 mm/a or 12% of MAP) and in line with the much larger permeabilities for these aquifers.

Recharge to the aquifer is from precipitation during the rainy season. Monitoring data have indicated that there is a good relationship between the CRD and the water level fluctuations in the dolomitic aquifer which indicates to dynamic recharge occurring. A good correlation between the flow of the Maloneys Eye and the CRD was also obtained indicating that rainfall is the driver behind the groundwater system's dynamics (Figure 4-3). The rainfall/recharge relationship is discussed in more detail under the transient calibration (in the appended model report [Appendix B](#)).

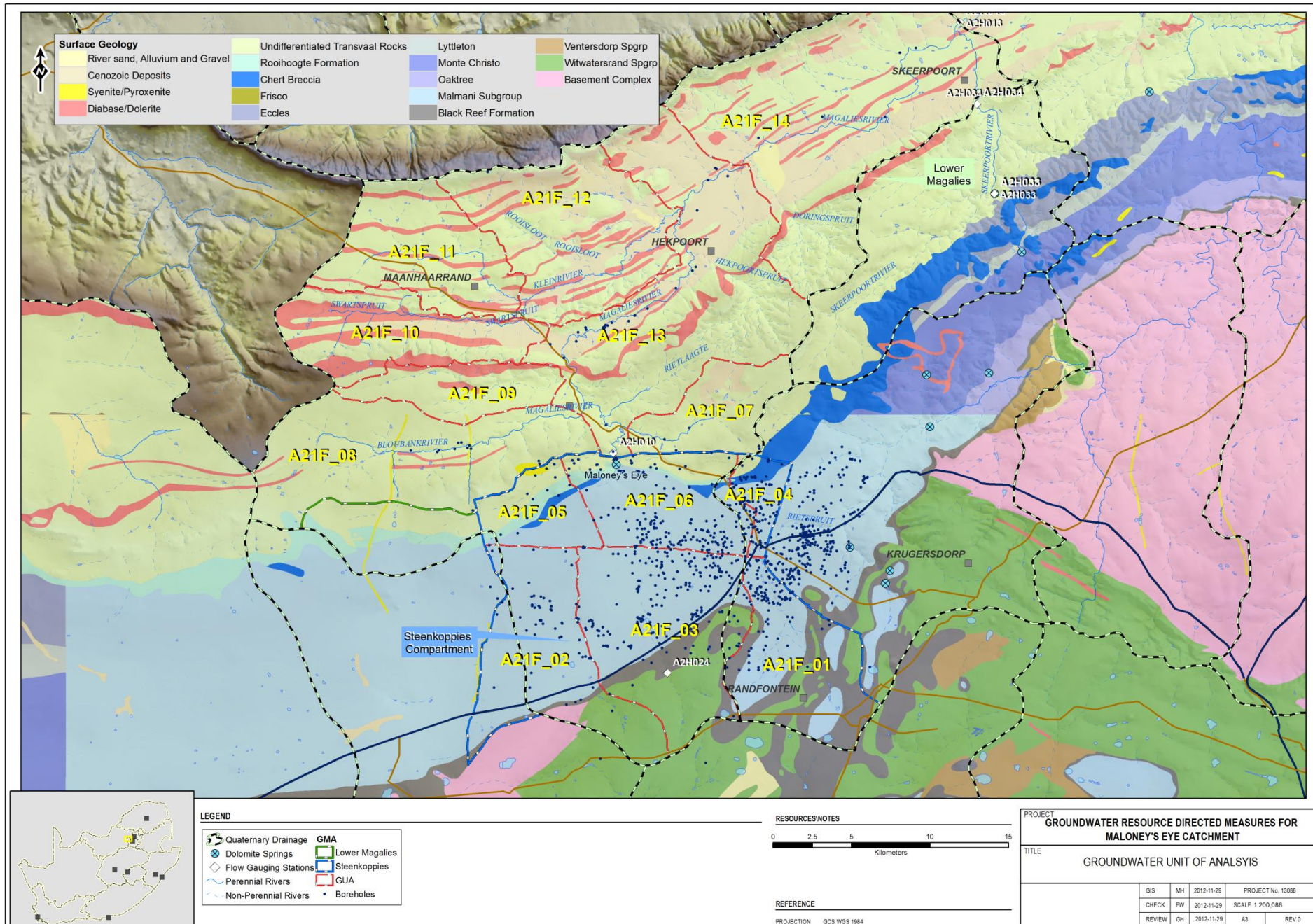


Figure 4-2. Delineated groundwater unit of analysis.

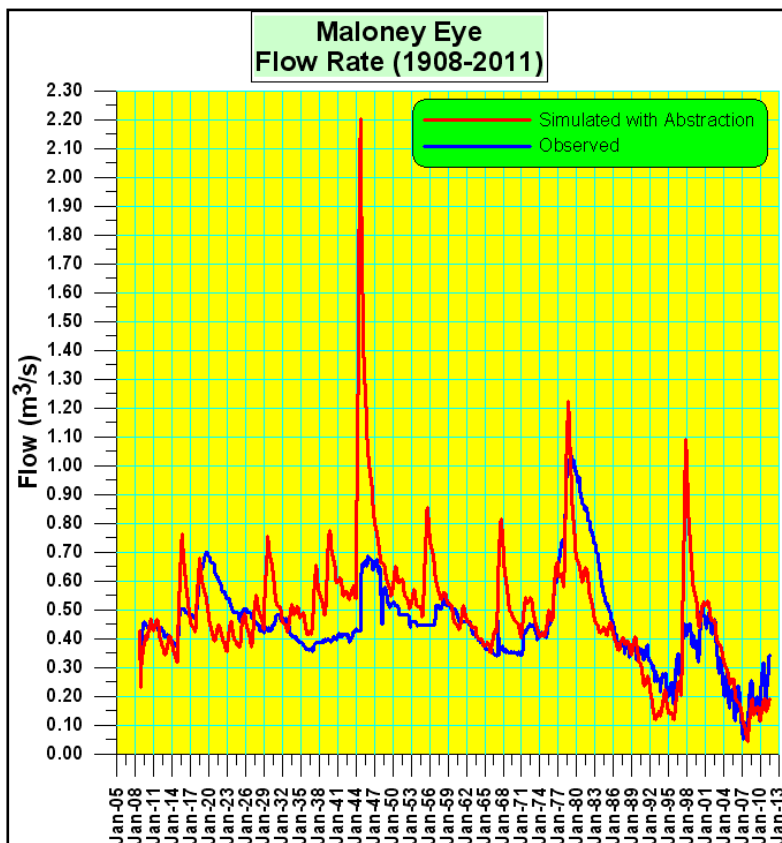


Figure 4-3. Simulated vs. observed flow rates at Maloney Eye using an exponential relationship between rainfall and recharge.

Based upon previous work conducted on dolomitic terrain it was concluded that an exponential relationship between recharge and rainfall produced acceptable results. Such a relationship would entail that moderate recharge rates would occur at moderate rainfall events. However once rainfall gets higher the rate of recharge would increase disproportionately with rainfall. This would make sense since the soil moisture deficits would already have been overcome with large monthly rainfalls effecting saturated conditions in the soil zone close to surface causing development of maximum hydraulic conductivity values maximizing vertical infiltration rates into the aquifers.

In the case of the Steenkoppies DC an additional (external) source of recharge was identified – since the hardrock area to the south the Steenkoppies DC has a well-developed steeper surface gradient it is thought that this would provide additional run-off to cause “flash flood” conditions onto the Steenkoppies DC. The Steenkoppies DC is riddled with sinkholes which would then provide the pathway for run-off water to recharge into the underground. Taking the above concepts into consideration, numerous simulation runs were performed over the historical period (2008-2011) and a recharge to rainfall relationship developed to represent the flow at the Maloney Eye on a trial-and error approach.

Final calibration parameters include the following:

- A nine month moving average was applied on the recharge series.
- Recharge (mm/month) was derived as a fraction of rainfall.
  - The recharge fraction was obtained from the following formula:

$$\text{Recharge Fraction} = 1.0 * [0.025e^{(0.011 * \text{Rainfall})}]$$

The obtained recharge to rainfall relationship is depicted in Figure 4-4 or the three recharge zones modelled. The spatial zoning used for the assignment of recharge is as follows:

- Zone 1 (Steenkoppies DC)
- Zone 2 (Witwatersrand rocks to the south of Steenkoppies DC.
- Zone 3 (Pretoria Group to the north of the Steenkoppies DC.

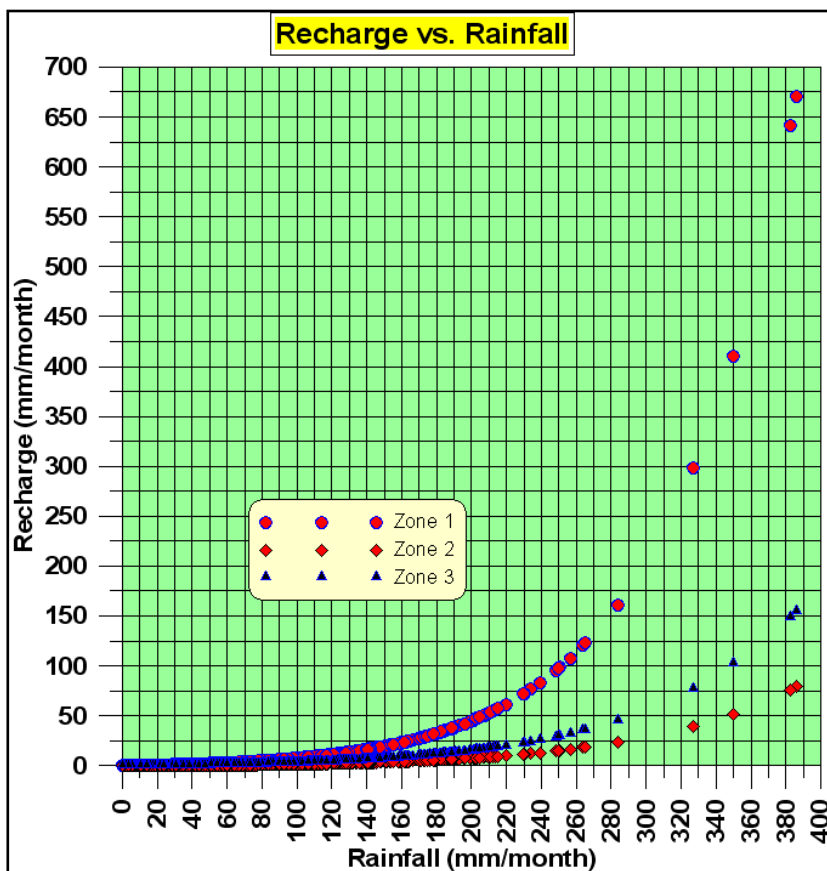


Figure 4-4. Recharge vs. Rainfall relationship obtained for all three zones modelled (linear Y-axis).

A breakdown of the statistics of the recharge rates for each of the GMU's are shown in Table 4.1

**Table 4.1. General statistics associated with the recharge on the GUA's in the study area.**

| Groundwater Management Area | GUA                   | Area (Km <sup>2</sup> ) | N     | Recharge (m <sup>3</sup> /d) |                              | Std. Dev                     |
|-----------------------------|-----------------------|-------------------------|-------|------------------------------|------------------------------|------------------------------|
|                             |                       |                         |       | Mean                         | Median                       |                              |
| Steenkoppies DC             | A21F-01               | 62.6                    | 1,233 | 8,837                        | 6,472                        | 9,967                        |
|                             | A21F-02               | 78.5                    |       | 15,531                       | 11,031                       | 18,799                       |
|                             | A21F-03               | 94.5                    |       | 16,817                       | 12,085                       | 19,874                       |
|                             | A21F-04               | 12.9                    |       | 3,251                        | 2,276                        | 4,045                        |
|                             | A21F-05               | 27.5                    |       | 6,802                        | 4,763                        | 8,459                        |
|                             | A21F-06               | 56.2                    |       | 13,754                       | 9,630                        | 17,113                       |
|                             | Total                 | 332                     |       | 64,992                       | 46,257                       | 78,257                       |
|                             | In Mm <sup>3</sup> /a |                         |       |                              | <b>23,7 Mm<sup>3</sup>/a</b> | <b>16.9 Mm<sup>3</sup>/a</b> |
| Lower Magalies River        | A21F-07               | 35.9                    | 1,233 | 1,775                        | 1,358                        | 1,713                        |
|                             | A21F-08               | 106.6                   |       | 4,844                        | 3,723                        | 4,602                        |
|                             | A21F-09               | 33.5                    |       | 1,580                        | 1,223                        | 1,475                        |
|                             | A21F-10               | 61.4                    |       | 2,760                        | 2,137                        | 2,577                        |
|                             | A21F-11               | 66.4                    |       | 2,928                        | 226                          | 2,733                        |
|                             | A21F-12               | 95.1                    |       | 4,187                        | 3,241                        | 3,908                        |
|                             | A21F-13               | 156.9                   |       | 7,010                        | 5,423                        | 6,564                        |
|                             | A21F-14               | 183.7                   |       | 7,818                        | 6,052                        | 7,298                        |
|                             | Total                 | 740                     |       | 32,902                       | 23,383                       | 30,870                       |
|                             | In Mm <sup>3</sup> /a |                         |       |                              | <b>12 Mm<sup>3</sup>/a</b>   | <b>8.3 Mm<sup>3</sup>/a</b>  |

#### 4.5 Groundwater levels

A total of 379 water levels were collated from historical reports and recent hydrocensus data. A summary of water level data within each groundwater unit is provided in Table 4.2.

**Table 4.2. Summary of water levels for each groundwater unit.**

| Groundwater Management Area | GUA     | Area (Km <sup>2</sup> ) | N   | Water levels (m below surface) |       |      | Water elevation (mamsl) |        |        |
|-----------------------------|---------|-------------------------|-----|--------------------------------|-------|------|-------------------------|--------|--------|
|                             |         |                         |     | min                            | max   | mean | min                     | max    | mean   |
| <b>Steenkoppies DC</b>      | A21F-01 | 62.6                    | 45  | 1.9                            | 75.6  | 32.4 | 1505.0                  | 1655.5 | 1565.9 |
|                             | A21F-02 | 78.5                    | 37  | 11.3                           | 107.9 | 63.1 | 1494.2                  | 1603.1 | 1523.7 |
|                             | A21F-03 | 94.5                    | 77  | 6.1                            | 98.2  | 64.8 | 1483.0                  | 1707.2 | 1508.9 |
|                             | A21F-04 | 12.9                    | 50  | 3.5                            | 84.9  | 54.5 | 1483.9                  | 1576.6 | 1514.1 |
|                             | A21F-05 | 27.5                    | 15  | 7.2                            | 126.5 | 52.8 | 1479.8                  | 1580.1 | 1536.1 |
|                             | A21F-06 | 56.2                    | 107 | 3.8                            | 178.9 | 63.4 | 1437.5                  | 1571.3 | 1498.2 |
| <b>Lower Magalies River</b> | A21F-07 | 35.9                    | 5   | 2.0                            | 80.0  | 21.5 | 1422.5                  | 1526.2 | 1490.1 |
|                             | A21F-08 | 106.6                   | 10  | 2.6                            | 90.0  | 16.4 | 1440.8                  | 1617.1 | 1515.6 |
|                             | A21F-09 | 33.5                    | -   |                                |       |      |                         |        |        |
|                             | A21F-10 | 61.4                    | -   |                                |       |      |                         |        |        |
|                             | A21F-11 | 66.4                    | -   |                                |       |      |                         |        |        |
|                             | A21F-12 | 95.1                    | 1   | 8.8                            |       |      | 1718.2                  |        |        |
|                             | A21F-13 | 156.9                   | 27  | 0.1                            | 22.6  | 6.5  | 1243.6                  | 1444.6 | 1333.8 |
|                             | A21F-14 | 183.7                   | 5   | 1.7                            | 7.2   | 3.5  | 1184.7                  | 1239.9 | 1212.8 |

Although DWAF has monitored groundwater levels since 1985, only 14 of the 37 stations within the Steenkoppies DC are still active. A number have of monitoring boreholes has ceased only in the last couple of years. A summary of the long-term monitoring stations are provided in Table 4.3 and illustrated spatially in Figure 4-1.

Table 4.3. Summary of long-term water level monitoring data for the Steenkoppies DC.

| UNIT    | BH_ID   | Commence |        | Last WL | WL   | Measured WL data |      |      |      |         | Ceased |
|---------|---------|----------|--------|---------|------|------------------|------|------|------|---------|--------|
|         |         | Date     | WL     | Date    | WL   | Count            | Min  | Mean | Max  | Min-Max |        |
| A21F-01 | A2N0576 | Mar-85   | 50.3   | May-11  | 42.2 | 251              | 30.2 | 46.7 | 61.9 | 31.7    |        |
|         | A2N0579 | Mar-85   | 26.0   | Feb-11  | 27.6 | 140              | 23.1 | 27.0 | 31.7 | 8.6     |        |
| A21F-03 | A2N0562 | Nov-85   | 80.0   | Jun-10  | 78.2 |                  |      |      |      |         | Yes*   |
|         | A2N0566 | Sep-85   | 58.2   | May-11  | 59.0 | 194              | 56.9 | 59.0 | 61.7 | 4.8     |        |
|         | A2N0567 | Sep-85   | 58.0   | May-07  | 58.5 | 236              | 57.8 | 59.3 | 61.8 | 4.0     |        |
|         | A2N0568 | Aug-85   | 62.0   | Feb-07  | 65.6 |                  |      |      |      |         | Yes    |
|         | A2N0569 | Mar-85   | 75.8   | Jun-01  | 75.0 |                  |      |      |      |         | Yes    |
|         | A2N0570 | Mar-85   |        | Apr-02  | 71.3 |                  |      |      |      |         | Yes    |
|         | A2N0574 | Mar-85   |        | Mar-11  | 75.0 |                  |      |      |      |         | Yes*   |
|         | A2N0575 | Mar-85   | 89.5   | Mar-05  | 86.2 |                  |      |      |      |         | Yes    |
|         | A2N0608 | May-87   | 70.6   | Nov-10  | 72.5 | 166              | 67.1 | 71.0 | 72.6 | 5.5     | Yes    |
|         | A2N0609 | Apr-87   | 71.8   | Mar-10  | 73.6 |                  |      |      |      |         | Yes*   |
|         | A2N0610 | Apr-87   | 60.1   | May-11  | 60.7 | 217              | 58.8 | 60.8 | 26.8 | 4.0     |        |
|         | A2N0611 | Jun-87   |        | Aug-01  | 55.4 |                  |      |      |      |         | Yes    |
|         | A2N0612 | Jul-87   | 55.1   | May-11  | 55.8 | 182              | 54.2 | 56.0 | 58.3 | 4.2     |        |
|         | A2N0613 | Jun-87   |        | Jul-96  | 53.4 |                  |      |      |      |         | Yes    |
|         | A2N0614 | May-87   | 67.5   | May-11  | 68.4 | 196              | 64.9 | 68.0 | 70.4 | 5.5     |        |
|         | A2N0615 | Jul-87   | 68.3   | Feb-11  | 70.1 | 181              | 64.9 | 69.0 | 71.2 | 6.3     |        |
|         | A2N0616 | Jun-87   | 68.6   | May-11  | 69.3 | 163              | 65.7 | 69.1 | 71.3 | 5.5     |        |
|         | A2N0617 | Apr-87   |        | Mar-10  | 63.6 |                  |      |      |      |         | Yes*   |
| A2N0618 | Jun-87  | 74.3     | Nov-99 | 74.7    |      |                  |      |      |      | Yes     |        |
| A2N0619 | Jul-87  | 74.5     | Jun-01 | 74.0    |      |                  |      |      |      | Yes     |        |
| A21F-04 | A2N0553 | Apr-85   | 66.4   | May-11  | 60.0 | 257              | 58.3 | 64.3 | 71.3 | 13.0    |        |
|         | A2N0555 | Mar-85   | 50.6   | Jan-90  | 56.1 |                  |      |      |      |         | Yes    |
|         | A2N0556 | Mar-85   | 42.3   | Apr-11  | 46.3 | 242              | 44.0 | 49.4 | 58.3 | 14.3    |        |
|         | A2N0577 | Apr-85   | 61.1   | May-10  | 57.7 |                  |      |      |      |         | Yes*   |
| A21F-05 | A2N0564 | Nov-85   | 75.9   | Nov-09  | 79.6 |                  |      |      |      |         | Yes*   |
| A21F-06 | A2N0554 | Mar-85   | 81.0   | May-11  | 3.5# |                  |      |      |      |         |        |
|         | A2N0558 | May-85   | 8.7    | Sep-10  | 8.6  | 614              | 7.3  | 8.6  | 9.7  | 2.4     |        |
|         | A2N0559 | May-85   | 8.1    | Sep-10  | 7.8  | 245              | 5.8  | 7.9  | 8.9  | 3.1     |        |
|         | A2N0560 | Dec-85   | 58.8   | Jun-93  | 59.7 |                  |      |      |      |         | Yes*   |
|         | A2N0561 | Nov-85   |        | Mar-10  | 63.6 |                  |      |      |      |         | Yes*   |
|         | A2N0563 | Aug-85   | 100.6  | Aug-09  | 65.3 |                  |      |      |      |         | Yes*   |
|         | A2N0565 | Sep-85   | 54.0   | Aug-01  | 57.5 |                  |      |      |      |         | Yes    |
|         | A2N0571 | Apr-85   | 72.2   | Nov-10  | 72.9 | 115              | 71.4 | 73.5 | 80.3 | 8.8     | Yes*   |
|         | A2N0572 | Mar-85   | 68.8   | May-11  | 69.5 | 257              | 67.9 | 69.6 | 71.2 | 3.2     |        |
| A2N0573 | Apr-85  | 72.2     | Nov-99 | 72.5    |      |                  |      |      |      | Yes     |        |

\* - Data missing

# - Faulty levels

#### 4.5.1 Groundwater hydrographs

The distribution of monitoring boreholes is presented in Figure 4-1. Generally, groundwater levels fluctuate according to the characteristics of precipitation events (i.e. amount, duration, and intensity) and various hydrogeological variables (i.e. topography, thickness of the unsaturated zone, and matrix composition of saturated and unsaturated materials). Groundwater level fluctuations from the observed hydrographs vary between 2.4 and 9 m. a well-identified seasonal water-level fluctuation is observed for most monitoring boreholes. Except for the mid to late 1980s the CRD (a short moving term average of 9 months and a long term moving average of 60 months) fits the observed water level trends reasonably well, especially towards the edges of the Steenkoppies DC (e.g. A21F-04) (Figure 4-5).

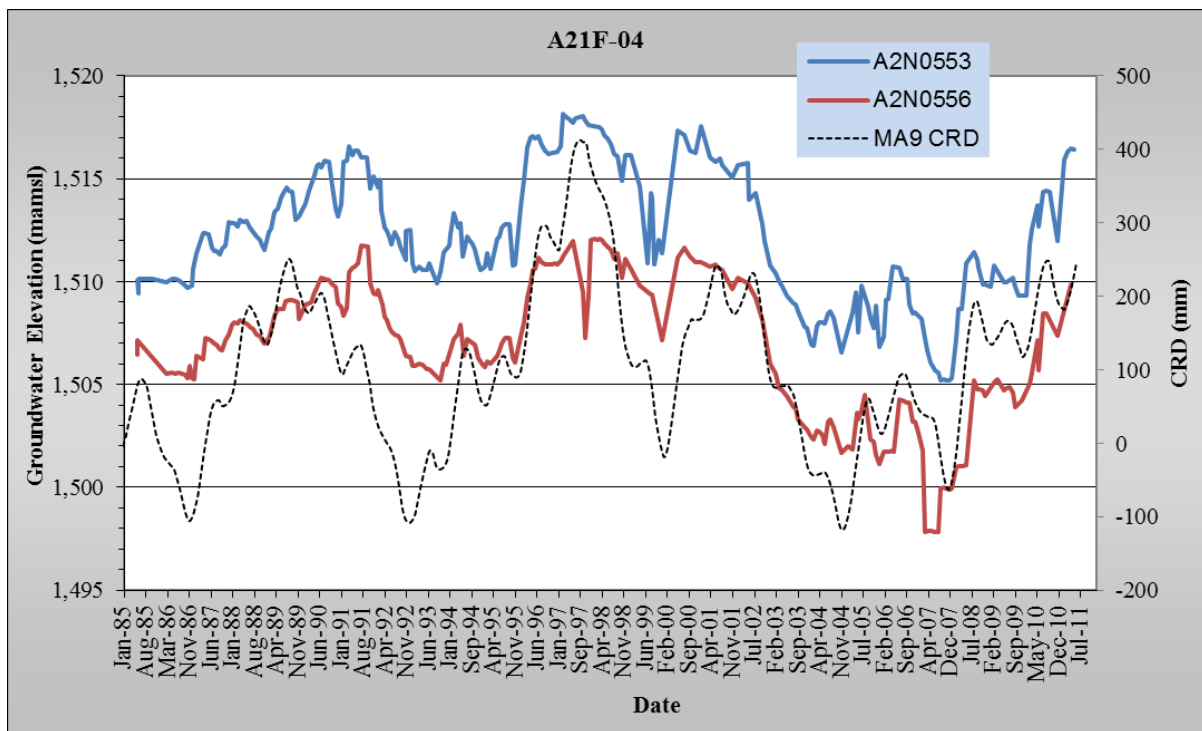


Figure 4-5. Borehole water levels within GUA A21F-04.

Towards the centre of the Steenkoppies DC south of the Wolwekrans dyke most monitoring boreholes shows similar trends (Figure 4-6 and Figure 4-7) in GUA A21F-03. The CRD graph seems to have a similar trend compared to the water levels towards the end of the 1990 and continuous throughout the last two decades.

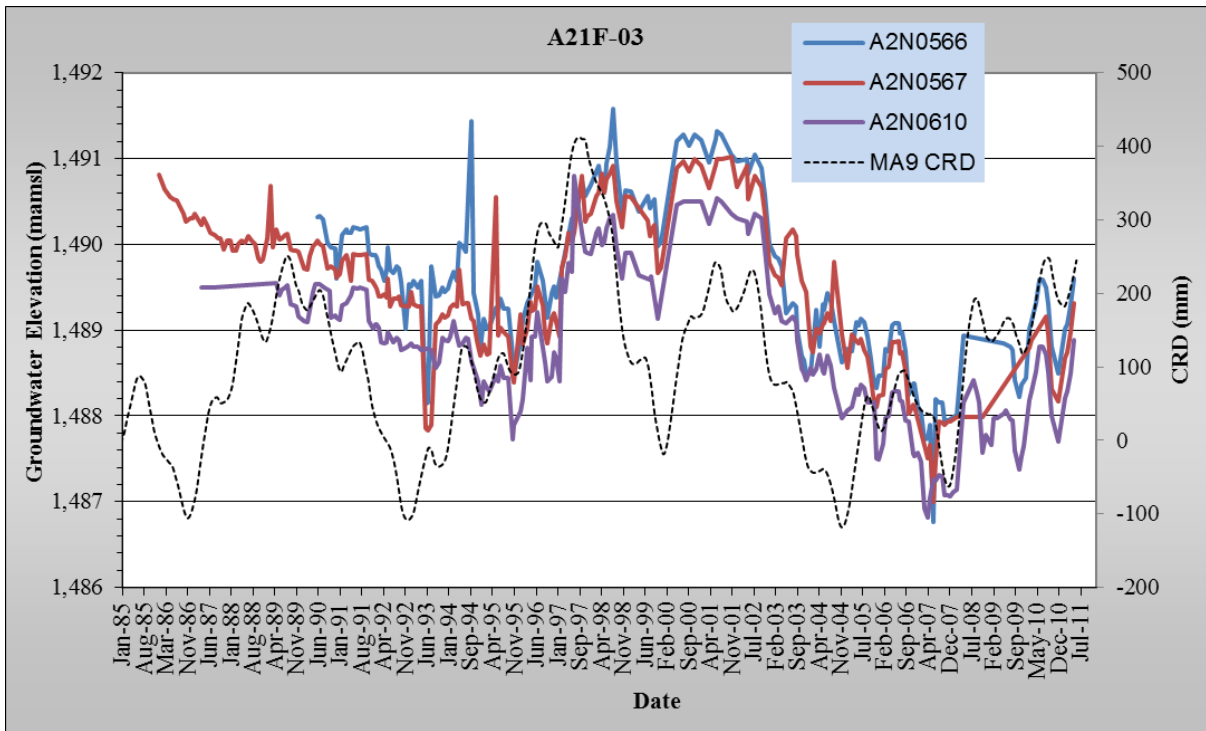


Figure 4-6. Borehole water levels within GUA A21F-03.

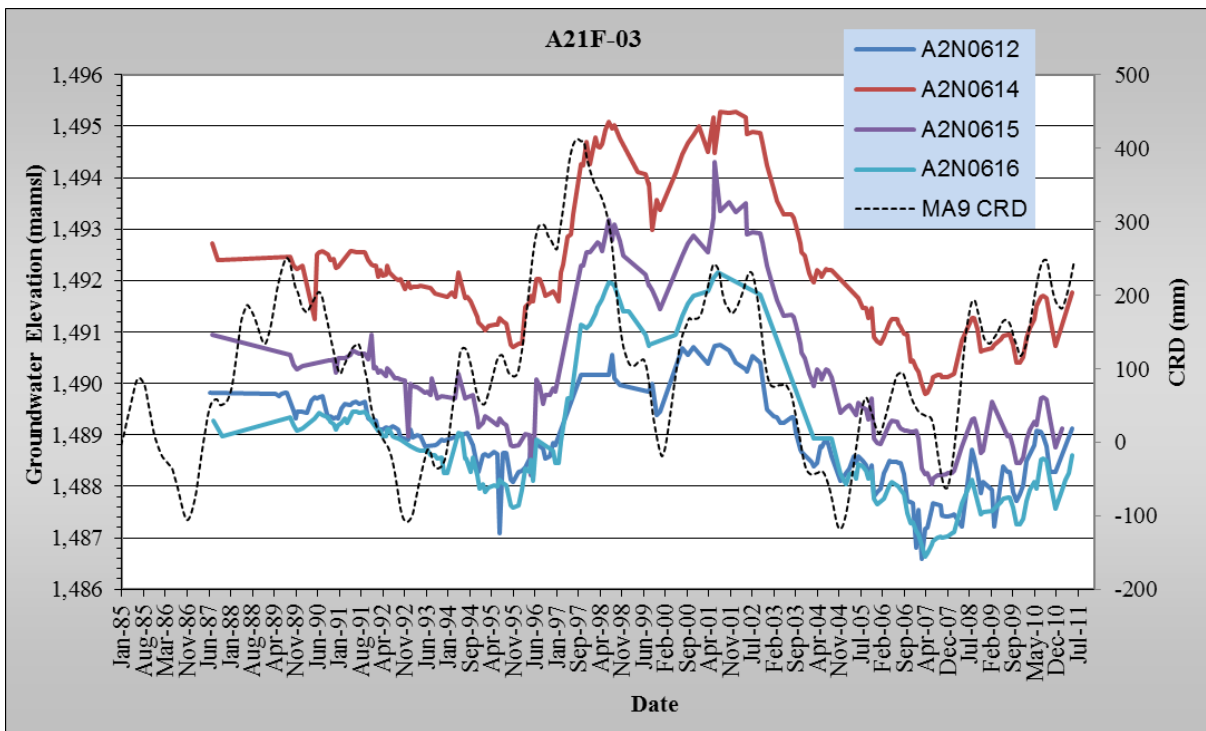


Figure 4-7. Borehole water levels within GUA A21F-03.

Water levels within the upper Rietspruit catchment (A21F-01) shows similar trends and an increase in water levels is observed in the last 4 years (Figure 4-8).

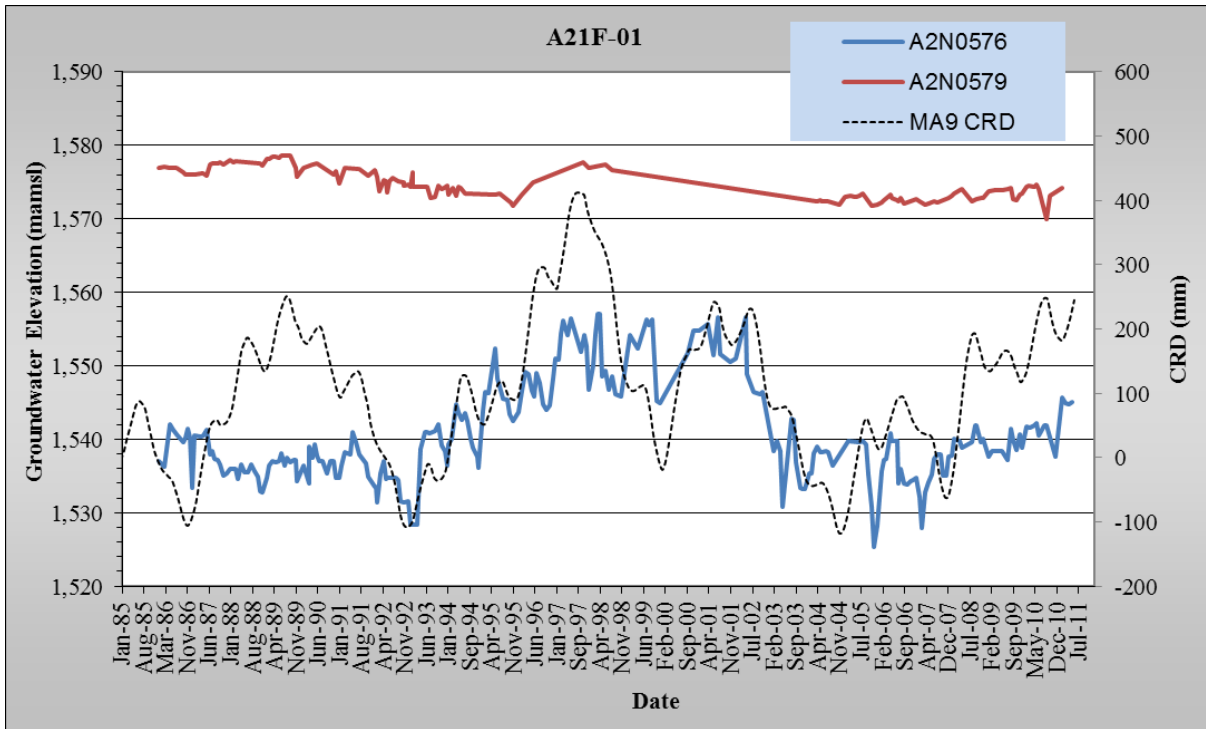


Figure 4-8. Borehole water levels within GUA A21F-01.

Towards the Maloney's Eye the main discharging groundwater unit, a more subtle water level fluctuation is observed (Figure 4-9).

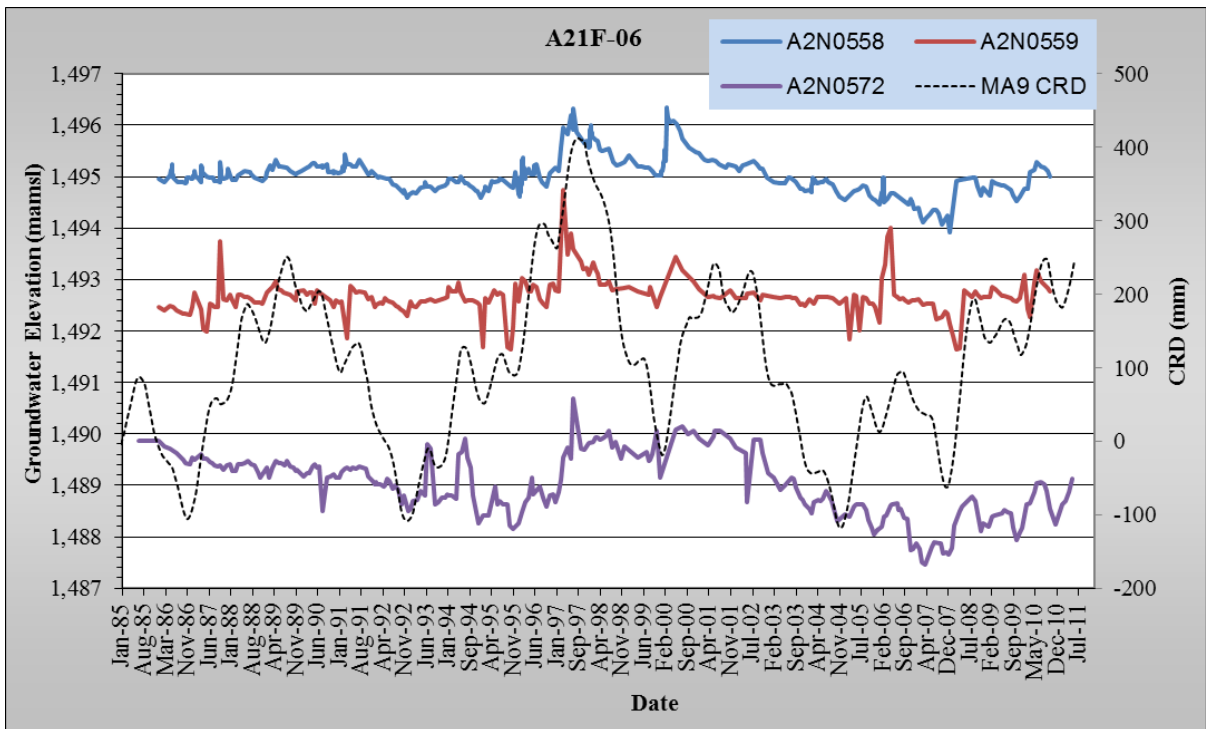


Figure 4-9. Borehole water levels within GUA A21F-06.

#### 4.5.2 Borehole loggers (SAMA)

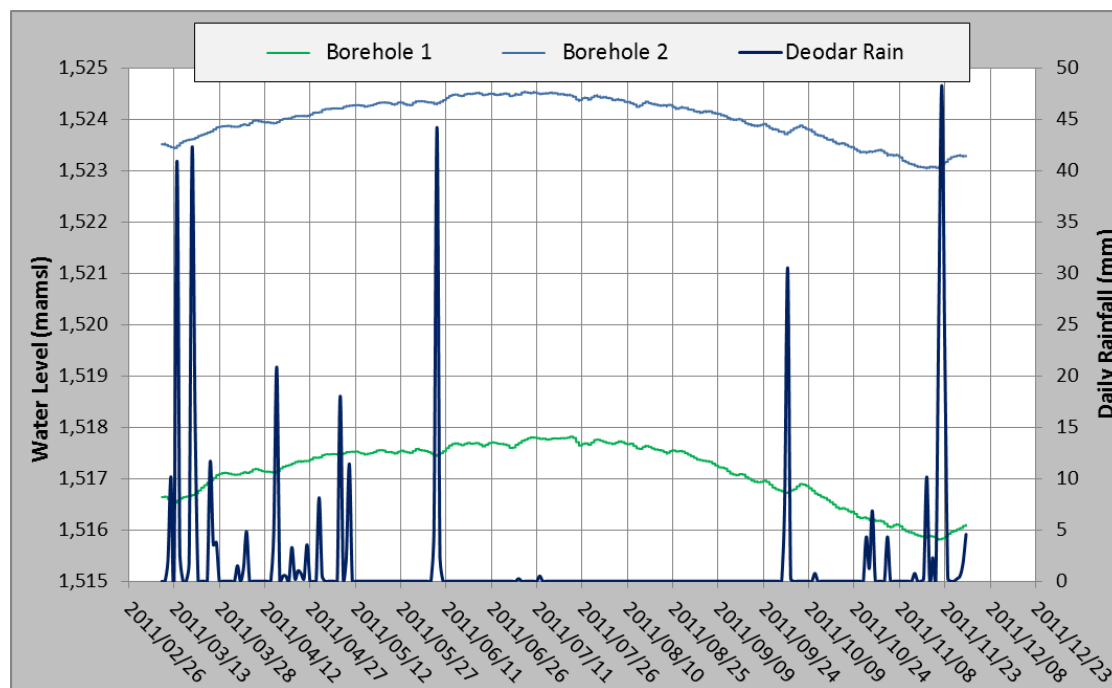
The distribution of the four borehole loggers installed in March 2011 by the Steenkoppies Aquifer Management Association (SAMA) is illustrated in Figure 4-1 and listed in Table 4.4.

**Table 4.4. Borehole logger summary.**

| ID         | Latitude | Longitude | Serial nr. data | WL (m below surface) | Comment      |
|------------|----------|-----------|-----------------|----------------------|--------------|
| Borehole 1 | 27.51854 | -26.1118  | 1053462         | 73.36                | Josie        |
| Borehole 2 | 27.58199 | -26.0871  | 1053500         | 61.48                | A2N0610      |
| Borehole 3 | 27.56632 | -26.0541  | 1054695         | 79.59                | Roberto      |
| Borehole 4 | 27.62917 | -26.053   | 1054706         | 3.94#                | A2N0554      |
| Barro 5    | 27.62917 | -26.053   | 1054705         |                      | Barro Logger |

# - Water levels are 70 m different compared to historical data.

All boreholes show similar trends with a distinct recharge period during the summer period (which constitutes up to 80% of the annual precipitation) and a recession period that starts more or less in July (Figure 4-10 and Figure 4-11).



**Figure 4-10. Continuous water level measurements for Borehole 1 and 2.**

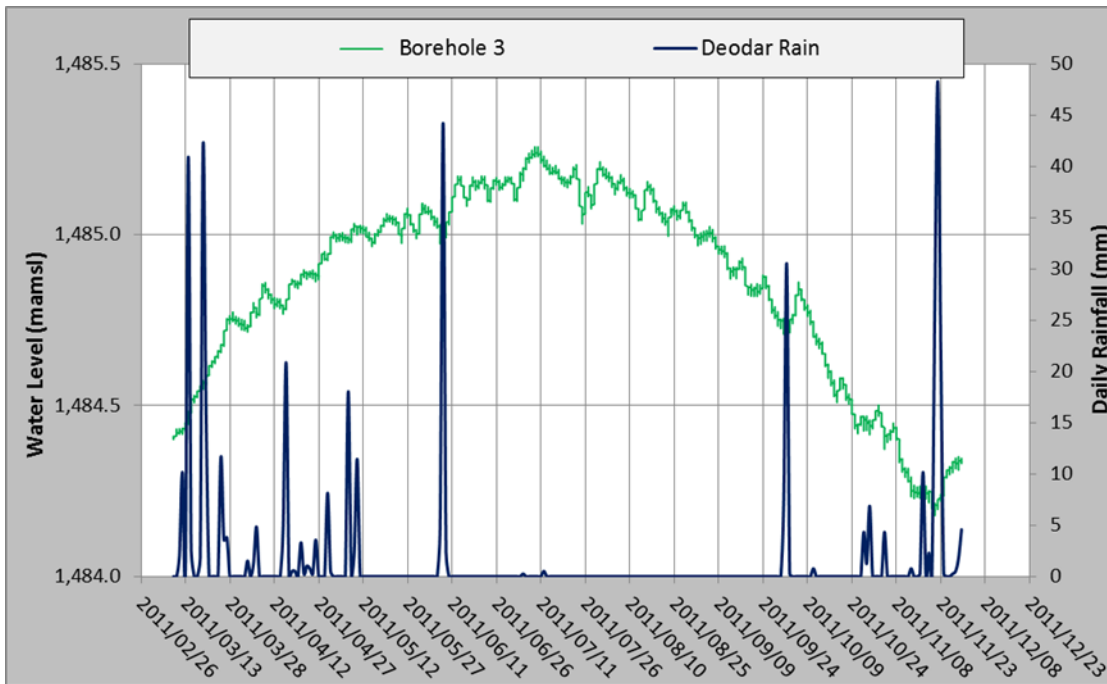


Figure 4-11. Continuous water level measurements for Borehole 3.

#### 4.5.3 Groundwater gradient

Groundwater flow is from areas of higher piezometric elevations to lower elevations. Groundwater flow directions mimic the surface topography. This is confirmed by the fair correlations between groundwater levels and the surface topography (see Figure 4-12).

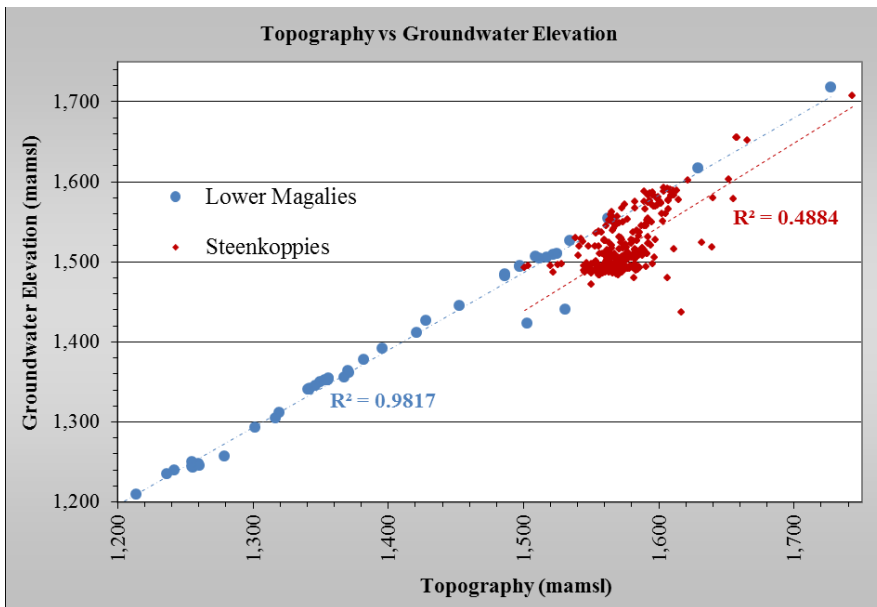


Figure 4-12. Plot of groundwater levels vs. topography.

From this figure it is evident that the dolomite water levels vs. topography are following a different relationship than that of the hard rock water levels vs. topography. Dolomite water levels are in general deeper than that of the hard rock aquifers. The dolomite water levels however still mimic the topography to a large extent. Figure 4-13 show the simulated steady state groundwater elevations and groundwater flow directions for the steady state calibration. There are insufficient boreholes with groundwater level data to create an observed water table map for the entire model area. Therefore, the model output has been evaluated in a qualitative manner by observing the shape of the water table contours near known hydraulic boundaries, divides and drainages. The calibrated model water table is similar to what would be expected at the location of internal watersheds divides and major drainages. The simulated water levels are discussed in more detail under the steady state calibration (in the appended model report Appendix B).

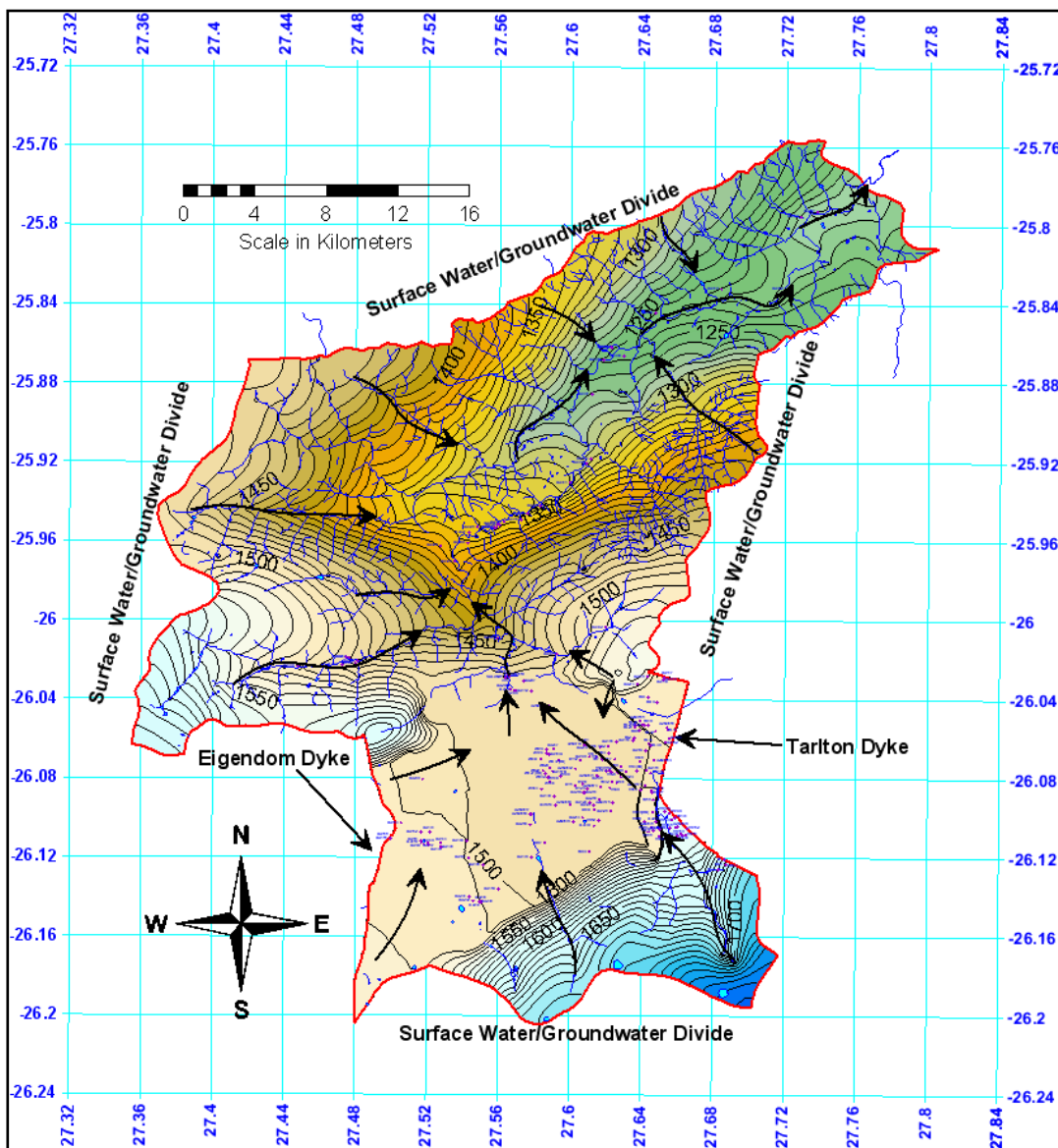


Figure 4-13. Simulated water levels based on the steady state mode calibration

## **4.6 Surface-groundwater interaction (Baseflow)**

### **4.6.1 Magalies River baseflow**

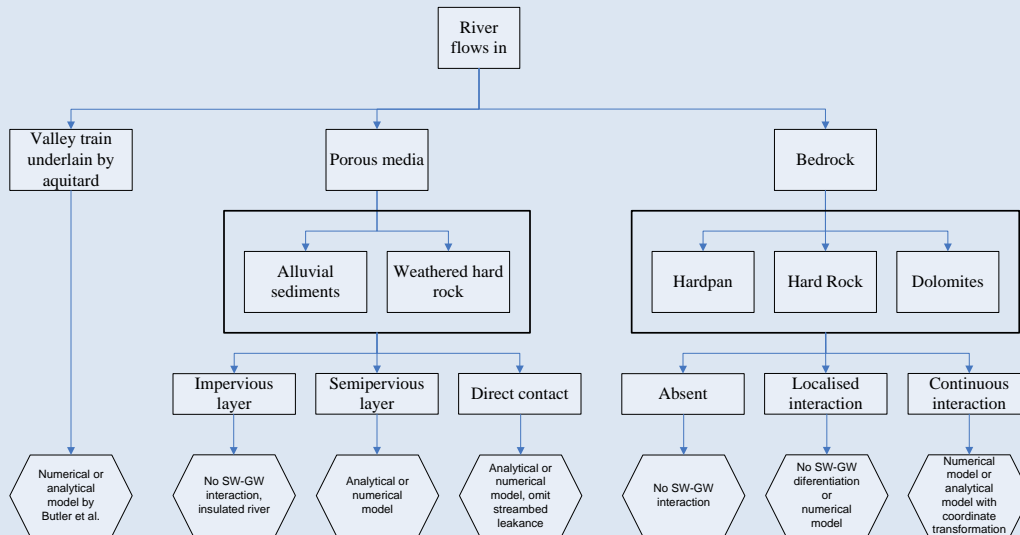
The first step in establishing the potential for surface-groundwater interaction is to classify the river system along its drainage course. The following characteristics of rivers can be regarded important for the understanding of surface-groundwater interaction:

- Gradient between piezometric surface and river stage (either side).
- Occurrence and characterisation of clogging layers in the riverbed.
- Hydrogeological characteristics of the strata along the river stretch.
- Regional groundwater gradients.

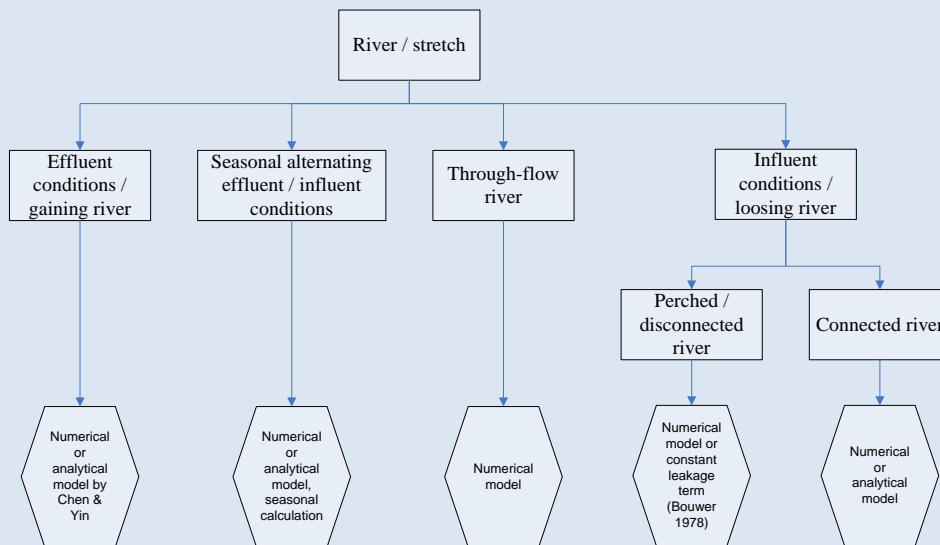
The only flow gauging stations potentially available for the recession analysis is the Maloney's Eye (A2H010) and Scheerpoort (A2H013). In the absence of flow hydrographs within the study area the focus will be largely on the classification and characterisation of groundwater-surface interaction with the main aim to provide insight into the significance of the flow of the Maloney's Eye on the Magalies River catchment.

**Groundwater – surface water interaction - classification.**

A simple two tier classification scheme, with a geological classification of the river-aquifer setting followed by a brief hydraulic classification of the interaction is proposed. The primary geological classification differentiates between rivers flowing in porous media or over bedrock. A third class accounts for valley trains underlain by aquitards, a typical situation of an alluvial aquifer along a river stretch underlain by impervious hard rocks.



Following the conceptualisation of the geological setting the type of surface-groundwater interaction is classified based on the prevailing hydraulic gradient.



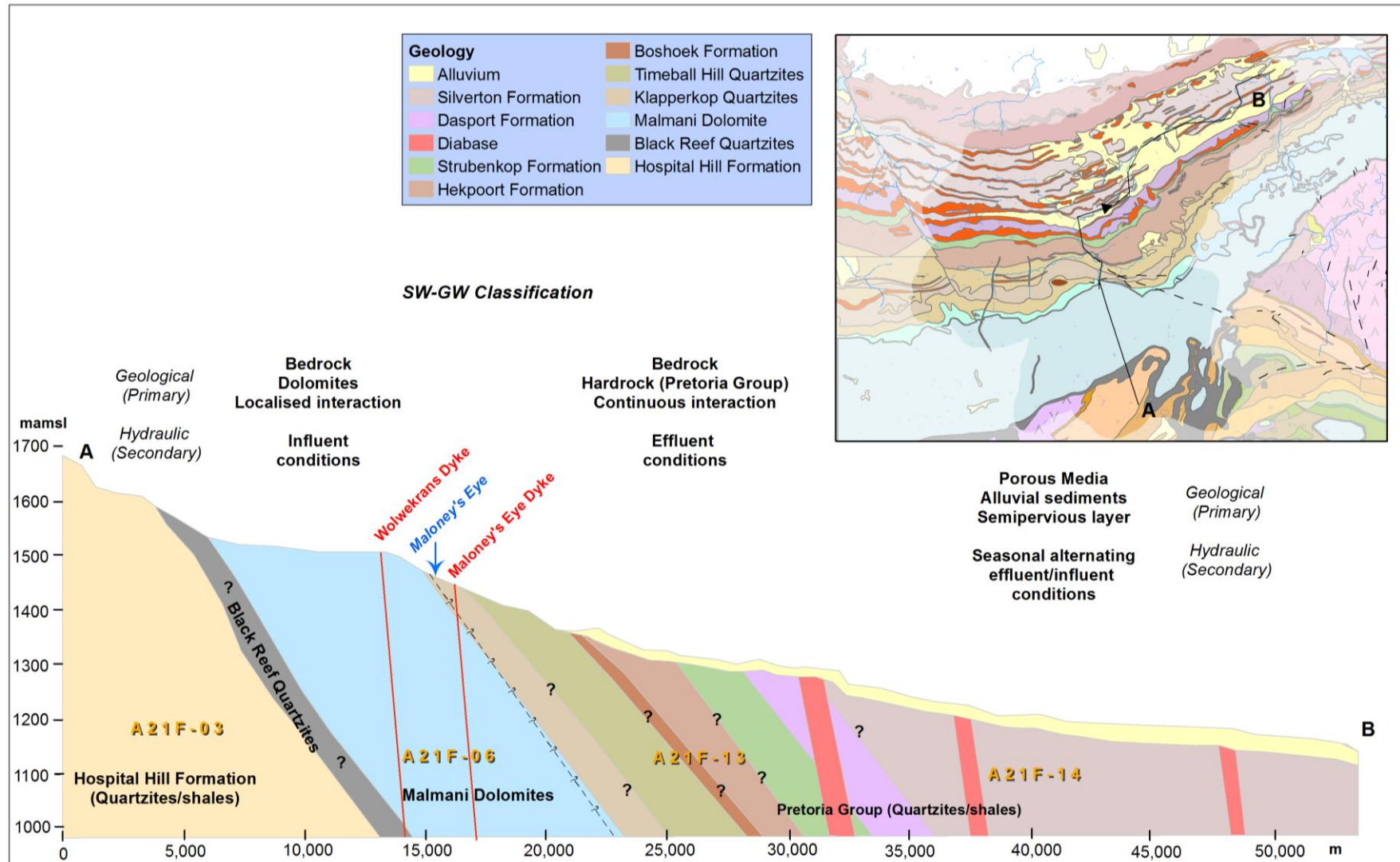


Figure 4-14. Simplified geological profile of the Magalies River.

The Steenkoppies DC is devoid of surface drainages and run-off from the quartzites to the south disappears relatively quickly in swallow holes or sinking streams, which is characteristic of karst terrains. Groundwater contributes to baseflow throughout the lower Magalies River catchment via sub surface seepage and springs. The Magaliesberg Range and the southern belt of Pretoria Group strata are important areas for groundwater recharge and baseflow. In the upper reaches of the Magalies River (north of the Maloney’s Eye) a higher gradient towards the River course is observed and where the alluvium is lacking the surface-groundwater exchange is directly from the regional aquifer to the River. Towards the lower reaches the Magalies River floodplain is characterised by a relatively thick alluvial layer. The surface-groundwater exchange between the alluvium and the Magalies River occurs on a far shorter time scale in comparison to the interaction between the regional and alluvial aquifers. Regional aquifers of the lower catchment show marginal gradients towards the River course and exchange water with the river only indirectly via the alluvial deposits. Surface-groundwater interaction is strongly seasonal as both effluent / influent conditions can occur depending on the recharge period of the alluvium.

Based on the GRA II dataset the Magalies River catchment (A21F) has a high probability of baseflow. A summary of the GRA II baseflow values is provided in Table 4.5.

**Table 4.5. Groundwater contribution estimates.**

| Quat | Area (Km <sup>2</sup> ) | MAR (Mm <sup>3</sup> ) | Recharge (Mm <sup>3</sup> ) | Hughes (Mm <sup>3</sup> ) | Shultz (Mm <sup>3</sup> ) | Pitmann (Mm <sup>3</sup> ) | GRA II (Mm <sup>3</sup> ) | Maint. Low flow (Mm <sup>3</sup> ) | PESC |
|------|-------------------------|------------------------|-----------------------------|---------------------------|---------------------------|----------------------------|---------------------------|------------------------------------|------|
| A21F | 1001                    | 25.1                   | 33.9                        | 12.1                      | 7.3                       | 10.2                       | 3.9                       | 3.1                                | C    |

\* - In-stream Flow Requirements (IFR) maintenance low flows based on the SPATSIM (Spatial and Time Series Information Modelling) flow modelling system (Hughes and Palmer, 2005) simulation runs conducted during this study (based on the PESC).

**Baseflow**

The Schultz figures consider baseflow to be the portion of ground water which contributes to the low flow of streams originating from the regional groundwater body. The Herold and Hughes interpretations of baseflow include all water which migrates through the subsurface, hence it includes seepage from perched aquifers, high lying springs and interflow. A large fraction of this water never reaches the regional aquifer, hence does not form part of the available groundwater resources. To determine potential baseflow depletion resulting from pumping the regional aquifer the Schultz figures may be more appropriate. To determine the potential impact of induced recharge, or to set subsurface water contribution to the ecological reserve, the Hughes figure and the hydrograph separation method provides a volumetric total of available baseflow.

Various methods with which the groundwater contribution to baseflow can be calculated are provided in Parsons and Wentzel (2007) and Dennis (2011). One of the most common methods to determine baseflow is through river hydrograph separation and recession curves. A river hydrograph consists of

three components: direct runoff, interflow through the unsaturated zone and groundwater discharge from the saturated zone (Figure 4-15). Although a baseflow is often defined as the groundwater discharge from the saturated zone in classic hydrogeological textbooks the word baseflow is generally known to many hydrologists as delayed flow components (mainly groundwater), as opposed to a quick, direct runoff. Thus, baseflow itself is not indicative of origins of water sources. The baseflow is normally separated by removing the direct runoff from a hydrograph. As a result, such a baseflow component may still contain some interflow component.

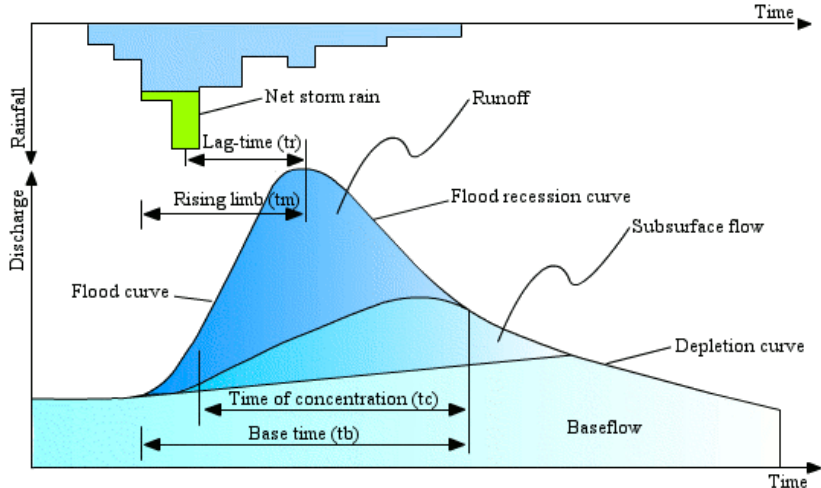


Figure 4-15. The flood hydrograph from a rainfall event (Musy, 2001).

A baseflow separation for the Magalies river downstream gauging station A2H013 for a 31 year period (Jan-1980 to Sep-2011) is illustrated in Figure 4-16 and summarised in Table 4.6. The mean annual baseflow obtained from the separation method is approximately 6.4 Mm<sup>3</sup>/a.

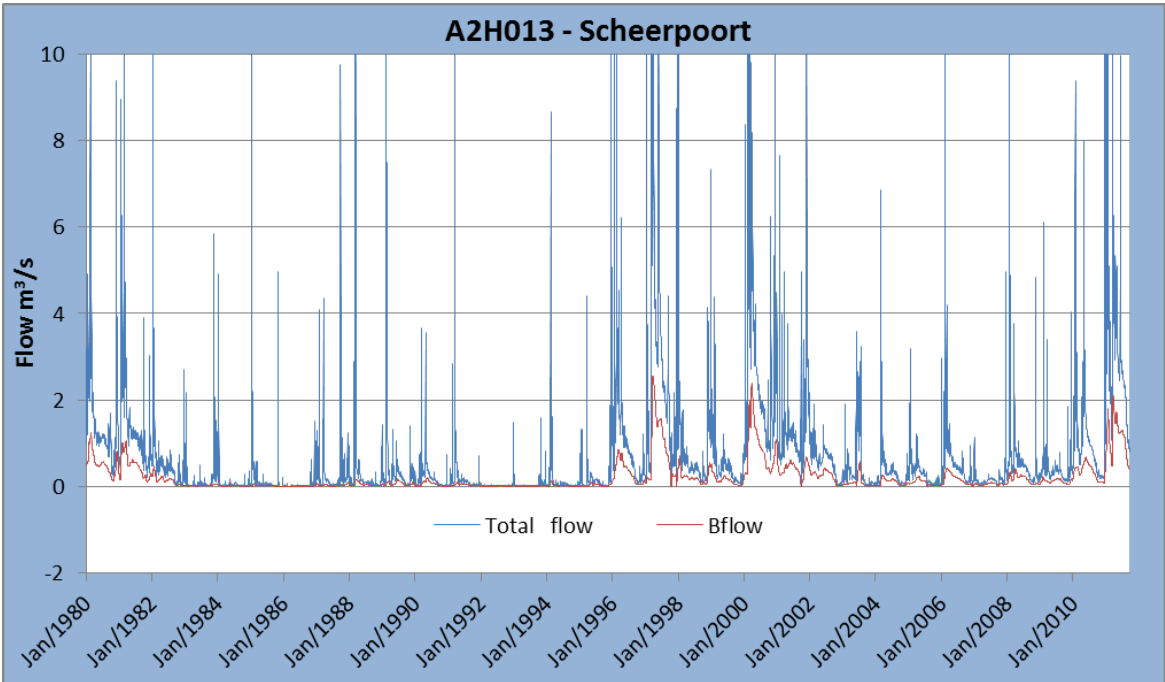


Figure 4-16. Baseflow separation for the Magalies River Scheerpoort station (A2H013).

**Table 4.6. Baseflow separation results.**

|                  | <b>Number of days of data</b> | <b>Mean flow (m<sup>3</sup>/s)</b> | <b>Mean baseflow (m<sup>3</sup>/s)</b> | <b>Mean baseflow (Mm<sup>3</sup>/a)</b> |
|------------------|-------------------------------|------------------------------------|--|---|
| <b>January</b>   | 992                           | 1.15                               | 0.25                                   | 7.32                                    |
| <b>February</b>  | 904                           | 1.91                               | 0.57                                   | 14.87                                   |
| <b>March</b>     | 992                           | 1.56                               | 0.55                                   | 16.06                                   |
| <b>April</b>     | 960                           | 0.90                               | 0.31                                   | 9.63                                    |
| <b>May</b>       | 992                           | 0.83                               | 0.25                                   | 7.70                                    |
| <b>June</b>      | 960                           | 0.72                               | 0.22                                   | 6.64                                    |
| <b>July</b>      | 992                           | 0.59                               | 0.15                                   | 4.88                                    |
| <b>August</b>    | 992                           | 0.43                               | 0.08                                   | 2.63                                    |
| <b>September</b> | 950                           | 0.34                               | 0.04                                   | 1.15                                    |
| <b>October</b>   | 961                           | 0.26                               | 0.02                                   | 0.53                                    |
| <b>November</b>  | 930                           | 0.37                               | 0.03                                   | 0.96                                    |
| <b>December</b>  | 961                           | 0.90                               | 0.15                                   | 3.92                                    |

#### 4.6.2 Simulated baseflow (numerical model)

During the model development Constant head boundary conditions were therefore specified along the major surface drainages, which are known to receive base flow from groundwater as, indicated in Figure 4-17. A constant head boundary condition was also specified at the location of the Maloney's Eye. The constant head boundary condition allows groundwater to discharge, in this case, from the model area at a rate dependent on the hydraulic conductivity and hydraulic gradient across the boundary. The constant head boundaries were constrained so that water can only be removed from the system – a reversal of the hydraulic gradient back towards the aquifer from the surface system would therefore not allow water to enter the aquifer from the surface water system. This therefore represents a true “drain type” boundary condition.

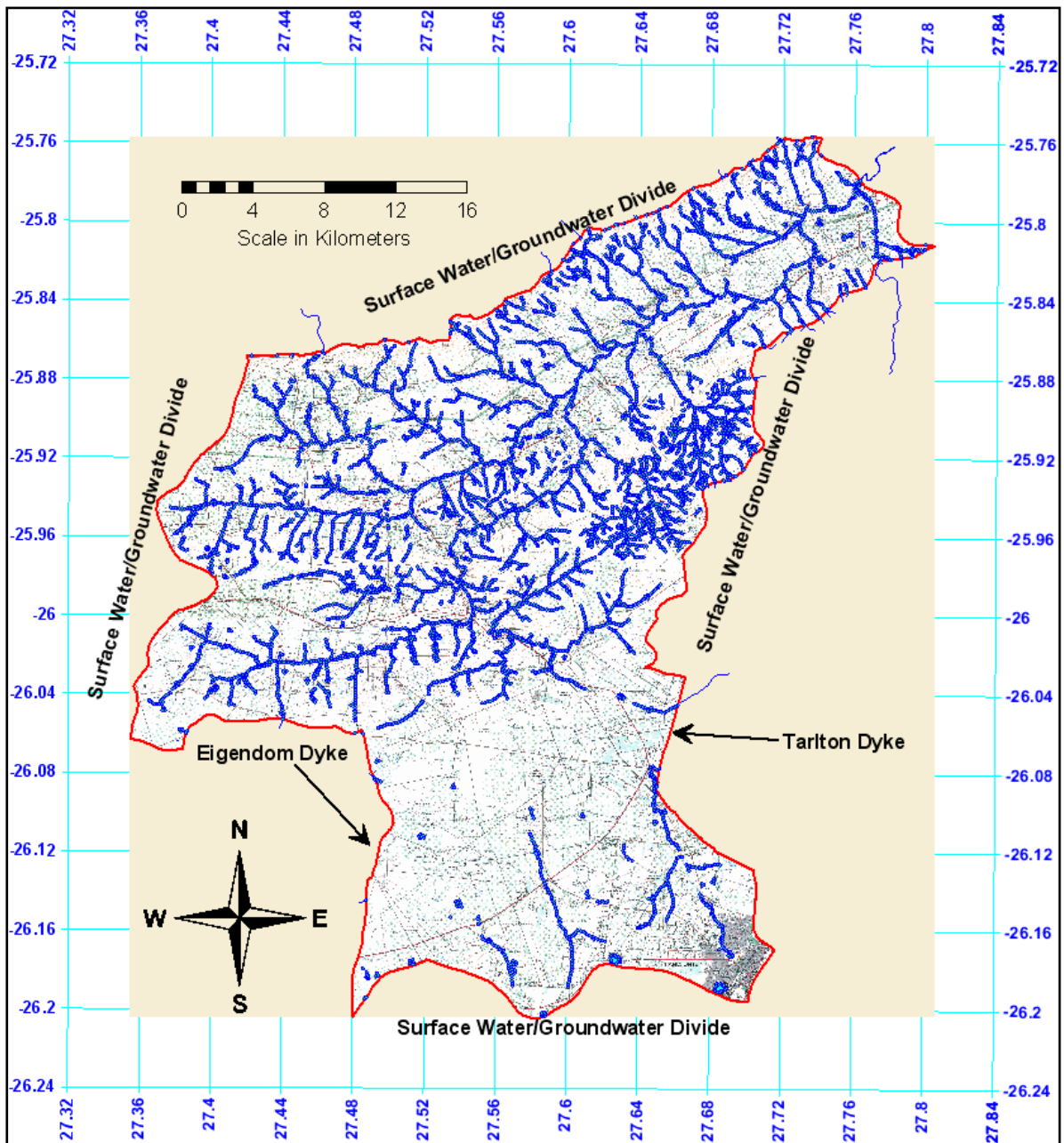


Figure 4-17. Internal modelling boundaries (Blue Circles) (Type I Dirichlet) representing drain nodes along rivers and streams.

A summary of the temporal baseflow statistics simulated across the six groundwater unit of analysis (GUA's) feeding to the Maloney Eye and the eight GUA of the Lower Magalies is provided in Table 4.7. The modeled baseflow volumes are higher compared to the baseflow separation values and more in range with the Hughes and Pitmann baseflow values (refer to the previous section). The model assumes that water leaves the model only via internal surface drainage and discharge to the base of river drainage. As a result, the baseflow component includes all subsurface flow such as seepage from perched aquifers and interflow.

**Table 4.7. General statistics associated with the baseflow on the GUA's in the study area.**

| Groundwater Management Area | GUA                        | Area (Km <sup>2</sup> ) | N     | Baseflow (m <sup>3</sup> /d) |                              |                             | Std. Dev |
|-----------------------------|----------------------------|-------------------------|-------|------------------------------|------------------------------|-----------------------------|----------|
|                             |                            |                         |       | Mean                         | Median                       | Minimum                     |          |
| Steenkoppies DC             | A21F-01                    | 62.6                    | 1,233 | 4,482                        | 3,676                        | 2,542                       | 2,732    |
|                             | A21F-02                    | 78.5                    |       | 377                          | 347                          | 224                         | 106      |
|                             | A21F-03                    | 94.5                    |       | 532                          | 479                          | 296                         | 185      |
|                             | A21F-04                    | 12.9                    |       | 0                            | 0                            |                             |          |
|                             | A21F-05                    | 27.5                    |       | 0                            | 0                            | 0                           | -        |
|                             | A21F-06                    | 56.2                    |       | 42,537                       | 40,359                       | 3,736                       | 19,269   |
|                             | Total                      | 332                     |       | 47,928                       | 44,861                       | 6,798                       | 22,294   |
|                             | <b>In Mm<sup>3</sup>/a</b> |                         |       | <b>17,5 Mm<sup>3</sup>/a</b> | <b>16,4 Mm<sup>3</sup>/a</b> | <b>2.4 Mm<sup>3</sup>/a</b> | -        |
| Lower Magalies River        | A21F-07                    | 35.9                    | 1,233 | 777                          | 721                          | 530                         | 205      |
|                             | A21F-08                    | 106.6                   |       | 4,615                        | 4,400                        | 3,474                       | 925      |
|                             | A21F-09                    | 33.5                    |       | 537                          | 478                          | 271                         | 223      |
|                             | A21F-10                    | 61.4                    |       | 3,750                        | 3,586                        | 2,864                       | 741      |
|                             | A21F-11                    | 66.4                    |       | 2,336                        | 2,190                        | 1,569                       | 618      |
|                             | A21F-12                    | 95.1                    |       | 4,566                        | 4,358                        | 3,408                       | 937      |
|                             | A21F-13                    | 156.9                   |       | 16,718                       | 15,815                       | 7,549                       | 5,342    |
|                             | A21F-14                    | 183.7                   |       | 7,665                        | 7,252                        | 5,532                       | 1,787    |
|                             | Total                      | 740                     |       | 40,964                       | 38,800                       | 25,197                      | 10,778   |
|                             | <b>In Mm<sup>3</sup>/a</b> |                         |       | <b>14,9 Mm<sup>3</sup>/a</b> | <b>14,2 Mm<sup>3</sup>/a</b> | <b>9.2 Mm<sup>3</sup>/a</b> | -        |

#### 4.7 Groundwater use (abstraction)

The exact time period when large scale groundwater abstraction commenced is unclear, although according to the biggest commercial farmers in the Tarlton area irrigation started about 35 years ago. No readily available groundwater abstraction data is available for the area. Two borehole surveys conducted by Bredenkamp *et al.* (1986) and Barnard (1997) are perhaps the earliest indication of the volume of groundwater abstracted for irrigation purposes. Other indications of groundwater use can be obtained in the Water User Authorisation and Management system (WARMS). This system contains information on water users which are registered with the DWAF. The spatial distribution and registered volumes per GUA is shown in Figure 4-18 and summarised in subsequent tables.

A recent water use verification project conducted by Schoeman & Associates on behalf of the DWAF aimed to determine existing lawful water use in the area prior to 1998. The two estimated water use datasets were produced for 1998 and 2004 with further verification and capturing of information during 2008/2009. Although some farmers have been consulted in the process, the assessment of existing lawful use prior to 1998 required the interpretation of satellite images of this era. The data was therefore produced by interpreting surface areas under irrigation and the respective types of crop irrigated.

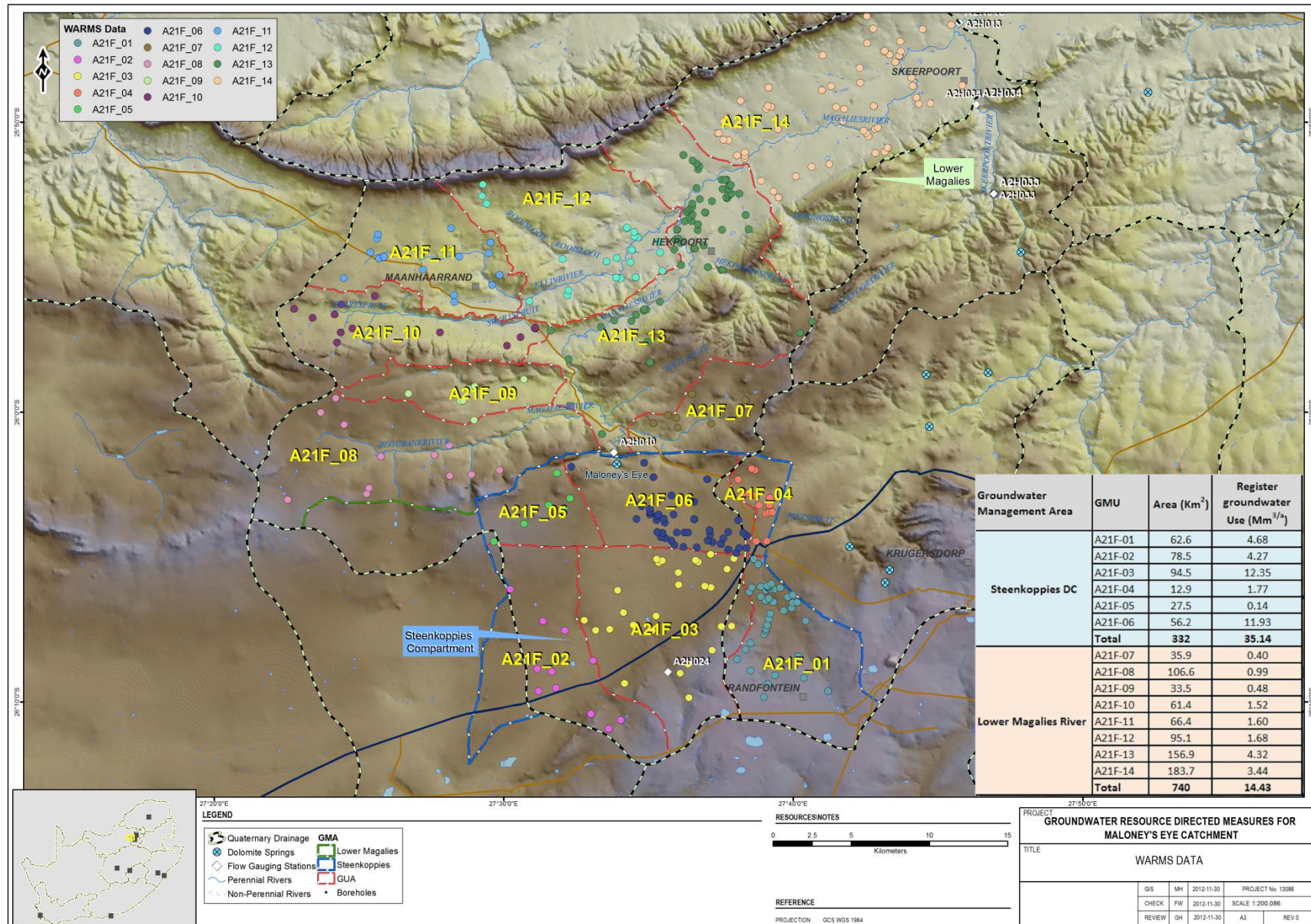


Figure 4-18. Registered groundwater use (WARMS).

### **Calculating groundwater use**

#### *WARMS (Water Use Authorisation & Registration Management System)*

The NWA makes registration with the National Register of Water Users mandatory. All water users, who do not receive their water from a service provider, local authority, water board, irrigation board, government water scheme or other bulk supplier need to register. This is with the exception of Schedule 1 users. It is important to note that the lawfulness of the registered water use still needs to be determined by the Department of Water Affairs. Validated data is available on quaternary catchment scale for the Limpopo WMA. WARMS is one of the only sources of data available that is based on actual current reporting. There are issues with under and over registration, but when these have been corrected it will be a fundamental functional dataset for the DWAF with a potentially long lifetime.

The approach adopted for this study was to compare abstraction rates from specialist reports with the WARMS database and the predicted abstraction based on irrigation requirements and simulated abstraction rates (from the numerical flow model). A final estimate is based on the most probable value taking into consideration the range of estimates and the knowledge of the region.

During this investigation the crop area was updated based on the latest satellite imagery. The irrigation requirement for each crop type and percentage crop distribution is based the preliminary results from Mr. Theunis Vahrmeijer' PhD research<sup>2</sup>. The crop irrigation was linked to the digitised crop area and calculated for each groundwater unit of analysis of the Steenkoppies DC.

Figure 4-19 indicates the distribution of coupling and pivot irrigated fields. The initial crop distribution and irrigation requirement is presented in Table 4.9. The water use is presented in Table 4.10. A summary of the estimated water use from the Steenkoppies DC is provided in Table 4.8. Based on the results and other sources of information on groundwater use in the Steenkoppies DC it is evident that depending on mean annual rainfall, crop type and crop distribution the water use within the DC for irrigation purposes range from 20 to 30 Mm<sup>3</sup>/a.

**Table 4.8. Summary of groundwater use for the Steenkoppies DC (Values in Mm<sup>3</sup>/a) (Holland et al., 2009)**

|              | <b>Bredenkamp <i>et al.</i> (1986)</b> | <b>Barnard (1997)</b> | <b>Schoeman &amp; Associates</b> |             |
|--------------|--|-----------------------|----------------------------------|-------------|
| Year         | 1986                                   | 1997                  | 1998                             | 2004        |
| Irrigation   | 13.5                                   | 19.0                  |                                  |             |
| Households   | 3.9                                    | 1.7                   |                                  |             |
| <b>Total</b> | <b>17.4</b>                            | <b>20.7</b>           | <b>34.9</b>                      | <b>33.6</b> |

<sup>2</sup> Personal Communication (14 April 2009). Mr. Theunis Vahrmeijer Steenkoppies Aquifer Management Association.

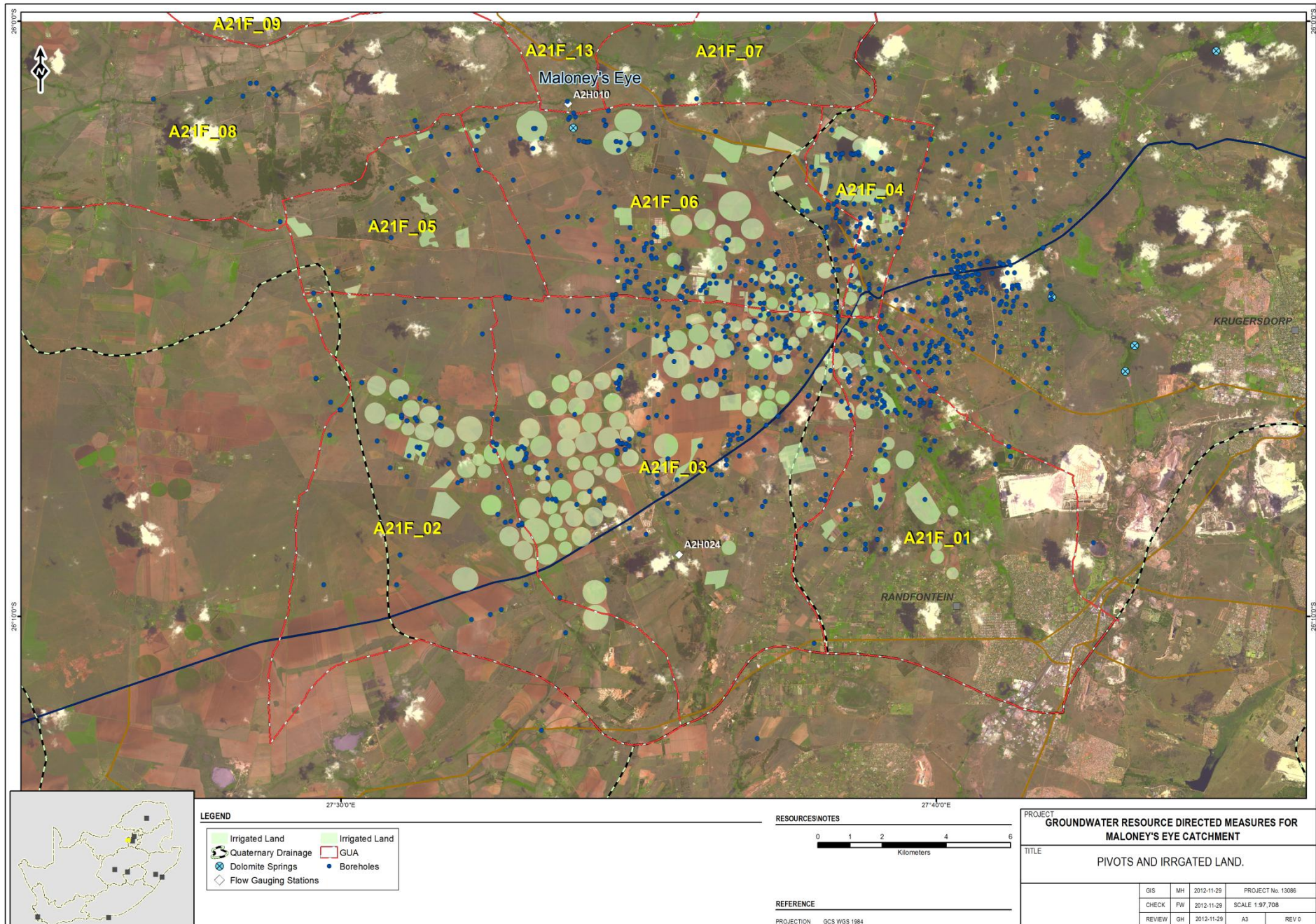


Figure 4-19. Irrigated land and pivots.

**Table 4.9. Crop irrigation distribution percentage and requirements.**

| Crop type | Percentage | Irrigation requirement |          |               |          |
|-----------|------------|------------------------|----------|---------------|----------|
|           |            | Summer (mm/a)          |          | Winter (mm/a) |          |
|           |            | Pivot                  | Coupling | Pivot         | Coupling |
| Maize     | 21%        | 193                    | 153      | 135           | 206      |
| Wheat     | 20%        | 282                    | 220      | 261           | 323      |
| Broccoli  | 19%        | 148                    | 148      | 194           | 457      |
| Lettuce   | 15%        | 282                    | 350      | 449           | 369      |
| Carrots   | 9%         | 229                    | 179      | 350           | 351      |
| Potatoes  | 7%         | 300                    | 300      | 396           | 396      |
| Beetroot  | 5%         | 613                    | 613      | 702           | 702      |
| Cabbage   | 4%         | 193                    | 153      | 135           | 206      |

**Table 4.10. Estimated groundwater use based on irrigated crop requirements.**

| Groundwater Management Area | GUA     | Area (Km <sup>2</sup> ) | Water Use (m <sup>3</sup> /a) |           |                   |
|-----------------------------|---------|-------------------------|-------------------------------|-----------|-------------------|
|                             |         |                         | Pivot                         | Coupling  | Combined          |
| Steenkoppies DC             | A21F-01 | 62.6                    | 1,015,434                     | 1,555,245 | 2,570,679         |
|                             | A21F-02 | 78.5                    | 3,860,639                     | 756,709   | 4,617,348         |
|                             | A21F-03 | 94.5                    | 11,357,884                    | 1,340,942 | 12,698,826        |
|                             | A21F-04 | 12.9                    | 411,081                       | 1,133,053 | 1,544,134         |
|                             | A21F-05 | 27.5                    | -                             | 867,003   | 867,003           |
|                             | A21F-06 | 56.2                    | 4,050,549                     | 1,912,692 | 5,963,241         |
| <b>TOTAL</b>                |         | 332                     | 20,695,587                    | 7,565,644 | <b>28,261,231</b> |

#### 4.7.1 Simulation of spring flow (impacted by abstraction)

To simulate the responses of the aquifers temporally and spatially, the specification of groundwater recharge (which obviously is a function of rainfall) and the specification of abstraction from the aquifers and is required. The objective then is to simulate as outputs the temporal observed water level and spring flow fluctuations. Due to the measureable effect abstraction has on the Maloney's Eye the temporal variation of abstraction was derived from the flow response of the spring to recharge over the entire catchment area. The simulation was based on similar modelling of springs in the Bo Molopo dolomite in relation to two components of recharge, generated in excess of 15 mm rainfall per month, in addition to:

- 1) Multiplying the recharge coefficient derived from a quadratic rainfall response, relative to the average rainfall over a characteristic period in excess of the threshold rainfall, and was multiplied by the average rainfall over a selected period. The latter was obtained by trial and error.

- 2) The second contribution from a rainfall-recharge coefficient that is multiplied by the ratio of the average rainfall over a second period relative to the long-term average rainfall.
- 3) Incorporating the pumping as an equivalent depth of precipitation.

$$Q_{\text{spring}}(i) = a \cdot (R_{f48}/R_{flt}) \cdot R_{f60} \cdot A + b \cdot (R_{f48}/R_{flt}) \cdot R_{f36} \cdot A - Q(i)$$

Where  $Q_{\text{spring}}$  = the flow of month (i) in cub m and  $A$  = the area of aquifer  $a$  and  $b$  = recharge coefficient applicable to the average rainfall over the preceding 48 months  $R_{f60}$  and  $R_{f36}$  the average rainfall over 60 and 36 preceding months respectively  $R_{flt}$  = the average rainfall over the full time series of rainfall (Bredenkamp, 2012).

Abstraction rates were assigned according to seven different abstraction functions over time as depicted in Figure 4-20 and table. The estimated abstraction was specified at each borehole positions based on the potential yield of the borehole and boreholes used for irrigation purposes.

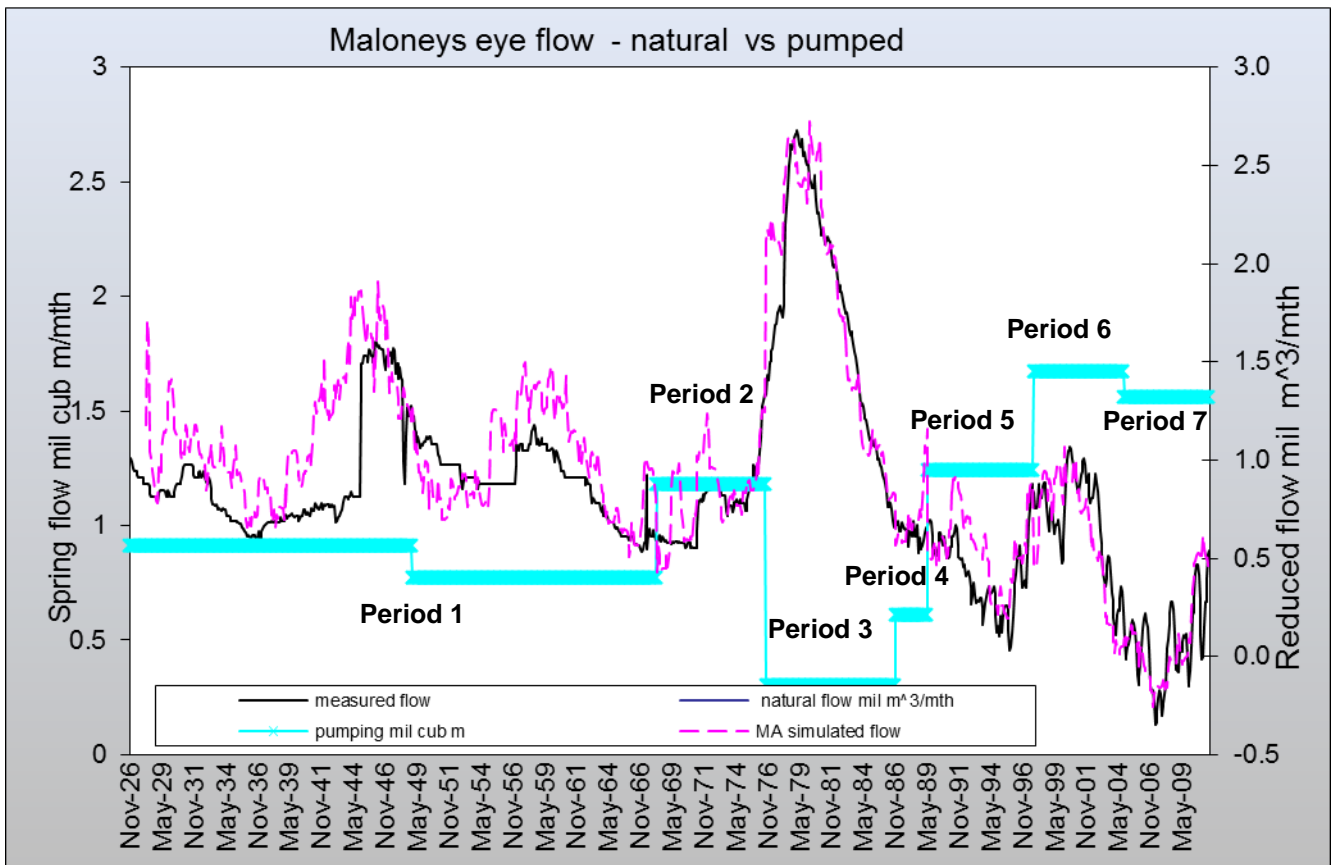


Figure 4-20. Simulation of the response of Maloney's eye with pumping incorporated over the period 1926 to 2001

Table 4.11. Estimated groundwater use based on irrigated crop requirements (compared with WARMS).

| Groundwater Management Area | GUA          | Water Use (Mm <sup>3</sup> /a) |                   | Simulated long term abstraction rates (Mm <sup>3</sup> /a) |             |             |              |             |              |
|-----------------------------|--------------|--------------------------------|-------------------|--|-------------|-------------|--------------|-------------|--------------|
|                             |              | WARMS                          | Crop Requirements | Period1to3   | Period4     | Period5     | Period6      | Period7     | Period8      |
| Steenkoppies DC             | A21F-01      | 4.68                           | 2.57              | 0.93   | 0.22        | 0.60        | 1.21         | 0.57        | 1.55         |
|                             | A21F-02      | 4.27                           | 4.62              | 2.07   | 0.49        | 1.33        | 2.71         | 1.28        | 3.44         |
|                             | A21F-03      | 12.35                          | 12.70             | 5.47   | 1.30        | 3.52        | 7.16         | 3.39        | 9.12         |
|                             | A21F-04      | 1.77                           | 1.54              | 0.66   | 0.16        | 0.43        | 0.87         | 0.41        | 1.10         |
|                             | A21F-05      | 0.14                           | 0.87              | 0.00   | 0.00        | 0.00        | 0.00         | 0.00        | 0.00         |
|                             | A21F-06      | 11.93                          | 5.96              | 2.48   | 0.59        | 1.59        | 3.24         | 1.53        | 4.13         |
|                             | <b>Total</b> | <b>35.14</b>                   | <b>28.26</b>      | <b>11.60</b>   | <b>2.76</b> | <b>7.46</b> | <b>15.19</b> | <b>7.18</b> | <b>19.34</b> |
| Lower Magalies River        | A21F-07      | 0.40                           |                   |  |             |             |              |             |              |
|                             | A21F-08      | 0.99                           |                   |  |             |             |              |             |              |
|                             | A21F-09      | 0.48                           |                   |  |             |             |              |             |              |
|                             | A21F-10      | 1.52                           |                   |  |             |             |              |             |              |
|                             | A21F-11      | 1.60                           |                   |  |             |             |              |             |              |
|                             | A21F-12      | 1.68                           |                   |  |             |             |              |             |              |
|                             | A21F-13      | 4.32                           |                   |  |             |             |              |             |              |
|                             | A21F-14      | 3.44                           |                   |  |             |             |              |             |              |
|                             | <b>Total</b> | <b>14.43</b>                   |                   |  |             |             |              |             |              |

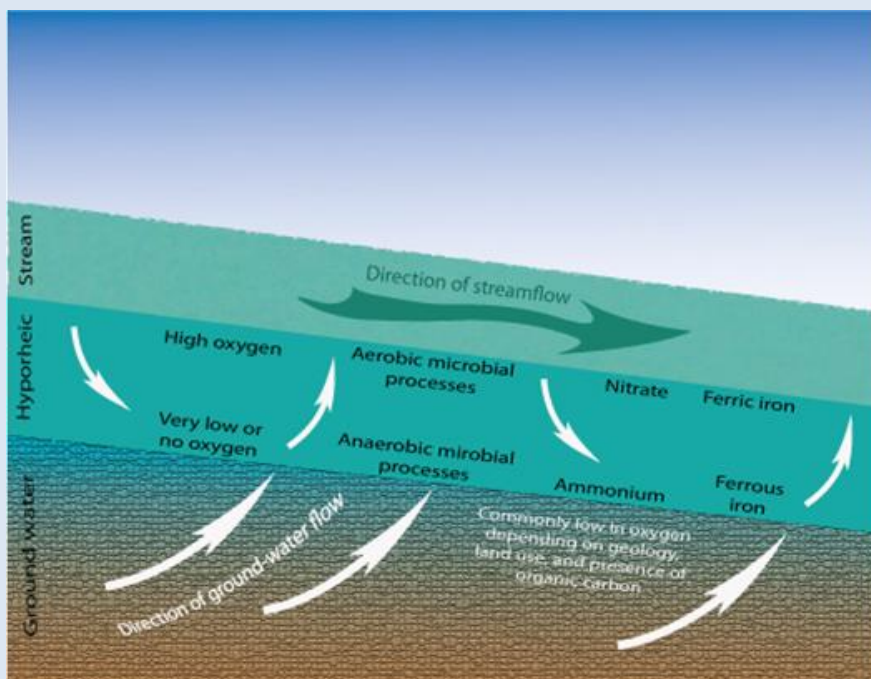
From the recharge/rainfall Figure 4-3 described in the previous section it is evident that the combination of temporal recharge, abstraction and boundary conditions assigned produced a reasonable resemblance between the observed and simulated flow of the Maloney Eye. This is especially valid since the late 1940's. The model still simulates however quite large peak flows during the high flow (high rainfall) events. This could be attributable to various factors; either the observed flow records did not capture all the flow during a high rainfall event or the modelled input of recharge still needs to be distributed further temporally.

#### 4.8 Groundwater quality

The major ions with some trace elements based on groundwater management units (GUAs) are depicted in Table 4.12. Generally the groundwater in the Steenkoppies DC is within acceptable drinking quality limits. However, groundwater units and A21F-01 and A21F-01 which receives effluent discharge water from the Randfontein sewage works in the Upper Rietspruit have a slightly poorer water quality with elevated concentrations of sulphate and chloride compared to the rest of the Steenkoppies DC. The elevated manganese and iron concentrations observed within A21F-06 is attributed to a single sample collected in January 2009. The borehole may be impacted by local pollution sources as no other form of iron and manganese was found.

### Groundwater quality

Domestic use (human consumption) is considered by the authors as the highest beneficial use, with the supposedly most stringent quality requirements. It is assumed that any water resource, which is deemed fit for human consumption, also meets the requirements of aquatic ecosystems. While the water quality requirements of aquatic ecosystems might differ and are in fact for several elements even more stringent than for domestic use (e.g. Cd), the chosen approach avoids the pitfall of equating groundwater quality in the sub-surface to water quality discharging into a surface water body. In other words, the methodology recognizes the processes occurring in discharge areas in general (e.g. evapotranspiration) and the enhanced microbiological and chemical reactions (e.g. Redox or cation exchange reactions) in the hyporheic zone specifically (Figure below), without trying to quantify them by setting only domestic use requirements for the groundwater resource itself.



It is therefore recommended to use the South African Water Quality Guidelines Vol. 1 – Domestic use (DWAF, 1996), or the national drinking water standard (SANS 241: 2006) for the present status category assessment of a water resource.

| PRESENT CATEGORY | 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 %                         |

Groundwater quality of the available dataset for the GUA is of good quality and the present status category can be categorised as I with more than 90 % of samples for all GUA apart from A21F-01 which is categorised as Class II (75 % compliance). A21F-01 shows elevated concentrations of Cl, SO<sub>4</sub> and NO<sub>3</sub>, confirming the impact of the Randfontein WWTW on the groundwater system. The lack of water quality data in the Lower Magalies make it not possible for any categorisation at this stage.

**Table 4.12. Groundwater quality for the study area (All units in mg/l, EC in mS/m).**

| GUA                   | Parameter | pH  | EC    | Ca    | Mg    | Na    | K    | SO <sub>4</sub> | Cl    | NO <sub>3</sub> as N | Fe   | Mn   | PO <sub>4</sub> |
|-----------------------|-----------|-----|-------|-------|-------|-------|------|-----------------|-------|----------------------|------|------|-----------------|
| Lower Magalies        | Nr        | 7   | 7     | 7     | 7     | 7     | 7    | 7               | 7     | 7                    |      |      |                 |
|                       | Mean      | 7.2 | 28.84 | 15.54 | 12.24 | 20.46 | 2.20 | 10.39           | 13.90 | 4.27                 |      |      |                 |
| A21F-01               | Nr        | 54  | 54    | 54    | 54    | 54    | 53   | 53              | 52    | 53                   | 10   | 10   | 51              |
|                       | Mean      | 6.5 | 29.92 | 18.29 | 10.34 | 15.46 | 1.27 | 68.75           | 19.13 | 1.54                 | 0.03 | 0.04 | 0.07            |
| A21F-02               | Nr        | 5   | 5     | 5     | 5     | 5     | 5    | 5               | 5     | 5                    | 3    | 3    | 5               |
|                       | Mean      | 8.0 | 161.7 | 44.52 | 26.42 | 4.36  | 1.52 | 3.04            | 2.92  | 2.03                 | 0.05 | 0.05 | 0.49            |
| A21F-03               | Nr        | 60  | 60    | 60    | 60    | 60    | 60   | 60              | 60    | 59                   | 7    | 7    | 54              |
|                       | Mean      | 6.7 | 18.00 | 12.19 | 6.83  | 3.76  | 0.61 | 8.33            | 4.39  | 0.21                 | 0.06 | 0.04 | 0.11            |
| A21F-04               | Nr        | 15  | 15    | 14    | 14    | 15    | 14   | 15              | 15    | 15                   | 8    | 8    | 12              |
|                       | Mean      | 7.9 | 76.44 | 29.91 | 20.02 | 24.42 | 1.54 | 40.85           | 25.72 | 1.71                 | 0.06 | 0.03 | 0.15            |
| A21F-05               | Nr        | 1   | 1     | 1     | 1     | 1     | 1    | 1               | 1     | 1                    |      |      | 1               |
|                       | Mean      | 7.8 | 28.10 | 30.00 | 17.00 | 2.00  | 0.30 | 5.00            | 3.00  | 0.05                 |      |      | 0.01            |
| A21F-06               | Nr        | 44  | 44    | 44    | 44    | 44    | 44   | 44              | 44    | 42                   | 11   | 11   | 39              |
|                       | Mean      | 7.4 | 51.87 | 22.83 | 16.43 | 6.32  | 0.91 | 9.84            | 6.87  | 0.46                 | 0.31 | 0.11 | 0.14            |
| Steenkoppies DC (all) | Nr        | 179 | 179   | 178   | 178   | 179   | 177  | 178             | 177   | 175                  | 39   | 39   | 162             |
|                       | Mean      | 7.0 | 38.89 | 19.07 | 11.91 | 9.66  | 0.98 | 29.27           | 11.09 | 0.85                 | 0.12 | 0.06 | 0.12            |

Class I

Class II

Blue font – lowest mean and red font – highest mean (A21F-05 excluded).

#### 4.8.1 Time series data

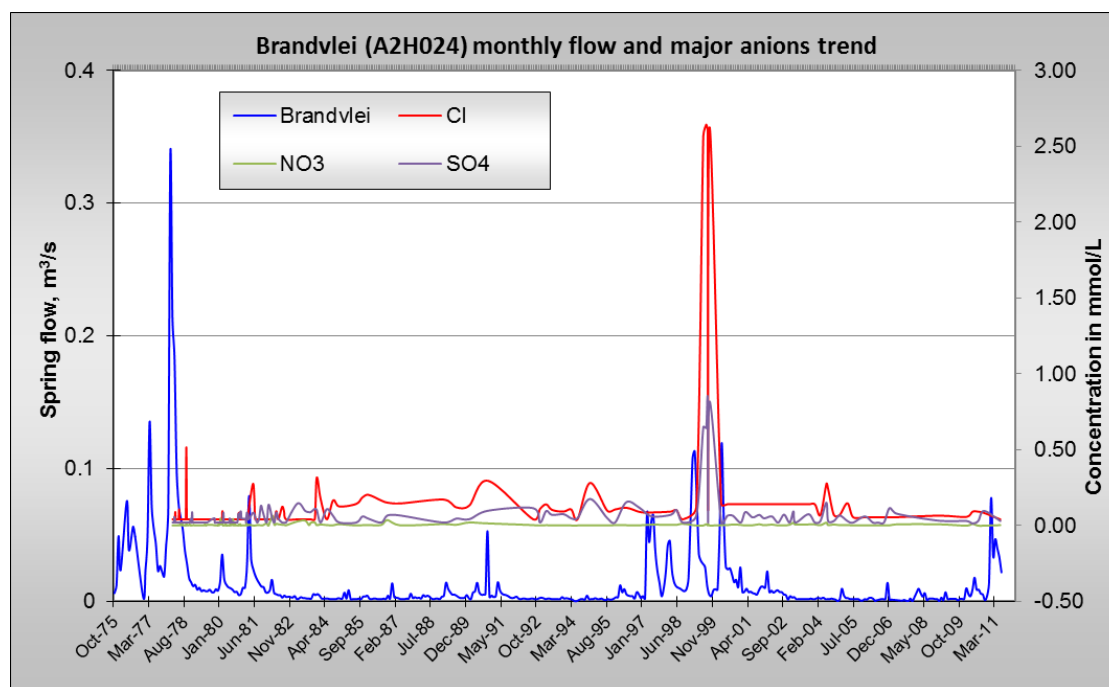
Long term water quality data for the Maloney's Eye (station 90163) was obtained from the DWAF. The location of this monitoring station is located at the Maloney's gauging station (A2H010) downstream of the Eye. This is also at the confluence of a stream draining the quartzites ridges towards the west of the Eye (Figure 3-5). The sampling location may have a distinct influence on the chemistry especially if the sample is taken after the confluence of the stream it will contain both a quartzite and dolomite water type signature. The quality of surface water entering the upper reaches of the Steenkoppies DC (station 90171) is mostly determined by the water quality from surface run-off from the quartzite hills of the Witwatersrand Supergroup. The quality of surface water leaving the Magalies River catchment is represented by station 90165 is mostly determined by the water quality from surface run-off from the Pretoria Group quartzites and shales. These station records contain major ions and selected trace elements since 1978.

A summary of the WQMS datasets are presented in Table 4.13 and a plot of the major anions and cations of the Maloney's Eye versus flow are illustrated Figure 4-21 to Figure 4-26 (units presented in mmol/L = mg/L/gram formula weight). The long term water quality of the mmoited surface water station is gerneally of good quality while no increasing or decreasing trend for any of the major ions could be established.

**Table 4.13. Summary information of time series of surface water quality data (All units in mg/l).**

| ID    | Station                |      | pH   | Ca    | Mg   | K    | Na   | Cl   | NO <sub>3</sub> as N | SO <sub>4</sub> | HCO <sub>3</sub> | F    | NH <sub>4</sub> -N | PO <sub>4</sub> -P |
|-------|------------------------|------|------|-------|------|------|------|------|----------------------|-----------------|------------------|------|--------------------|--------------------|
| 90171 | A2H024 - Brandvlei     | N    | 206  | 206   | 206  | 206  | 206  | 206  | 206                  | 206             | 203              | 201  | 206                | 206                |
|       |                        | min  | 5.0  | 0.5   | 0.5  | 0.1  | 0.2  | 1.5  | <0.1                 | 1.4             | 4.9              | <0.1 | <0.1               | <0.1               |
|       |                        | mean | 6.5  | 3.2   | 2.0  | 0.7  | 2.7  | 4.4  | 0.1                  | 5.4             | 18.2             | 0.1  | 0.1                | 0.1                |
|       |                        | max  | 8.6  | 52.3  | 29.2 | 7.0  | 51.8 | 93.7 | 0.9                  | 80.2            | 188.6            | 0.5  | 1.1                | 0.3                |
| 90163 | A2H010 - Maloney's Eye | N    | 217  | 252   | 252  | 253  | 249  | 251  | 239                  | 252             | 269              | 220  | 252                | 251                |
|       |                        | min  | 7.0  | 3.0   | 2.2  | 0.2  | 0.2  | 1.5  | 0.0                  | 0.4             | 0.0              | <0.1 | <0.1               | <0.1               |
|       |                        | mean | 7.9  | 26.6  | 16.4 | 0.9  | 2.6  | 3.3  | 0.3                  | 5.0             | 145.8            | 0.1  | 0.1                | 0.1                |
|       |                        | max  | 9.9  | 111.7 | 59.1 | 5.8  | 65.9 | 18.6 | 4.1                  | 207.2           | 358.4            | 1.3  | 1.9                | 1.4                |
| 90165 | A2H013 - Scheerpoort   | N    | 1395 | 1314  | 1314 | 1314 | 1309 | 1314 | 1375                 | 1313            | 1322             | 1278 | 1366               | 1382               |
|       |                        | min  | 4.7  | 8.0   | 3.7  | 0.1  | 0.2  | 0.5  | <0.1                 | 0.4             | 63.6             | 0.1  | <0.1               | <0.1               |
|       |                        | mean | 8.1  | 31.5  | 21.2 | 0.7  | 3.0  | 4.5  | 0.7                  | 7.1             | 189.7            | 0.2  | 0.1                | 0.1                |
|       |                        | max  | 8.8  | 39.3  | 30.9 | 7.4  | 41.8 | 36.8 | 4.0                  | 53.3            | 241.5            | 3.9  | 1.4                | 0.7                |

Blue font – lowest mean and red font – highest mean (A21F-05 excluded).



**Figure 4-21. Chemical trend of major anions and flow (Brandvlei).**

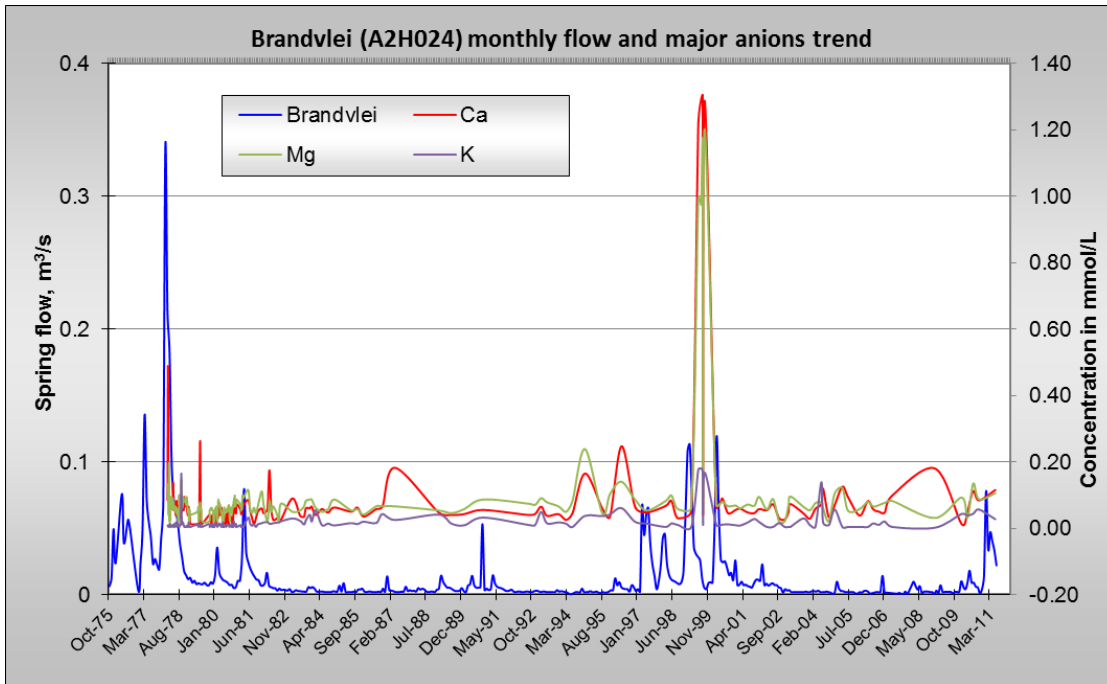


Figure 4-22. Chemical trend of major cations and flow (Brandvlei).

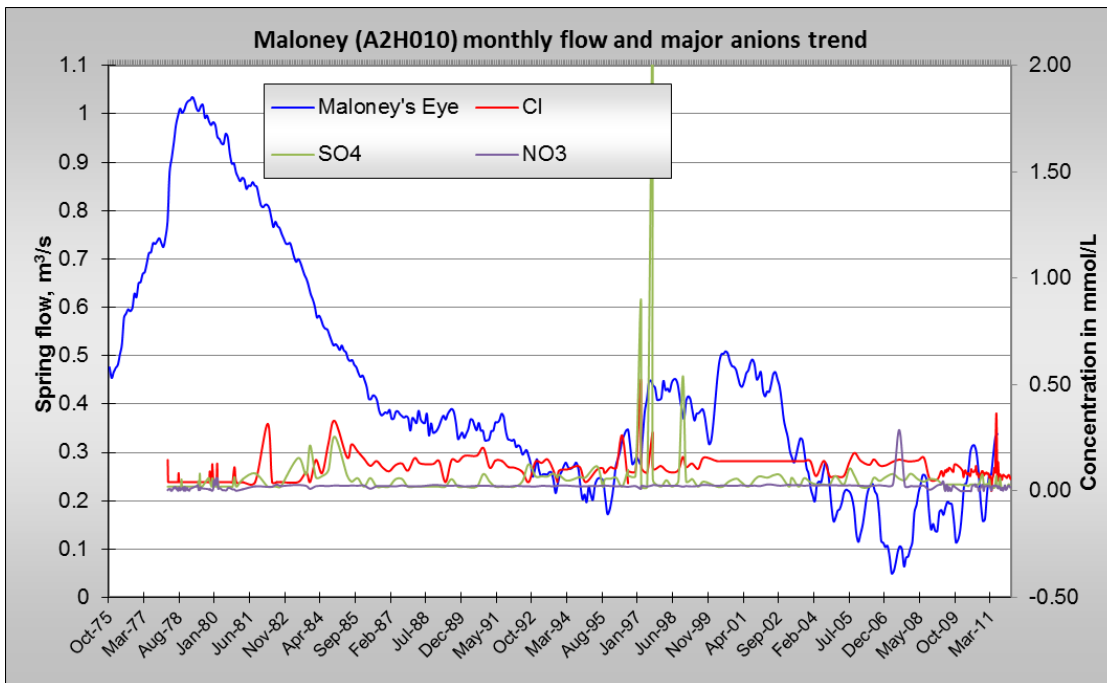


Figure 4-23. Chemical trend of major anions and flow (Maloney's Eye).

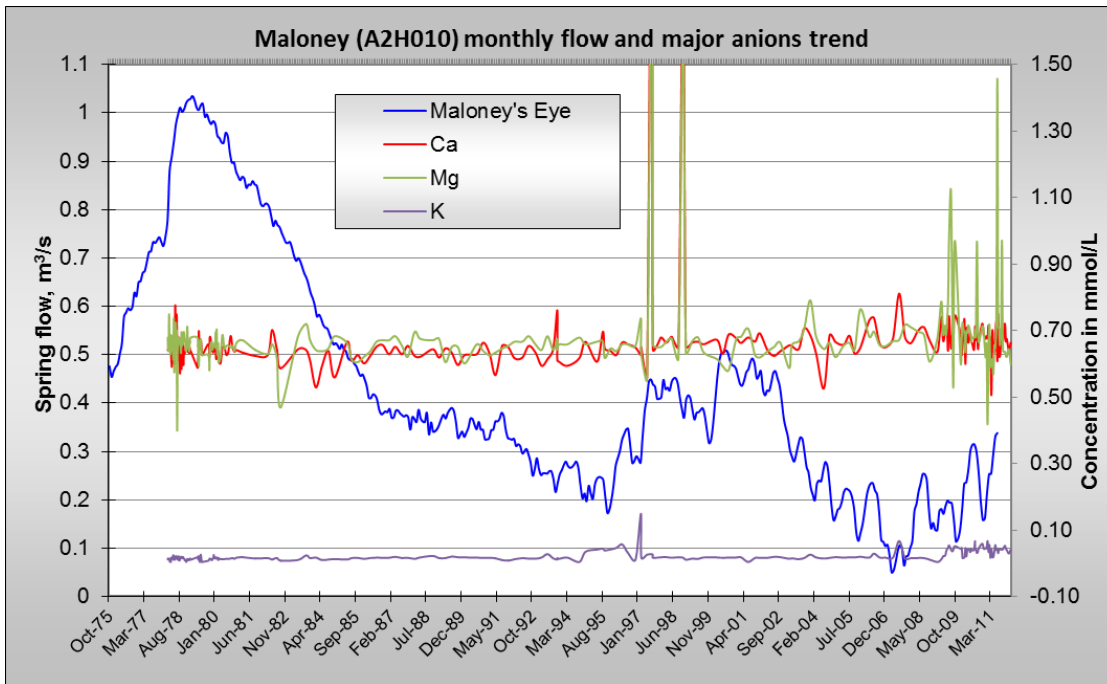


Figure 4-24. Chemical trend of major cations and flow (Maloney's Eye).

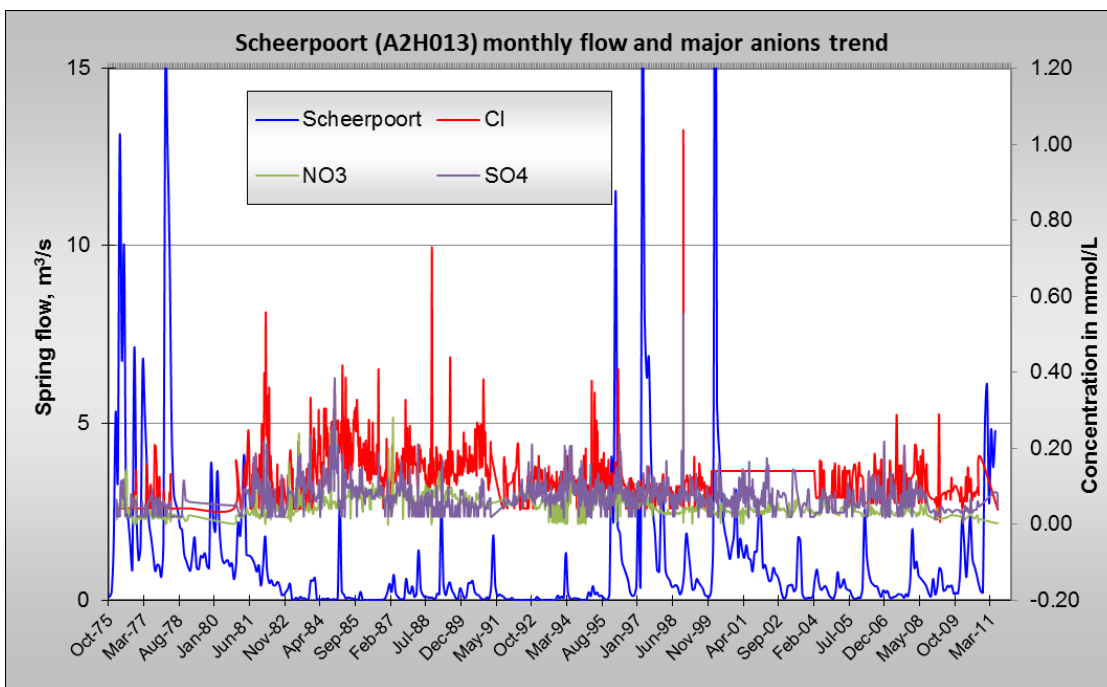


Figure 4-25. Chemical trend of major anions and flow (Magalies River).

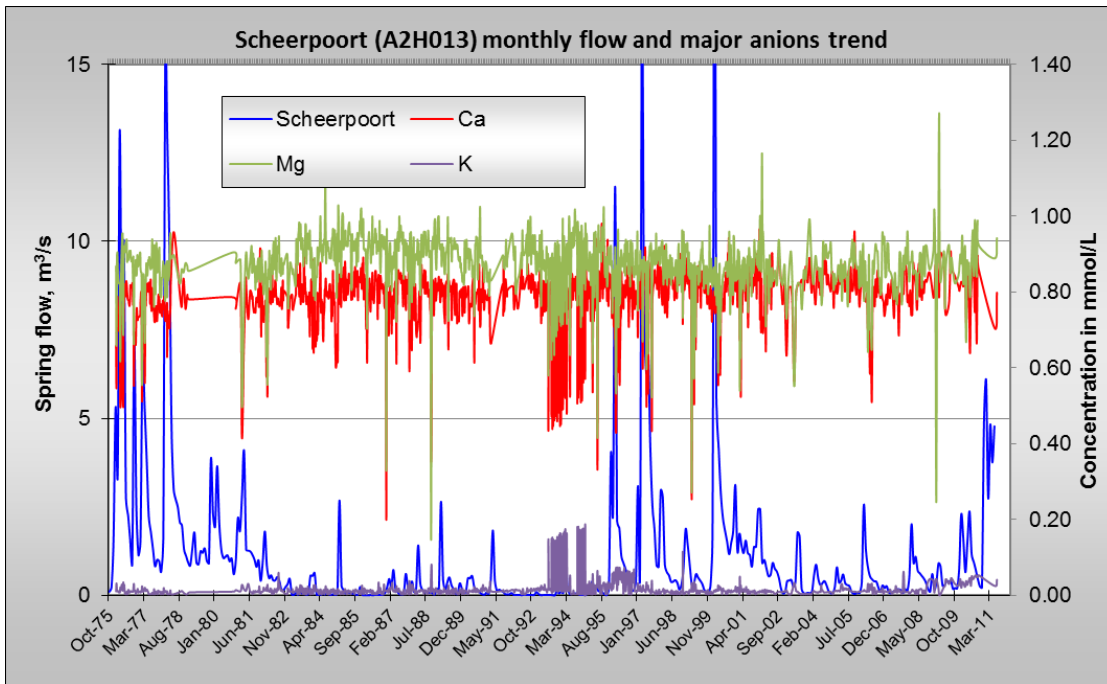


Figure 4-26. Chemical trend of major cations and flow (Magalies River).

## 5 RESERVE DETERMINATION AND CATEGORISATION

### 5.1 Groundwater reserve

#### **Reserve determination**

The groundwater component of the Reserve is the part of the groundwater resource that sustains basic human needs and in some instances contributes to EWR. To be able to quantify the groundwater component of the Reserve, the volume of groundwater needed for BHN and contributing to EWR needs to be quantified. The EWRs of the Resource in question must consider the following:

- Groundwater contribution to baseflow in rivers.
- Groundwater contribution to wetlands.
- Groundwater contribution to springs and other Groundwater Dependant Ecosystems.

The groundwater component of the Reserve is defined by the following relationship:

$$Reserve(\%) = \frac{EWR_{gw} + BHN_{gw}}{Re} \times 100$$

Where:

Re = recharge  
BHN<sub>gw</sub> = basic human needs derived from groundwater  
EWR<sub>gw</sub> = groundwater contribution to EWR

Groundwater should only be allocated to users and potential users once the volume of groundwater that contributes to sustaining the Reserve has been quantified and RQOs have been met.

Due to the scale of this assessment in addition to the difficulty in quantifying groundwater contributions to wetlands, springs and GDEs, the EWR<sub>gw</sub> is mainly based on the groundwater contribution to baseflow. However, mentioning of potential GDEs, wetlands and springs occurring within each GUA will allow the RDM office to initiate more detailed studies to account for these contributions to the Reserve.

#### 5.1.1 Basic Human Needs (BHN)

Currently, basic human needs (BHN) are set at 25 ℓ/p/d. Although normally quite small in comparison to other uses, it must be borne in mind that this is a right to water and must be legally protected. Although numerous sources of population data are available over the larger region no breakdown per GUA could be provided. The total population over the Magalies River catchment based on the GRA II dataset was used to determine the BHN. To cater for any uncertainty in the data and based on the premise that the data is outdated the total population figure was multiplied by three. The estimated BHN based on a population of 11636 (x3) is 0.3 Mm<sup>3</sup>/a.

### 5.1.2 Reserve determination summary

The Reserve assessment is provided per groundwater unit analysis and is based on the recharge and baseflow estimated provided in subsequent sections (Table 5.1). The long term minimum baseflow requirements were based on the model simulation.

**Table 5.1. Groundwater reserve summary.**

| Groundwater Management Area | GUA          | Area (Km <sup>2</sup> ) | Recharge Mm <sup>3</sup> /a | GW to Baseflow Mm <sup>3</sup> /a | BHN Mm <sup>3</sup> /a | Reserve Mm <sup>3</sup> /a | Reserve %  |
|-----------------------------|--------------|-------------------------|-----------------------------|-----------------------------------|------------------------|----------------------------|------------|
| <b>Steenkoppies DC</b>      | A21F-01      | 62.6                    | 3.23                        | 0.93                              | 0.02                   | 0.95                       | 29%        |
|                             | A21F-02      | 78.5                    | 5.67                        | 0.08                              | 0.02                   | 0.10                       | 2%         |
|                             | A21F-03      | 94.5                    | 6.14                        | 0.11                              | 0.02                   | 0.13                       | 2%         |
|                             | A21F-04      | 12.9                    | 1.19                        | 0.00                              | 0.02                   | 0.02                       | 2%         |
|                             | A21F-05      | 27.5                    | 2.48                        | 0.00                              | 0.02                   | 0.02                       | 1%         |
|                             | A21F-06      | 56.2                    | 5.02                        | 1.36                              | 0.02                   | 1.39                       | 28%        |
|                             | <b>Total</b> | <b>322</b>              | <b>23.72</b>                | <b>2.48</b>                       | <b>0.14</b>            | <b>2.62</b>                | <b>11%</b> |
| <b>Lower Magalies River</b> | A21F-07      | 35.9                    | 0.65                        | 0.19                              | 0.02                   | 0.22                       | 33%        |
|                             | A21F-08      | 106.6                   | 1.77                        | 1.27                              | 0.02                   | 1.29                       | 73%        |
|                             | A21F-09      | 33.5                    | 0.58                        | 0.10                              | 0.02                   | 0.12                       | 21%        |
|                             | A21F-10      | 61.4                    | 1.01                        | 1.05                              | 0.02                   | 1.07                       | > 100 %    |
|                             | A21F-11      | 66.4                    | 1.07                        | 0.57                              | 0.02                   | 0.60                       | 56%        |
|                             | A21F-12      | 95.1                    | 1.53                        | 1.24                              | 0.02                   | 1.27                       | 83%        |
|                             | A21F-13      | 156.9                   | 2.56                        | 2.76                              | 0.02                   | 2.78                       | > 100 %    |
|                             | A21F-14      | 183.7                   | 2.85                        | 2.02                              | 0.02                   | 2.04                       | 72%        |
| <b>Total</b>                | <b>740</b>   | <b>12.01</b>            | <b>9.20</b>                 | <b>0.18</b>                       | <b>9.38</b>            | <b>78%</b>                 |            |

### 5.1.3 Groundwater use and availability

#### **Defining stress**

The concept of stressed water resources is addressed by the NWA, 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.
- Where water resource quality is under threat.

The groundwater stress index reflects water availability versus water used. Groundwater use should include water utilised by current water users, water required to sustain the Reserve as well as for BHN. The Stress Index for an assessment area is defined as follows:

$$SI(\%) = \frac{gwUse}{Recharge} \times 100$$

Where:

*gwUse* = Current groundwater use

*Recharge* = Recharge (as a volume)

In calculating the Stress Index, the variability of annual recharge is taken into account in the sense that not more than 65% of average annual recharge can be allocated on a catchment scale).

| PRESENT CATEGORY | DESCRIPTION     | COMPLIANCE (SPATIAL/TEMPORAL) |
|------------------|-----------------|-------------------------------|
| I                | Minimally used  | ≤20%                          |
| II               | Moderately used | 20% – 65%                     |
| III              | Heavily used    | > 65%                         |

A guide for quantifying groundwater use is documented below.

| ACTIVITY  | PERCENTAGE OF RECHARGE                     |
|---|--|
| Stock watering, farm domestic water supply, rural water supply                          | Use ranges between 5% and 20% of recharge  |
| Small-scale irrigation, rural water supply, water supply for villages and small towns   | Use ranges between 20% and 40% of recharge |
| Water supply for large rural communities, medium to large towns, large-scale irrigation | Use ranges between 40% and 65% of recharge |

Groundwater use estimates vary between the WARMS, crop requirements and simulated abstraction based on the response to the Maloney's Eye flow (Table 4.11). The categorisation of stress was based on the simulated groundwater abstraction for the Steenkoppies DC (Period 8) and the WARMS dataset for the Lower Magalies River (Table 5.2). The registered WARMS dataset (June 2010) might be an overestimate of groundwater use and require verification. Based on the stress index shown in Table 5.2 the Lower Magalies River is under stress and any future groundwater abstraction should take existing water use into consideration within each GUA. Future abstraction should also be subject to licensing. The determination of groundwater use per GUA makes it possible to establish over-allocation and identify certain GUA for future development (while taking cognisance of the RQOs set).

Table 5.2. Groundwater use and associated stress.

| Groundwater Management Area | GUA          | Area (Km <sup>2</sup> ) | Recharge Mm <sup>3</sup> /a | GW Use Mm <sup>3</sup> /a | Stress Index (GW Use as % of Recharge) | Present Category |
|-----------------------------|--------------|-------------------------|-----------------------------|---------------------------|--|------------------|
| <b>Steenkoppies DC</b>      | A21F-01      | 62.6                    | 3.23                        | 0.93                      | 48%                                    | II               |
|                             | A21F-02      | 78.5                    | 5.67                        | 0.08                      | 61%                                    | II               |
|                             | A21F-03      | 94.5                    | 6.14                        | 0.11                      | > 100%                                 | III              |
|                             | A21F-04      | 12.9                    | 1.19                        | 0.00                      | 93%                                    | III              |
|                             | A21F-05      | 27.5                    | 2.48                        | 0.00                      | 0%                                     | I                |
|                             | A21F-06      | 56.2                    | 5.02                        | 1.36                      | 82%                                    | III              |
|                             | <b>Total</b> | 322                     | 23.72                       | 2.48                      | 82%                                    | III              |
| <b>Lower Magalies River</b> | A21F-07      | 35.9                    | 0.65                        | 0.19                      | 62%                                    | III              |
|                             | A21F-08      | 106.6                   | 1.77                        | 1.27                      | 56%                                    | III              |
|                             | A21F-09      | 33.5                    | 0.58                        | 0.10                      | 83%                                    | III              |
|                             | A21F-10      | 61.4                    | 1.01                        | 1.05                      | >100 %                                 | III              |
|                             | A21F-11      | 66.4                    | 1.07                        | 0.57                      | >100 %                                 | III              |
|                             | A21F-12      | 95.1                    | 1.53                        | 1.24                      | >100 %                                 | III              |
|                             | A21F-13      | 156.9                   | 2.56                        | 2.76                      | >100 %                                 | III              |
|                             | A21F-14      | 183.7                   | 2.85                        | 2.02                      | >100 %                                 | III              |
|                             | <b>Total</b> | 740                     | 12.01                       | 9.20                      | >100 %                                 | III              |

#### 5.1.4 Categorisation and management options

##### **Baseline class**

Defining the point at which a resource is no longer being used in a sustainable manner is generally very difficult. The level of sustainability probably fluctuates through time, and impacts from over-use could manifest themselves sometime after the impact was caused. The change from sustainable use to over-use is gradational, and not necessarily marked by some distinct change.

Indicators of quantitative unsustainable groundwater use include:

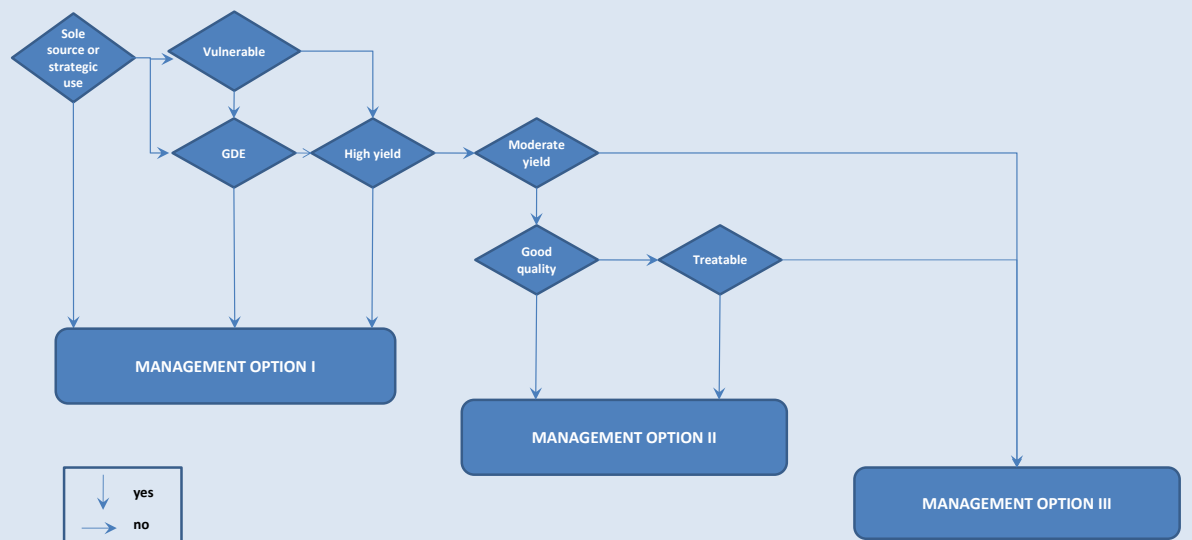
- Land subsidence or sinkhole formation.
- Long-term declining water levels on a regional level.
- Long-term declining water quality levels.

A guide for assessing the status of groundwater units based on observed impacts resulting from groundwater abstraction is presented below.

| PRESENT CATEGORY     | 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: <ul style="list-style-type: none"> <li>– spring flow</li> <li>– river flow</li> <li>– vegetation</li> <li>– land subsidence</li> <li>– sinkhole formation</li> <li>– groundwater quality</li> </ul> |
| Heavily used (III)   | The water resource is significantly altered from its pre-development condition | Moderate to significant impacts to: <ul style="list-style-type: none"> <li>– spring flow</li> <li>– river flow</li> <li>– vegetation</li> <li>– land subsidence</li> <li>– sinkhole formation</li> <li>– groundwater quality</li> </ul>                |

### Management Options

Monitoring forms an essential part of what must be a seamless process of managing the country's water resources. Monitoring essentially falls outside the GRDM process, but is required to ensure that the Reserve and Resource Quality Objectives are both realistic and are adhered to. Groundwater monitoring has the simple goal of quantifying the behaviour and response of groundwater systems to various controls and stressors (recharge, discharge, abstraction, etc.). Extensive monitoring already takes place, but both surface and groundwater monitoring programmes need to be revised and updated on a regular basis. However it is costly and labour intensive to monitor extensively. Considering that also moderate yielding aquifers can have a significant contribution to water supply schemes, it is proposed to combine the actual or potential importance of an aquifer and the groundwater quality to arrive at a recommended monitoring class for all aquifers as shown below.



The management options are defined according to table below.

| 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  |

Water quality analysis should include the following parameters: pH, EC, Ca, Mg, Na, K, Palk, MAIk, F, Cl, Br, NO<sub>3</sub>(N), PO<sub>4</sub>, SO<sub>4</sub>.

A summary of the final categorisation for the Steenkoppies DC and the Lower Magalies River provided in Table 5.3

**Table 5.3. Final groundwater categorisation and management options for each GUA.**

| <b>Groundwater Management Area</b> | <b>GUA</b> | <b>Area (Km<sup>2</sup>)</b> | <b>Present Category (Stress)</b> | <b>Present Category (Impact)</b> | <b>Present Category (Quality)</b> | <b>Final Present Category</b> | <b>Management Option</b> |
|------------------------------------|------------|------------------------------|----------------------------------|----------------------------------|-----------------------------------|-------------------------------|--------------------------|
| <b>Steenkoppies DC</b>             | A21F-01    | 62.6                         | II                               | II                               | II                                | II                            | I                        |
|                                    | A21F-02    | 78.5                         | II                               | I                                | I                                 | II                            | I                        |
|                                    | A21F-03    | 94.5                         | III                              | III                              | I                                 | III                           | I                        |
|                                    | A21F-04    | 12.9                         | III                              | II                               | I                                 | III                           | I                        |
|                                    | A21F-05    | 27.5                         | I                                | I                                | I                                 | I                             | I                        |
|                                    | A21F-06    | 56.2                         | III                              | III                              | I                                 | III                           | I                        |
| <b>Lower Magalies River</b>        | A21F-07    | 35.9                         | III                              | II                               | *                                 | III                           | II                       |
|                                    | A21F-08    | 106.6                        | III                              | II                               |                                   | III                           | II                       |
|                                    | A21F-09    | 33.5                         | III                              | II                               |                                   | III                           | II                       |
|                                    | A21F-10    | 61.4                         | III                              | II                               |                                   | III                           | II                       |
|                                    | A21F-11    | 66.4                         | III                              | II                               |                                   | III                           | II                       |
|                                    | A21F-12    | 95.1                         | III                              | II                               |                                   | III                           | II                       |
|                                    | A21F-13    | 156.9                        | III                              | II                               |                                   | III                           | II                       |
|                                    | A21F-14    | 183.7                        | III                              | II                               |                                   | III                           | II                       |

\* - The amount of water quality data availability for the Lower Magalies does not justify categorisation at this stage.

## 6 RESOURCE QUALITY OBJECTIVES

RQOs must set objectives for the management of water resources in a catchment or other GUAs, (if applicable) and by its very nature be applicable on that scale. In general terms, RQOs establish clear goals relating to the quantity and quality of a water resource. They provide goals and objectives that frame the vision for sustainable use of a water resource, and hence form the basis for catchment decision-making and management. When setting RQOs, a balance must be found between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other.

**Resource Quality Objectives (RQOs)**

Although no formal methodologies exist with respect to setting RQOs for the groundwater component. Guidelines and methodologies are documented in Colvin et al. (2004) and Parsons and Wentzel (2007). A generic process to develop and implement RQOs has been developed in 2011 (DWA, 2011). In the process groundwater is dealt with separately as not only are the Resource Units completely different to the surface water systems, so are the variables of concern. These processes have been aligned with the above mentioned guidelines but the most notable difference is the description of RQOs as narrative and with attendant Numerical Limits.

| Generic steps<br>(applied to Rivers, Wetlands, & Estuaries)   | Groundwater RQO steps  |
|---|--|
| Step 1. Delineate IUAs and RUs  | Step 1. Follow Parsons & Wentzel 2006  |
| Step 2. 7 Step visioning process  | Step 2. Follow Step 2 of RQO process   |
| Step 3. Prioritise Resource Units ( <b>Using Resource Unit Prioritisation Tool</b> )  | Step 3. No methodology available.  |
| Step 4. Prioritise sub-components, select indicators and propose direction of change ( <b>Using Resource Unit Evaluation Tool</b> ) | Step 4. Follow Step 1, 2, 3 & 4 of Colvin et al. (2004)                            |
| Step 5. Develop Draft RQOs & Numerical limits   | Step 5. Follow Step 5 of Colvin et al. (2004) plus translation into narrative RQOs |
| Step 6. Agree with Stakeholders   | Step 6. Follow Step 6 of Colvin et al. (2004)                                      |
| Step 7. Finalise & Gazette RQOs   | Step 7. Follow Step 7 of Colvin et al. (2004) and Step 7 of RQO process            |

According to the National Water Resources Strategy (DWAF, 2004) deals with RQOs for groundwater saying that “Resource Quality Objectives for groundwater resources are considered crucial for the effective protection of groundwater. Numeric or descriptive statements for a groundwater resource will be set in order to guide the use and management thereof, typically these will relate to - groundwater levels or gradients (time and locality specific); groundwater abstraction rates; groundwater quality; spring flow; and targets for the health and terrestrial ecosystems that are dependent on groundwater”.

## 6.1 Steenkoppies RQO's

- A21F-01 – The upper Rietspruit GUA receives approximately 1.5 Mm<sup>3</sup>/a of treated effluent from the Randfontein WWTW. Long term groundwater quality data indicate the impact of sewage effluent flows on the surface stream with elevated sulphate, chloride, nitrate and bicarbonate values compared to the Brandvlei and Maloney's sampling stations. Most water sue is rom surface water abstraction and compared to the rest of the Steenkoppies DC groundwater use is marginal. Water levels appear to recover back to levels observed in the mid-1980s.
  - RQO's should include:
    - Continuous monitoring of water levels at DWA stations.
    - Compile database for the effluent discharges from the Randfontein WWTW.
    - Continuous monitoring of groundwater quality at DWA stations.
    - Compulsory licensing.
- A21F-02 – The most western GUA is devoid of any surface drainage and sub-surface flow dominates. No DWA monitoring station is within the GUA, however, the SAMA have installed a continuous logger as part of their management programme. An estimated 60 % of recharge is being abstracted in the GUA. Compared to the rest of the Steenkoppies DC groundwater quality is poor but still within recommended drinking limits and at a present status category of I.
  - RQO's should include:
    - Establishment of monthly of water level monitoring stations (boreholes).
    - Establish groundwater quality monitoring programme at DWA stations.
- A21F-03 – One of two major GUAs contributing to the flow of the Maloney's Eye and is also the most utilised with groundwater use exceeding recharge by 50 %. Although numerous DWA monitoring stations are located within the GUA, they are limited to the northern parts south of the Wolwekrans dyke. Groundwater quality is of great quality and has the lowest mean concentrations for most elements in the Steenkoppies DC. Groundwater levels appear to have recovered somewhat from the lowest recovered values in 2007.
  - RQO's should include:
    - Continuous monitoring of water levels at DWA stations.
    - Establishment of monthly of water level monitoring stations (boreholes) towards the south of the GUA.
    - Continuous monitoring of groundwater quality at DWA stations.
    - Motivate and implement monitoring of groundwater discharges for large scale irrigation activities.
    - Compulsory licensing.

- A21F-04 – The GUA is immediately east of the Tarlton dyke and receives water discharging from A21F-01. As a result the signature of the Randfontein effluent return flows is evident in the water qualities. Water levels in this GUA show the highest seasonal fluctuations due to lower permeabilities over the region. Water levels appear to have recovered to levels observed in the mid-1980s levels. However, groundwater use is almost 90 % of recharge over the GUA.
  - RQO's should include:
    - Continuous monitoring of water levels at DWA stations.
    - Continuous monitoring of groundwater quality at DWA stations.
    - Motivate and implement monitoring of groundwater discharges for large scale irrigation activities.
- A21F-05 – The GUA has the least groundwater information and utilisation of the resource is minimal.
  - RQO's should include:
    - Establishment of monthly of water level monitoring stations (boreholes).
    - Continuous monitoring of water levels at DWA stations.
    - Establish groundwater groundwater quality monitoring stations.
- A21F-06 – This GUA hosts the Maloney's Eye and should receive management priority. Groundwater quality is good and well within recommended drinking water quality limits. Abstractions within the GUA are within 80 % of the natural replenishment although water levels do show a slight increase over the couple of years, due to above average rainfall events. Although some DWA monitoring stations are located within the GUA, they are limited to either at the Maloney's Eye or towards the south, north of the Wolwekrans dyke.
  - RQO's should include:
    - Continuous monitoring of water levels at DWA stations.
    - Establishment of monthly of water level monitoring stations (boreholes) towards the central parts of the GUA.
    - Continuous monitoring of groundwater quality at DWA stations.
    - Motivate and implement monitoring of groundwater discharges for large scale irrigation activities.
    - Establishment of protection zones and management thereof accordingly (refer to next section).
    - Compulsory licensing.
- Lower Magalies River – Due to the general lack of data within the lower Magalies River groundwater management area, RQO's is not specified based on individual GUA but rather generically proposed. According to the WARMS dataset groundwater is utilised extensively in the lower Magalies River and may have significant impacts on the groundwater contribution to baseflow of the Magalies River.
  - RQO's should include:

- Establish groundwater monitoring programme (water quality and water levels) throughout the Lower Magalies.
- Motivate and implement monitoring of groundwater discharges for large scale irrigation activities.
- Compulsory licensing for A21F-13 and A21F-14.

## 6.2 Maloney's Eye protection zone

The Maloney's Eye is groundwater driven and therefore need to be protected. One approach to protect the spring is by establishing protection zones which then managed to minimize the potential of groundwater contamination by human activities that occur on the land surface or in the subsurface. However, it must be noted that the Steenkoppies DC host numerous existing lawful water users and many of the land uses cannot be altered. Nevertheless establishment of the protection zones of th Maloney's catchment is a pro-active approach to the sustainable management of the Maloney's Eye.

### 6.2.1 Approach

In many countries there is no policy that directly addresses the protection of groundwater used for drinking water. In South Africa, feasibility studies towards the policy development on aquifer protection zoning have been conducted in 2008 (DWAF, 2008). The timeline for the implementation of the protection zone policy is not known at the time of this study. A wide variety of techniques can be used to determine protection zone, varying from simple non-analytical methods to complex numerical transport models (EPA, 1993). The size and shape of the spring protection zone depends on the hydrogeologic characteristics of the aquifer system.

Numerical simulations of the groundwater system offer the best available analysis of the flow system and the best available delineation of the zone of contribution (ZOC) for a given well. In this study the developed numerical model was used to delineate protection zones according to the following guidelines:

Commonly, zones are delineated to achieve the following levels of protection (Jolly and Reynders, 1993; Chave et al, 2005):

- An *Operational Zone* immediately adjacent to the site of the spring to prevent rapid ingress of contaminants to the spring (also referred to as the '*Accident Prevention Zone*').
- An *Inner Protection Zone* based on the time expected to be needed for a reduction in pathogen presence to an acceptable level (often referred to as the '*Microbial Protection Area*').
- An *Outer Protection Zone* based on the expected time required for dilution and effective attenuation of slowly degrading substances to an acceptable level. A further consideration in the delineation of this zone is sometimes also the time needed to identify and implement remedial intervention for persistent contaminants.
- A further much larger zone, the *Total Capture Area*, sometimes covers the total catchment area of a particular abstraction where all water will eventually reach the abstraction point. This is designed to avoid long term degradation of quality.

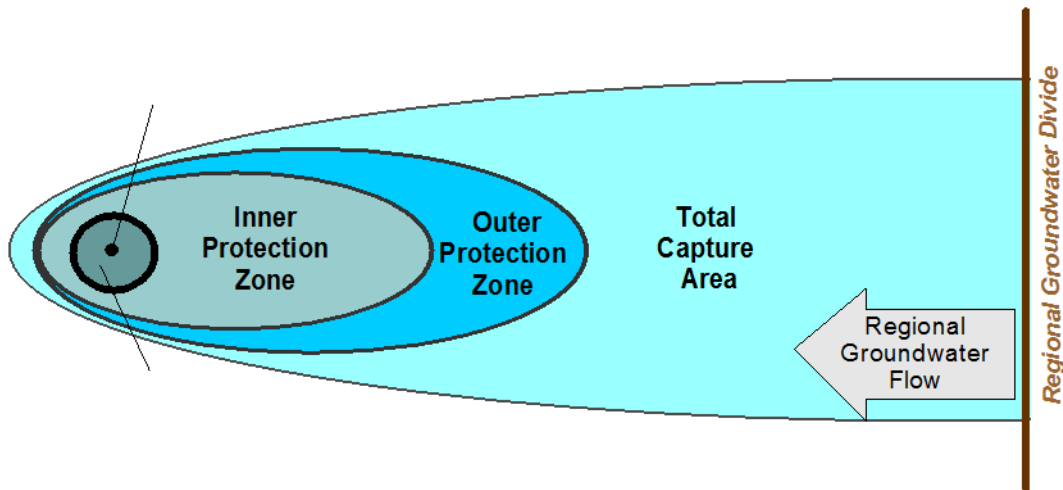


Figure 6-1. Common protection areas delineated around drinking water supplies (DWAF, 2008).

### 6.2.2 Results

The developed numerical model was used in combination of the reverse particle tracking method to delineate the time-of-travel based on the capture zone of the wells. The time-of-travel capture zones were used to rank the degree of risk based on the contaminant travel time to reach the water supply wells. For the Maloney's Eye the following criteria was used:

- Zone 1 – Immediate vicinity of the Maloney's Eye – 150 m (fixed radius).
- Zone 2 – Inner protection zone – 100 day time-of-travel (*Due to the extremely high conductivity of the dolomite the zone falls within the immediate vicinity of the Eye*).
  - Is based on the information that enteric viruses survive in water and water for an average 100 days.
  - This zone also includes the time required to ensure the natural or appreciable reduction in microbiological organisms, which is 50 days (EPA, 1993).
- Zone 3 – Outer protection zone – 5, 10 and 20 year time-of travel
  - In the case of severe pollution (e.g. hazardous spill) within the recharge area of the wellfields (A delay of groundwater within the aquifer of at least 10 years is needed (EPA, 1993)).
- Zone 4 – Capture zone – The entire Steenkoppies DC forms the catchment area of the Maloney's Eye and is therefore regarded as the capture zone based on the premise that all water within the zone will eventually reach the production wells (< 50 years).

Based on the simulated time-of-travel for the Maloney's Eye protection zones were captured (Figure 6-2). The end points of the simulated paths (Travel Lines) represent the origins in the groundwater system of particles that would eventually reach the Maloney's Eye within the identified period.

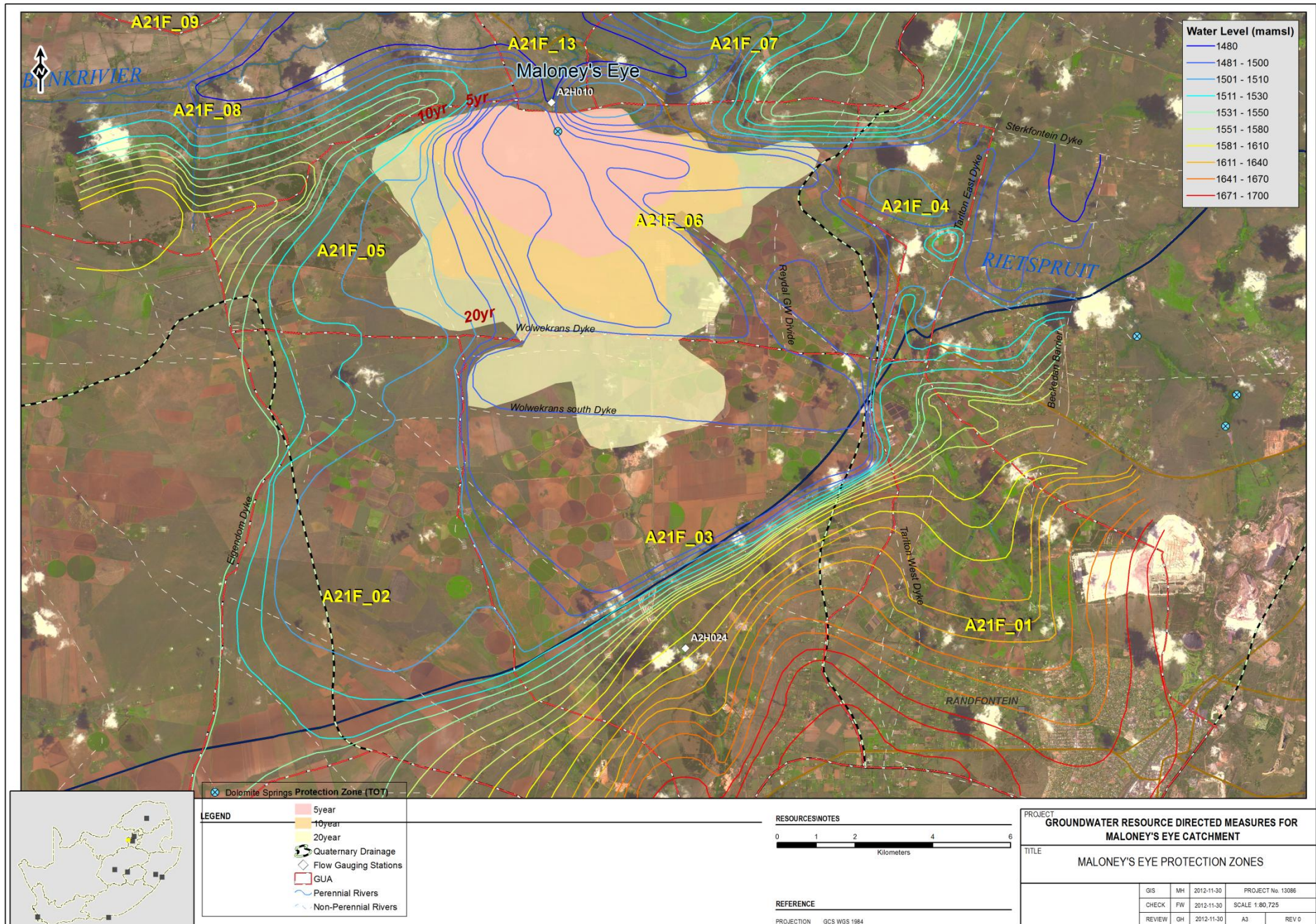


Figure 6-2. Protection zones for the Maloney's Eye based on travel time of particles.

## 7 CONCLUSIONS AND RECOMMENDATIONS

The Steenkoppies DC hosts one of the most valuable resources of groundwater in the country, key to an irrigated agricultural industry worth three quarters of a billion Rand and employing thousands of people. The flow of the Maloney's Eye spring also depends on the groundwater in the compartment. A steady increase in irrigation has taken place since the 1970's in the Steenkoppies DC, and sporadic attempts to resolve the water crisis in the compartment before it occurred have not been successful. It is considered that there is enough data to make certain fundamental recommendations.

It is evident that irrigation abstraction influenced the flow of the Maloney's Eye significantly since the mid 1980's. The flow simulated for pristine conditions (no abstraction) indicate a minimum flow of 450 l/s (14.2 Mm<sup>3</sup>/a) from the Maloney's Eye for the period 1908-2011.

Crucial to the sustainable use of the groundwater resource in the Steenkoppies and Lower Magalies River is the establishment of a groundwater management plan. Numerous studies have documented and reported on measures to better manage the Maloney's Eye (e.g. Bredenkamp et al., 1987, Barnard, 1997 and Holland, et al., 2009). However, a groundwater management plan that provides the framework to implement a long groundwater management strategy is lacking. As a result, although, the Steenkoppies Aquifer Management Association (SAMA) is in the process of establishing a WUA and the farmers are keen to install flow meters, rainfall stations and to equip boreholes with loggers to improve management of their groundwater resource. However, the roles and responsibilities need to be established and at this stage it's unclear what DWA's role is but it's hoped that they will assist with the interpretation of the data and assist with management of the resource. There remains, however, the problem of inadequate technical capacity at DWA.

A regional groundwater model has been developed for the Steenkoppies DC and the Lower Magalies River. The model can be utilized to simulate the effect of different operational and management scenarios and their impact on the flow of the Maloney's Eye. The presented model can be used as a tool to determine the optimal abstraction rate while giving cognizance to the sustainability of the resource. With minimal further customization the model can be expanded to a mass transport model to simulate water quality impacts across the entire quaternary catchment

Groundwater protection zones have been developed and proposed for the Maloney's Eye. By placing some form of regulatory control on activities taking place on land which falls within the various zones, their impact on the quantity (and quality) of the Eye can be minimised. The concept can be applied to currently utilized groundwater resources as well as to aquifers (boreholes) that might be utilised at some time in the future.

Groundwater protection zones may be a key component of a management plan for a given groundwater supply, and protection zones would typically be control measures in this context. This would subject them (a) to operational monitoring for assessing whether or not the required restrictions on land use and control of human activities are in place, and (b) to verification for checking whether they are indeed effectively protecting groundwater at the point of abstraction. Groundwater quality monitoring in this context would serve to verify the effectiveness of the specific protection zone concept in terms of both its design and implementation. However, monitoring implementation and verification of water quality are equally important for supplies that are not incorporated in a management plan.

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**APPENDIX A – Gravity survey A1 map**

## **APPENDIX B – Numerical groundwater model report**