water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

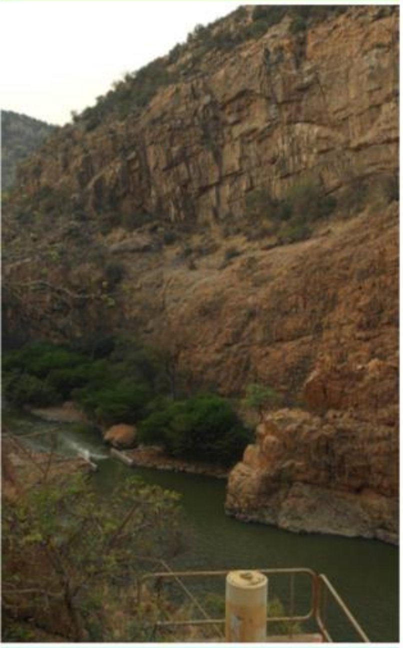
REPORT NO: PWMA 01/000/00/02914/6





THE DEVELOPMENT OF THE LIMPOPO WATER MANAGEMENT AREA NORTH RECONCILIATION STRATEGY

GROUND WATER ASSESSMENT AND UTILISATION



FINAL

DECEMBER 2015

W78_2014/J02173

Project Name	***Limpopo Water Management Area North Reconciliation Strategy***
Report Title	***Groundwater Assessment and Utilisation***
Authors	***CJ Sonnekus, R Titus and I Bleche***
DWS Report No.	***PWMA 01/000/00/02914/6***
DWS Contract No.	***WP 10768***
PSP Project Reference No.	***60326619***
Status of Report	***Final***
Date:	***December 2015***

CONSULTANTS: AECOM in association with Hydrosol, Jones & Wagener and VSA Rebotile Metsi Consulting

*Approved for **AECOM***

FGB de Jager	***JD Rossouw***
Task Leader	*Study Leader*

DEPARTMENT OF WATER AND SANITATION (DWS)
Directorate: National Water Resource Planning

*Approved for **DWS***

Reviewed: Dr B L Mwaka	***T Nditwani***
Director: Water Resources Planning Systems	*Acting Director: National Water Resource Planning*

Prepared by:

AECOM

AECOM SA (Pty) Ltd
PO Box 3173
Pretoria
0001

In association with:

Hydrosol Consulting — hydrosol Water Resources Solutions

Jones & Wagener — Jones & Wagener Engineering & Environmental Consultants

VSA Rebotile Metsi Consulting — VSA Rebotile Metsi

Limpopo Water Management Area North Reconciliation Strategy

Date: December 2015

- **Phase 1: Study planning and Process Initiation**
  - PWMA 01/000/00/02914/1 **Inception Report**
- **Phase 2: Study Implementation**
  - PWMA 01/000/00/02914/2 **Literature Review**
  - PWMA 01/000/00/02914/3 **Hydrological Analysis**
    - PWMA 01/000/00/02914/3/1 Supporting Document 1: **Rainfall Data Analysis**
  - PWMA 01/000/00/02914/4 **Water Requirements and Return Flows**
    - PWMA 01/000/00/02914/4/1 Supporting Document 1: **Irrigation Assessment**
    - PWMA 01/000/00/02914/4/2 Supporting Document 2: **Water Conservation and Water Demand Management (WCWDM) Status**
    - PWMA 01/000/00/02914/4/3 Supporting Document 3: **Socio-Economic Perspective on Water Requirements**
  - PWMA 01/000/00/02914/5 **Water Quality Assessment**
  - PWMA 01/000/00/02914/6 **Groundwater Assessment and Utilisation**
  - PWMA 01/000/00/02914/7 **Yield analysis (WRYM)**
    - PWMA 01/000/00/02914/7/1 Supporting Document 1: **Reserve Requirement Scenarios**
  - PWMA 01/000/00/02914/8 **Water Quality Modelling**
  - PWMA 01/000/00/02914/9 **Planning Analysis (WRPM)**
  - PWMA 01/000/00/02914/10 **Water Supply Schemes**
    - PWMA 01/000/00/02914/10/1 Supporting Document 1: **Opportunities for Water Reuse**
    - PWMA 01/000/00/02914/10/2 Supporting Document 2: **Environmental and Social Status Quo**
    - PWMA 01/000/00/02914/10/3 Supporting Document 3: **Screening Workshop Starter Document**
  - PWMA 01/000/00/02914/11A **Preliminary Reconciliation Strategy**
  - PWMA 01/000/00/02914/11B **Final Reconciliation Strategy**
  - PWMA 01/000/00/02914/12 **International Obligations**
  - PWMA 01/000/00/02914/13 **Training Report**
- **Phase 3: Study Termination**
  - P WMA 01/000/00/02914/14 **Close-out Report**

Executive summary

The Department of Water and Sanitation (DWS) identified the need for a Reconciliation Strategy for the Limpopo Water Management Area (WMA) North to provide solutions for an adequate and sustainable water supply up to 2040. AECOM SA (Pty) Ltd, in association with three sub-consultants Hydrosol, Jones and Wagener and VSA Rebotile Metsi Consulting were appointed to compile the strategy that will identify and describe water resource management interventions resulting from the current and future water requirements with the available surface and groundwater resources of the WMA up to the year 2040. This report represents a desktop assessment of the groundwater component which focussed on the occurrence, quantity, quality, availability, utilization and abstraction of groundwater in the WMA.

For the study the current abstraction of groundwater was evaluated and compared to the harvest potential (available groundwater storage) and exploitation potential (extractable groundwater, generally less than the harvest potential due to natural and logistical reasons) obtained from various previous studies to assess if the estimated future demands can be met within the catchments and present schemes.

Groundwater availability and property data for the study was obtained from the National Groundwater Archive (NGA), the GRIP database and previous Groundwater Resource Assessment studies (GRA1 and GRA2). Groundwater quality data was obtained from the DWS Water Management System (WMS).

The northern border of the WMA is the Limpopo River, which flows in an north-easterly and later easterly direction into Mozambique and drains into the Indian ocean. Six major river systems, the Matlabas, Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele, together with other smaller tributaries, all flow north into the Limpopo River and make up the six tertiary catchments.

The WMA regional geology of mostly granites, gneisses, schists and sandstones influences the morphology which can generally be described as plains with low to moderate relief with areas of low to higher mountains with or without plateaus. Surface water run-off and its contribution to the recharge of the aquifers (underground water storage areas) in the WMA is dependent on the morphology and the climate, with evaporation generally exceeding precipitation, which decreases from 700 mm in the south to 300 mm in the north and north-west.

The aquifers in the WMA are characterised by the lithology and structural geology of the area in which they occur. They range from poor to moderate in terms of quality (chemically influenced by the rocks) and quantity (yield) in mafic and granitic zones to good and very good aquifers in some of the gneiss zones and sandstones, mostly associated with weathering of the rocks and faults, and a dolomitic zone (karst – large underground voids due to chemical weathering). Some of the latter have been developed as well fields and single source (boreholes) supplies but also significant to water supply are the shallow alluvial deposits of sand and silt in the major rivers.

Higher nitrate and fluoride concentrations are natural in certain areas due to underlying geology, but increased nitrate may also be due to human influences like irrigation and sanitation and therefore is prevalent in densely populated rural areas and large irrigation schemes.

From the monitoring of water levels over a long period of time (from 1960 to present) it is evident that these have dropped considerably in the last 20 years in the central area of the WMA due to increased abstraction for irrigation and water supply to the rural and urban population. Individually analysed water levels in some of the boreholes on the other hand show rising water levels due to wetter years (increasing recharge) or changed groundwater use (e.g. ceasing irrigation in the area).

The highest recharge in the WMA occurs in the south western part and the southern border in the north-eastern part, both areas of which are mainly underlain by sandstones with prevalent fracturing/weathering. Although the recharge is high in these areas the available storage (harvest potential) and exploitable volumes are lower than in the northern, central and north-eastern parts of the WMA. Using the present groundwater utilisation data and comparing it with the exploitable volumes shows that the central and southern central areas (from Polokwane to the north-west and north-east of Mogwadi are over-utilised (using more groundwater than can be safely abstracted without lowering the groundwater levels). This is also evident from the deeper water levels observed in these areas.

The water schemes in the WMA vary greatly in size from individual irrigation centre pivots to large rural/semi-urban water supply areas. Calculating their available storage and exploitability makes little sense as their groundwater resource is not restricted to their area and is often influenced by neighbouring schemes and catchments, conjunctive use with surface water and sometimes even transfer from outside the WMA. However, the schemes were evaluated in terms of present groundwater use, available boreholes, *tested groundwater availability and necessary interventions recommended for future sustainability. These include the testing and equipping of readily available boreholes.*

The evaluation of the water balance per quaternary catchment show that some of the catchments are already over-utilised in terms of groundwater and will not be able to sustain the current usage in future while other catchments will only reach those levels in 2030 or 2040. The same applies to the schemes where the analysis of the water balance shows that about 20% of the schemes have already reached the upper limit of exploitability and will not be able to expand or sustain future use.

Proposed intervention measures for future sustainable supply include a) groundwater management with constant database updates of water levels, rainfall and chemistry, b) artificial recharge (injection of water into boreholes and increasing infiltration) in suitable areas, c) development and utilisation of natural (riverbeds) and artificial (old mines) subsurface storage and d) the development of new sources.

The conclusions of the reconciliation study show that there are areas (catchments and schemes) already under stress due to over-utilisation resulting in declining water levels. The recommendations therefore are more efficient groundwater management by implementing monitoring systems (abstraction and water levels) and further development of groundwater sources by means of well fields in suitable (under-utilised) areas and possible creation of artificial underground storage areas.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

APPENDICES

APPENDIX A AQUIFER UNITS AND LITHOLOGY MAPS

APPENDIX B GROUNDWATER CHEMISTRY MAPS

APPENDIX C GROUNDWATER CHEMISTRY TABLES

APPENDIX D MAXIMUM YIELD TABLES

APPENDIX E GROUNDWATER LEVEL GRAPHS

APPENDIX F WATER LEVELS (“HEATMAPS”) MAPS

APPENDIX G GRA 2 DATASET TABLES

APPENDIX H RECHARGE, HARVEST POTENTIAL AND EXPLOITATION POTENTIAL MAPS

APPENDIX I INTERVENTION POTENTIAL AND COST ESTIMATES

APPENDIX J WATER BALANCES TABLES

LIST OF ABBREVIATIONS

AECOM	AECOM SA (Pty) Ltd
CDR	Cumulative Rainfall Departure
DM	District Municipality
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
GRA-1	Groundwater Resource Archive First Edition
GRA-2	Groundwater Resource Archive Second Edition
GRIP	Groundwater Resource Information Project
LM	Local Municipality
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
NGA	National Groundwater Archive
NGDB	National Groundwater Database
NWRS-1	National Water Resource Strategy First Edition
NWRS-2	National Water Resource Strategy Second Edition
RSA	Republic of South Africa
WARMS	Water Authorisation and Resource Management System
WCWDM	Water Conservation and Water Demand Management
WMA	Water Management Area
WMS	Water Management System
WRPM	Water Resources Yield Model
WRSM2000	Water Resources Simulation Model of 2000
WRYM	Water Resources Yield Model

LIST OF UNITS

kℓ	kilolitre
km	kilometre
ℓ/c/d	litre per capita per day
ℓ/s	litres per second
m^3	cubic meter
m^3/d	cubic meters per day
$m^3/km^2/a$	cubic meter per square kilometre per annum
pH	potential of hydrogen ions

1 INTRODUCTION

1.1 APPOINTMENT OF PROFESSIONAL SERVICE PROVIDER (PSP)

The Department of Water and Sanitation (DWS), then Department of Water Affairs (DWA) appointed **AECOM SA (Pty) Ltd** in association with three sub-consultants **Hydrosol**, **Jones and Wagener** and **VSA Rebotile Metsi Consulting** with effect from 1 March 2014 to undertake the **Limpopo Water Management Area North Reconciliation Strategy**.

1.2 BACKGROUND TO THE PROJECT

The DWS (then DWA) identified a need for the development of the Limpopo Water Management Area (WMA) North Reconciliation Strategy. The Limpopo WMA North refers to the Limpopo WMA described in the first edition of the *National Water Resource Strategy* (NWRS-1) published in 2004. The 19 initial WMAs were consolidated into nine WMAs during 2012 and acknowledged in the second edition of the *National Water Resource Strategy* (NWRS-2) of 2013. The newly defined Limpopo WMA also includes the original Crocodile (West) and Marico WMA as well as the Luvuvhu River catchment, previously part of the Luvuvhu and Letaba WMA. However, these additional areas will not be part of this Reconciliation Strategy.

The Limpopo WMA North comprises of six main river catchments; Matlabas, Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele and are shown in **Figure 1.1**. The very small Nwanedi River catchment forms part of the Nzhelele River catchment. Most of these river catchments rely on their own water resources and are managed independently from neighbouring catchments. This implies that some river catchments require separate and independent reconciliation strategies whilst others need integrated water management reconciliation strategies.

The main urban areas within the WMA include Mokopane, Polokwane, Mookgophong, Modimolle, Lephalale, Musina and Louis Trichardt. Approximately 760 rural communities are scattered throughout the WMA, mostly concentrated in the central region. The main economic activities are irrigation and livestock farming as well as expanding mining operations due to the vast untapped mineral resources in the area. The water resources, especially surface water resources, are heavily stressed due to the present levels of development. It is crucial that water supply is secured and well managed.

The most western area of the Limpopo WMA North, the Matlabas River catchment, is a dry catchment with no significant dams and with a low growth potential for land-use development.

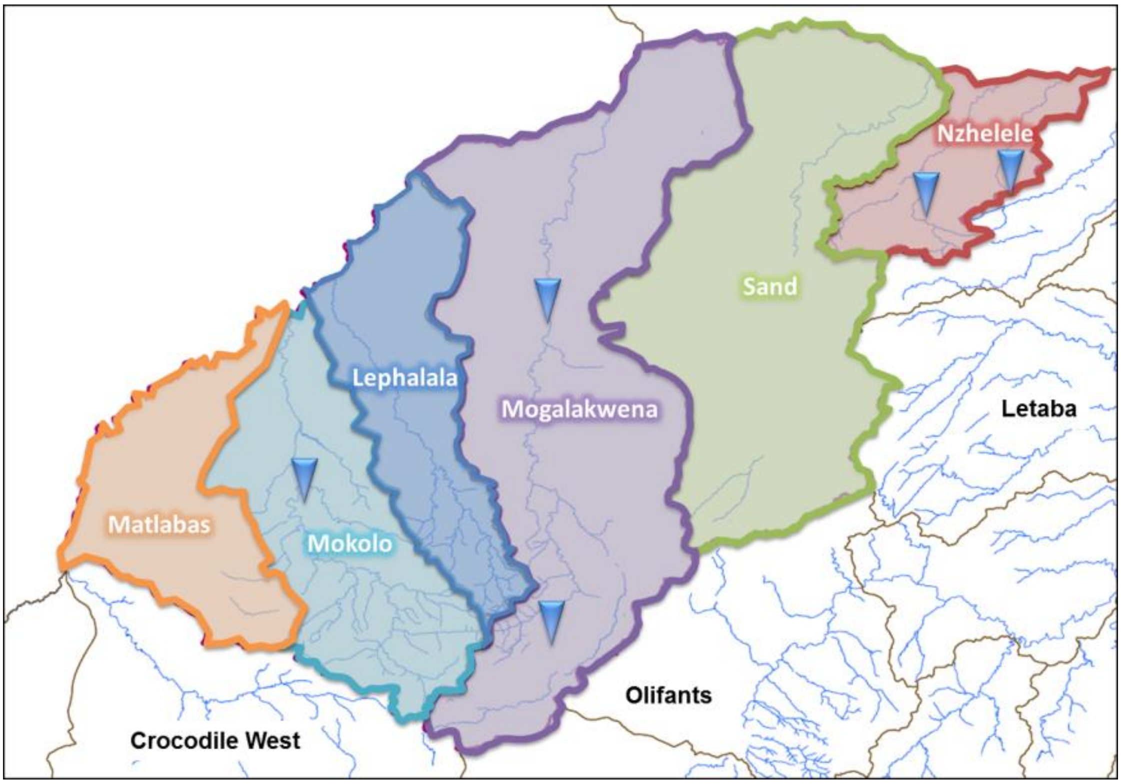


Figure 1.1 Overview of the catchments of the Limpopo WMA North

The large Mokolo Dam, in the Mokolo River catchment, supplies water to the Matimba Power Station, Medupi Power Station, Grootegeluk Coal Mine, the Lephalale Local Municipality (LM) as well as a number of downstream irrigators. The dam is able to meet the bulk of the current requirements but will in future rely on transfers from other WMAs to meet the water requirements at a sufficiently high assurance of supply.

The middle reaches of the Lephalala River catchment have a high conservation value with irrigation activities dominant in the remainder of the catchment. Irrigation in this area is supplied by surface water and alluvial aquifer abstraction.

The bulk of the water resources in the Mogalakwena River catchment have been fully developed. The Doorndraai Dam is over-allocated. Additional water to support the rapid expanding mining activities in the vicinity of Mokopane needs to be augmented by transfers from the Flag Boshielo Dam in the adjacent Olifants River Catchment. Glen Alpine Dam presently supplies water to emerging farmers, who has not yet taken up their full allocated quota, and is expected to supply the growing domestic requirements in future.

Groundwater resources in the Mogalakwena and the Sand river catchments have been extensively utilised, and possibly over-exploited by the dominating irrigation sector. The expanding urban and industrial requirements of Polokwane and Makhado LMs, currently supplied by Albasini Dam, rely heavily on water transfers from adjacent WMAs. This includes transfers from the Ebenezer Dam, Dap Naude Dam, Flag Boshielo Dam and Nandoni Dam in the Olifants WMA.

Domestic and irrigation water in the small but highly developed Nzhelele River catchment is supplied through the Mutshedzi Dam Regional Water Supply Scheme and the Nzhelele Dam Regional Water Supply Scheme as well as extensively from groundwater resources. The inflows to the Mutshedzi and Nzhelele dams have been reduced as a result of afforestation upstream of these dams. The area is in deficit due to the over-allocation and over development of irrigation.

The Sand and Nzhelele river catchments have high coal mining potential but the availability of local water resources may limit future mining development.

1.3 STUDY AREA

The Limpopo WMA North is the most northern WMA in South Africa and refers to the area described as the Limpopo WMA in NWRS-1. Refer to **Figure 1.2** for the location and general layout of the study area. The areas indicated in grey show the additional catchment and WMA areas included in the Limpopo WMA as per NWRS-2 and which do not form part of the study area for this reconciliation strategy.

The Limpopo WMA North forms part of the internationally shared Limpopo River Basin which also includes sections of Botswana, Zimbabwe and Mozambique. The Limpopo River forms the entire length of the northern international border between South Africa and Botswana and Zimbabwe before flowing into Mozambique and ultimately draining into the Indian Ocean. The dry Limpopo WMA North is augmented with transfers from the adjacent Letaba, Olifants and Crocodile West river catchments. No transfers are currently made from the Limpopo WMA North to other WMAs.

The main rivers in the study area, which form the six major catchment areas, are the Matlabas, Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele rivers. These rivers, together with other smaller tributaries, flow northwards and discharge into the Limpopo River.

The climate over the study area is temperate and semi-arid in the south to extremely arid in the north. Mean annual rainfall ranges from 300 mm to 700 mm with the potential evaporation well in excess of the rainfall. Rainfall is seasonal with most rainfall occurring in the summer with thunderstorms. Runoff is low due to the prevalence of sandy soils in the most of the study area, however, loam and clay soils are also found.

The topography is generally flat to rolling, with the Waterberg on the south and the Soutpansberg in the north-east as the main topographic features. Grassland and sparse bushveld shrubbery and trees cover most of the terrain.

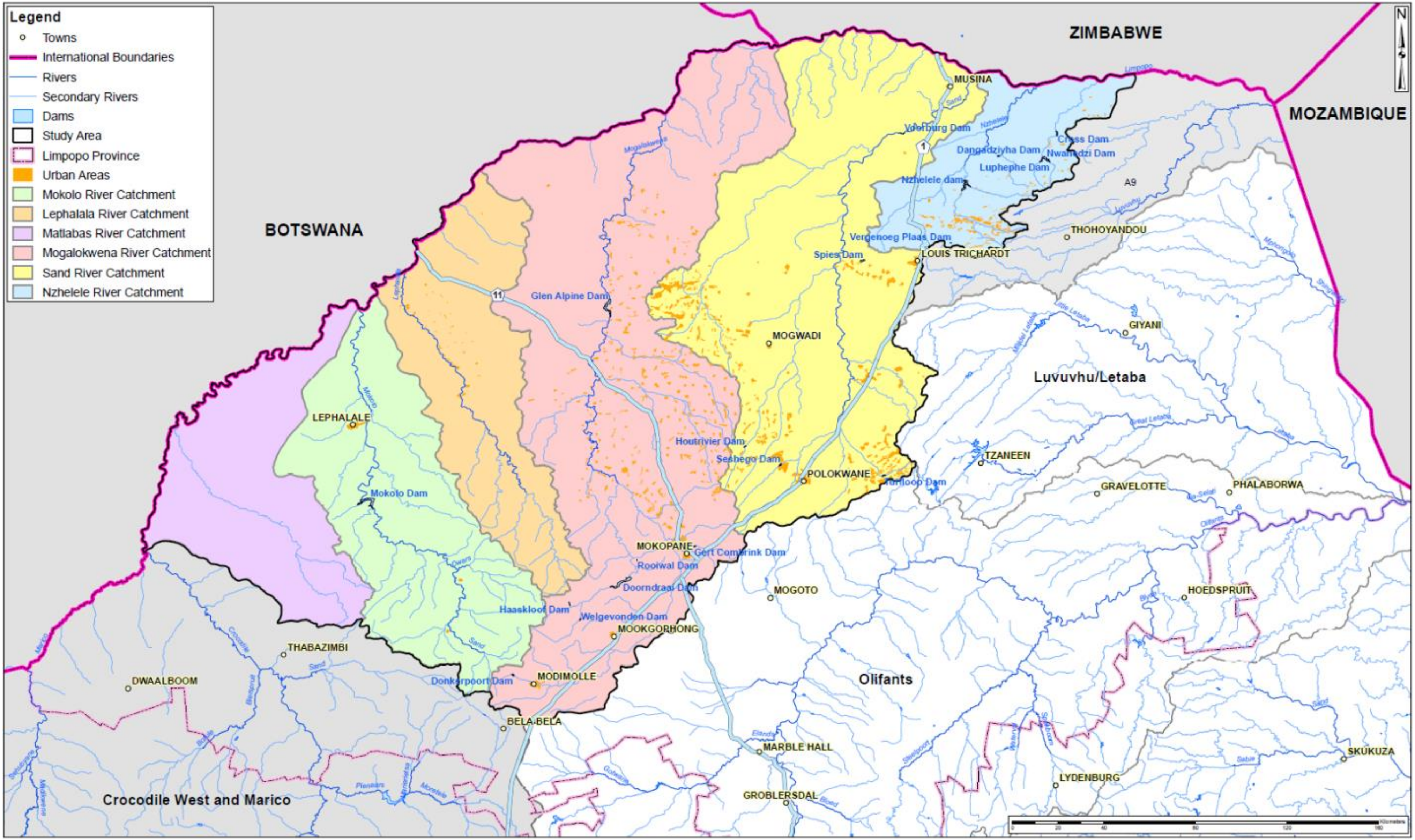


Figure 1.2 General layout of the study area

The southern and western parts of the WMA are mainly underlain by sedimentary rocks, whilst metamorphic and igneous rocks are found in the northern and eastern parts. With the exception of some alluvium deposits and dolomites near Mokopane and Thabazimbi, these formations are mostly not of high water bearing capacity. The mineral rich Bushveld Igneous Complex extends across the south-eastern part of the WMA, and precious metals are mined at various localities throughout the area. Large coal deposits are found in the north-west.

Several wildlife and nature conservation areas have been proclaimed in the WMA, of which the Nylsvley Nature Reserve, Mapungubwe National Park and the Marekele National Park are probably the best known.

1.4 MAIN OBJECTIVES OF THE STUDY

The main objective of the study is to formulate a water resource reconciliation strategy for the entire Limpopo WMA North up to 2040. The Reconciliation Strategy must:

a) address growing water demands as well as water quality problems experienced in the catchment,

b) identify resource development options and

c) provide reconciliation interventions, structural and administrative/ regulatory.

To achieve these objectives, the following aspects are included in the study:

- Review of all available information regarding current and future water requirements projections as well as options for reconciliation;
- Determine current and future water requirements and return flows and compile projection scenarios;
- Configure the system models (WRSM2000 rainfall-runoff catchment model, also known as the Pitman Model, the Water Resources Yield Model (WRYM) and the Water Resources Planning Model (WRPM) in the study area at a quaternary catchment scale, or smaller, where required, in a manner that is suitable for allocable water quantification. This includes updating the hydrological data and accounting for groundwater surface water interaction;
- Assess the water resources and existing infrastructure and incorporate the potential for Water Conservation and Water Demand Management (WCWDM) and water reuse as reconciliation options; and
- Develop a preliminary short-term reconciliation strategy followed by a final long-term reconciliation strategy.

1.5 SCOPE OF THIS REPORT

The main objective of the report is to compile a Reconciliation Strategy that will identify and describe water resource management interventions. This can be grouped and phased to jointly form a solution to reconcile the current and future

Limpopo WMA North up to the year 2040. This report represents a desktop assessment of the groundwater component of the WMA. The assessment focused on the occurrence, quantity, quality, availability, utilisation and abstraction of groundwater. The maximum yield and quality characteristics of the groundwater was evaluated using the latest (March 2015) available groundwater data and the same aquifer units as depicted on the 1:500 000 hydrogeological map series. The evaluation on the availability, utilisation and abstraction of groundwater was done to quaternary catchment and water scheme level to investigate and identify the most favourable previously identified options for groundwater development. Groundwater in the WMA is used as a single source, as a cluster of sources (well fields) and in conjunctive use with surface water; the information is presented as tables and maps. The current abstraction of groundwater was evaluated to the harvest potential and exploitation potential to assess if the estimated future demands can be met within the schemes. Areas with possible excess groundwater were identified as target zones for future groundwater development.

The strategy focuses on domestic supply as the basic domestic needs are prioritized above other users. Other water users that need water such as mines, industries and agriculture are not ignored in the Strategy as the development and continuation of it is equally important for future economic development. The future demands of these users were not always available for evaluation but the current estimated use and availability on catchment level will give an indication of the feasibility of large developments. Mining companies in general conduct large scale studies to ensure water supply to mines, this data was however not readily available for the strategy. The cost estimates on the water schemes were divided into maintenance cost and future development cost estimates. Available information was obtained from various reports, including the small town study reports, municipal master and IDP plans as well as from the Groundwater Resource Information Project (GRIP) database.

In short the reconciliation strategy must a) address growing water demands as well as water quality problems experienced in the catchment, b) identify resource development options and c) provide reconciliation interventions, structural and administrative regulatory. Within the study area groundwater resources are essential; its current and future use is either as a sole resource on a local scale or as a supplementary/conjunctive source to surface resources that is usually on a larger regional scale.

This report covers Task 3e: Groundwater assessment and groundwater surface interaction and Task 10: Groundwater Utilisation scenarios.

The objective of Task 3e was to assess groundwater resources using the following approaches:

- Desktop assessment of the characteristics of the groundwater resource. Delineation of groundwater units based on hydrogeological criteria and the distribution of lithology's per Quaternary catchment.
- A graphic and tabular overview of the available groundwater resources (at least on quaternary level) in terms of groundwater harvest potential, exploitation potential and base flow as per the groundwater Resource Archive GRA2 and other sources. Dolomitic areas were to be highlighted in the analysis.
- Assessment of the Basic groundwater quality in each groundwater unit.
- Modelling of the surface-groundwater interactions using WRSM2000, using project derived estimates of groundwater use and calibration against observed base flow and recharge figures. (addressed in the hydrological report)
- Assumptions of historical growth in groundwater use with best available current day use data and estimates for the whole WMA.
- A desktop assessment of the Groundwater Reserve (where data are available and identification of places where Reservoirs will be required).
- Groundwater balance to compare the existing available groundwater per quaternary to the estimated current utilisation and reserve requirements.

The objectives of Task 10 were to focus on assessing various scenarios related to groundwater use. The sub-tasks were:

- Select the most favourable previously identified options for groundwater development.
- Identify options for conjunctive use of surface and groundwater.
- Prepare cost estimates of schemes including their yield, storage, water quality, unit cost, infrastructure cost, URV, Reserve requirements and environmental impacts

2 INVESTIGATION APPROACH

2.1 SCALE OF INVESTIGATION

Groundwater resources were assessed to various levels in terms of:

- Quaternary catchment.
- Aquifer unit.
- Water supply schemes.

Utilisation of groundwater was assessed to various levels in terms of:

- Quaternary catchment.
- Water supply schemes.

2.2 DATA SOURCES

The investigation was based on existing data collated from:

- The National Groundwater Archive (NGA).
- The GRIP database for Limpopo Province.
- The GRA 2 database.
- The WMS database.
- WARMS data and the irrigation water use verification study.
- Published maps from the GRA 1 project and other sources: 1:500 000 hydrogeological map series, 1:250 000 geological map series, Groundwater resources of South Africa, Groundwater Harvest Potential and various other maps.
- Mines, industries, municipalities, border posts.
- Various reports and previous studies.

The National Groundwater Archive (NGA) is a comprehensive borehole database of South Africa and is managed by DWS. The GRA1 and the GRA2 assessment report commented that the quality of data is variable with a common problem incompleteness of records, positioning of boreholes at the centre of cadastral farms (especially with older records) and the apparent decline in data capturing in recent years.

The GRIP database for the Limpopo Province is more detailed especially for areas with rural settlements. DWS is in a process to import GRIP data to the NGA. The Groundwater Resource Assessment process phase 1 (GRA1) resulted in the hydrogeological map series for South Africa with the completion of 21 maps in 2003. Estimates on the available groundwater volumes that can be abstracted did not form part of the map series, and the Groundwater Resource Assessment process 2 (GRA2) began to resolve this by addressing quantification of the resource, recharge and groundwater/surface interactions, the classification of aquifers and the quantification of groundwater use for the whole country. The review of the process in 2009 highlighted the relative lack of groundwater data in South Africa and questioned some of the algorithms used in the process; results can therefore be misunderstood by persons not familiar with the process. The most recent (January 2015) chemical data was obtained from the Water Management System (WMS) water quality database.

The basic chemical evaluation of the WMS was done using a combination of this data and GRIP data. Authorized water use data was obtained from the Water Authorisation Resource Management System (WARMS) data set; the irrigation abstraction data used were from the verified data set (DWA, 2013a). Various published maps on geology, hydrogeology, vegetation etc. were used in the study; lists are included in the reference section of the report. Attempts were made to obtain up to date data from mines, industries and other large users of groundwater to verify existing use and to obtain an understanding of the future use, interventions, management strategies, protection strategies etc. Varied levels or no feedback was received. During the study various reports and previous studies were referenced to obtain information on the characteristics of groundwater in the area.

2.3 INVESTIGATIVE CONSIDERATIONS

Long-term negative trends of the regional static water level may be indicative of over-abstraction. To increase the level of confidence in the results of the water balances the available static water level data was plotted for different periods from 1960 to produce “heat maps’’ that represent regional water levels below surface and indicate “hot spots’’ (areas under stress). The effect of natural seasonal changes was minimized by using averages over a few years for each map. The migration of these hot spots over time is related to changes in irrigation methods and the movement of large scale irrigation farmers to more suitable areas as along the Limpopo River. The Sand River basin shows stress from 1980 in an area near Mogwadi (Dendron), this is related to irrigation. The irrigation in this area decreased as the cost of pumping became uneconomical. From 1995 the decrease in water levels in this catchment is related to increased domestic use as well as irrigation along the Sand River north of Polokwane. Treated sewerage (13.78 million m^3/a) from the Polokwane municipal treatment plant are pumped to the mines north of Mokopane and also into the Sand River. It is believed that this contribution to the Sand River helps to sustain irrigation in the catchment. This water originates from the Levuvhu / Letaba WMA. Farming is controlled by economic factors, if the water level decreases to an unsustainable level the irrigation will stop, while rural villages do not disappear and intervention is needed to sustain supply.

To evaluate the longer period fluctuations between wet and dry cycles, time series data for several boreholes spread over the area was also plotted, and, where possible, the data of the closest rainfall station added to the same graph.

For domestic areas possible intervention actions may include artificial recharge and protection of the low lying areas against erosion (recharge areas especially in the areas underlain by rocks of the basement complex). The feasibility of such intervention proposals will need to be investigated for each area. Factors to take into consideration will include, but not limited to, the availability of nearby surface sources, geology, usage and economic factors. If the usage is domestic intentional intervention needs to be investigated, if the usage is agriculture economic factors will lead to a change in irrigation methods, change in crop or type of farming. Migration of large scale irrigation farming to more suitable areas such as the Weipe area near the Limpopo is an example of the effects of natural intervention.

Interventions to protect water quality within the WMA will include, but not limited to, the enforcement of the mandatory conditions as listed under the various sections of the Water Law. The basis of effective groundwater management is based on the availability of reliable long term data. The GRA2 study identified more data-intensive groundwater assessment methodologies. There is a need for increasing data density and availability on a centralized database, to ensure that future studies have adequate data. Intervention to ensure the continuation of data capturing and verification of data on the groundwater database of the Limpopo Province (GRIP data) and the continuous migration of this data to the National Groundwater Archive (NGA) is essential. Intervention to increase the current Provincial monitoring network for groundwater levels is recommended. In addition data that is monitored as part of the mandatory conditions of registered users must be added to the Provincial database. This includes the monitoring of quality, abstraction and water levels at specific intervals and at specific locations.

The basic calculation of groundwater availability can be compared to inflow and outflow in a dam; the storage capacity can be compared to the volume of the dam. The calculation to determine the inflow, outflow and storage of groundwater is more complex as it cannot be physically measured to exact volumes. Inflow (recharge) into the system is dependable on parameters such as ”effective rainfall” (intensity and duration), infiltration that is controlled by factors such as the character of the overburden, unsaturated zone, slope and vegetation. Outflow would be parameters such as evapo-transpiration, base flow, flow into adjacent aquifers and physical abstraction. Abstraction of groundwater due to pumping is the only outflow parameter that can be accurately measured; for regional studies abstraction will always be 'calculated estimates' with assumptions as accurate data is not available. The calculation of abstraction is dependent on the methodology followed and the accuracy of data sets used. The capacity of dams can be accurately measured, in groundwater the subsurface is represented by inhomogeneous material; numeric models and calculations assumes homogeneous conditions. The magnitude of the aquifer extent is very large and the hydrological parameters assigned to the equations represent small values. It is a factor that must be kept in mind in the calculation of recharge, for instance a recharge of 1% of MAP; calculated as 2% will result in the doubling of the available volume of groundwater.

3 DESCRIPTION OF THE STUDY AREA

3.1 LOCATION

The Limpopo WMA North is the most northern water management area in South Africa. It forms part of the internationally shared Limpopo River Basin, which also includes sections of Botswana, Zimbabwe and Mozambique. The Limpopo River forms the entire length of the international border between the WMA, Botswana and Zimbabwe before flowing into Mozambique, draining into the Indian Ocean. The dry Limpopo WMA North is augmented from the adjacent Letaba, Olifants and Crocodile West River catchments. No transfers are currently made from the Limpopo WMA North to other WMAs.

3.2 SURFACE HYDROLOGY

The main river systems in the study area are the Matlabas, Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele. These rivers, together with other smaller tributaries, all flow northwards into the Limpopo River, the quaternary catchments making up the study area are summarised in **Table 3.1**. The major dams and surface sources significant to WMA is summarised in **Table 3.2**.

.

3.3 TERRAIN MORPHOLOGY

The morphology is a function of the underlying geology and structural history of the area. Areas underlain by rocks or the Basement Complex and Karoo Supergroup is characterized by plains with low to moderate relief; the Bushveld Complex forms lowlands with mountains; the Soutpansberg Group forms low mountains and the areas underlain by rocks of the Waterberg Supergroup forms conspicuous plateau. The terrain morphology is reflected in **Figure 3.1**.

Table 3.1 Drainage regions

River system	Tertiary drainage	Quaternary catchments	Description	Total area (km²)	% of WMA
Matlabas	A41	A41A, B, C, D	Matlabas	6 004	9.9
		A41E	Steenbokpan		
Mokolo	A42	A42A, B, C, D, E, F	Mokolo (Upper)	8 392	13.9
		A42G, H, J	Mokolo (Lower)		
Lephalala	A50	A50A, B, C, D, E, F	Lephalala (Upper)	6 721	11.1
		A50G, H	Lephalala (Lower)		
		A50J	Soutkloof		
Mogalakwena	A61	A61A, B, C	Nyl (Upper)	19 305	32.0
		A61D, E	Nyl (Middle)		
		A61F, G	Mogalakwena (Middle)		
		A61H, J	Sterk		
	A62	A62A, B, C, D, E,F, G, H, J	Mogalakwena (Middle)		
	A63	A63C	Doringsfonteintjie-spruit		
		A63A, B, ,D	Mogalakwena (Lower)		
		A63E	Kolope		
Sand	A71	A71A, B, C, D	Sand (Upper)	15 766	26.1
		A71E, F, G	Hout		
		A71H, J, K	Sand (Lower)		
		A71L	Kongoloop / Soutsloot		
	A72	72A,B	Brak		
Nzhelele	A80	A80A, B, C	Nzhelele (Upper)	4 197	7.0
		A80D, E, F, G	Nzhelele (Lower)		
		A80H, J	Nwanedi		
Total				**60 385**	

Table 3.2 Major dams and surface sources significant to WMA

Dam/surface source name	Drainage basin	River	Storage capacity (10^6 m^3)	Significance to WMA
Seshego		Mulaudzi		Rural water supply
Albasini		Luvuvhu	28.2	Makhado Municipality, transfer
Luphephe	A8	Luphephe	14.0	Irrigation
Mutshedzi	A8	Mutshedzi	2.3	Nzhelele North RWS 2.27 million m³/a, irrigation
Nwanedi	A8	Nwanedi	5.2	Regional water supply scheme, rural, nature reserve
Nzhelele	A8	Nzhelele	51.3	Irrigation, future mining, Nzhelele RWS 3.67 million m³/a
Houtrivier Mathala		Houtrivier		Houtrivier RWS 0.794 million m³/a
Glen Alpine	A6	Mogalakwena	18.9	Emerging farmers
Mokolo	A4	Mokolo	145.4	Matimba Power Station, Medupi Power Station, Grootegeluk Coal Mine, Lephalala urban RWS 17.2 million m³/a
Doorndraai	A6	Sterk	43.8	Mokopane 4.38 million m³/a requested additional allocation, mines
Turfloop				Rural water supply, nature reserve
Nandoni				Makhado RWSS 3.189 million m³/a
Dap Naude	B8	Broederstroom	1.9	Polokwane Municipality, transfer scheme
Ebenezer	B8	Groot Letaba	69.1	Mugabe RWSS, 1.36 million m³/a, Sebayeng-Digale RWSS 2.66 million m³/a, Segwasi RWSS 0.24 million m³/a, Badimong RWS 1.92 million m³/a, Laaste Hoop RWSS 0.06 million m³/a, Mankweng RWS 2 million m³/a, Polokwane, transfer scheme
Welgevonden / Frikkie Geyser	A6		0.93	Mookgopong RWSS 0.504 million m³/a, Irrigation estimated 1.38 million m³/a
Flag Boshielo (formerly Arabie)	B5	Olifants	185.1	Pipeline to be built to supply Mogalakwena and mines, Polokwane Municipality transfer scheme
Donkerpoort	A6	Klein Nyl	0.93	Modimole urban RWS 2.923 million m³/a
Roodeplaat Dam				Magalies water transfer: Modimole urban RWS 1.95 million m³/a
Limpopo River	A7	Limpopo		Musina RWS 8 million m³/a, various border posts 0.37 million m³/a, Weipe irrigation
Olifantspoort Weir				Transfer Olifants Sand RWSS, 23.83 million m³/a,
Blouberg Mountains				Taaibosgroet 0.068 million m³/a, Glenferness
Tshifiri / Murunwa Weir				Tshifiri Murunwa RWS 0.498 million m³/a

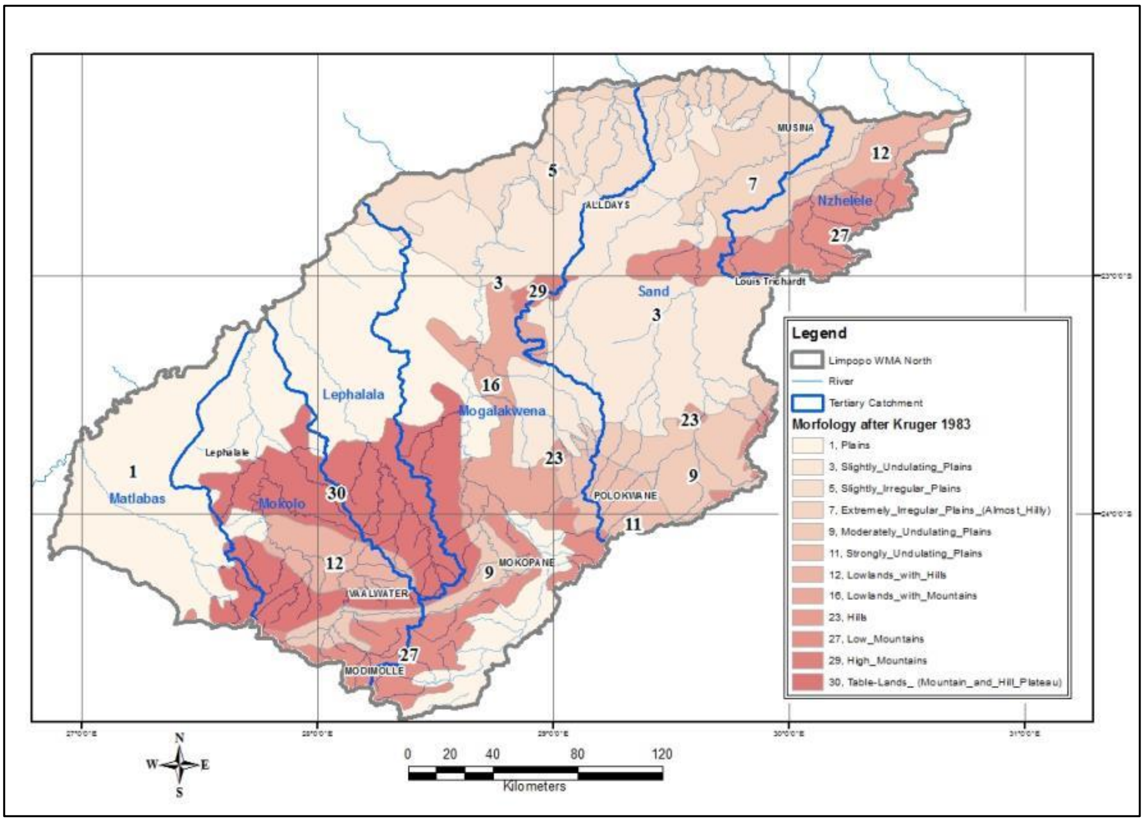


Figure 3.1 Terrain morphology (after Kruger 1983)

The morphology per quaternary catchment is summarised in Table 3.3 and the explanation for the terrain morphology is summarised in

Table 3.4.

3.4 CLIMATE

The study area falls within the summer rainfall area, rainfall events are irregular and mostly in the form of heavy thunder showers.

Precipitation decreases from 700 to 300 mm from the south to the north and north-west. The north eastern section along the Limpopo River has the lowest MAP. As a result of the generally high summer temperatures and low humidity, the potential evaporation is high ranging from 1 700 mm in the south to >2 000 mm in the north and north-west. The area around the Soutpansberg has an annual precipitation of 800 to 1 000 mm (see Figure 3.2) and a potential evaporation of 400 to 1 700 mm (see Figure 3.3). The average annual temperature is 23.6 °C.

Table 3.3 Morphology per quaternary catchment (only listed if more than 10%)

Major river system	Map symbol	Description	Quaternary catchments
Matlabas	1	Plains	A41A, A41B, A41C, A41D, A41D, A41E
	30	Table Mountains (mountains and hill Plateau)	A41A, A41B
Mokolo	1	Plains	A42H, A42J
	9	Moderately undulating plains	A42A, A42B, A42C
	12	Lowlands with hills	A42D, A42E, A42F, A42C
	30	Table Mountains (mountains and hill Plateau)	A42G, A42H
Lephalala	1	Plains	A50E, A50F, A50G, A50H, A50J
	12	Lowlands with hills	A50C
	30	Table Mountains (mountains and hill Plateau)	A50D, A50E, A50F
Mogalakwena	1	Plains	A61B, A61C, A61D, A61E, A61F, A61G, A62B, A62C, A62D, A62G, A62J, A63A
	3	Slightly undulating plains	A62E, A62F, A62G, A62H, A63A, A63B, A63C, A63D
	5	Slightly irregular plains	A63B, A63C, A63D, A63E
	9	Moderately undulating plains	A61H, A61J
	11	Strongly undulating plains	A61F, A61G, A62E
	16	Lowlands with mountains	A61G, A62A, A62B, A62C, A62F, A62G, A62H, A62J, A63A
	23	Hills	A62E, A62F
	27	Low mountains	A61A, A61B, A61C, A61D, A61E, A61F, A61G, A61H, A61J,
	29	High mountains	A63A, A63B, A63D
Sand	3	Slightly undulating plains	A71C, A71D, A71E, A71F, A71G, A71H, A71J, A71L, A 72A, A72B
	5	Slightly irregular plains	A71L
	7	Extremely irregular plains (almost hilly)	A71J, A71K, A71L, A72B
	9	Moderately undulating plains	A71A, A71B, A71C, A71E, A71F
	11	Strongly undulating plains	A71A, A71E, A71F
	23	Hills	A71C
	27	Low mountains	A71J
Nzhelele	1	Plains	A80J
	7	Extremely irregular plains (almost hilly)	A80F, A80G
	12	Lowlands with hills	A80G, A80J
	27	Low mountains	A80A, A80B, A80C, A80D, A80E, A80F, A80G, A80H, A80J

Table 3.4 Explanation for Figure 3.1 terrain morphology

Broad division	Map symbol	Description	Drainage density* (km/km^2)	Stream frequency (streams / km^2)	% of area with slopes <5%
Plains with low relief	1	Plains	0-2	0-6	>80%
	2	Plains and pans	0-2	0-6	>80%
	3	Slightly undulating plains	0-2	0-6	>80%
	4	Slightly undulating plains and pans	0-2	0-6	>80%
Plains with moderate relief	5	Slightly irregular plains	0-2	0-6	>80%
	6	Slightly irregular plains(scattered low hills)	0-2	0-6	>80%
	7	Extremely irregular plains (almost hilly)	2-3.5	6-10.5	>80%
	8	Slightly irregular undulating plains and occasional hills	0-2	0 - 6	>80%
	9	Moderately undulating plains	0-2	0 - 6	>80%
	10	Moderately undulating plains and pans	0-2	0 - 6	>80%
	11	Strongly undulating plains	0-2	0 - 6	>80%
Lowlands, hills and mountains with moderate and high relief	12	Lowlands with hills	0-2	0 - 6	50-80%
	13	Lowlands with parallel hills	0-2	0 - 6	50-80%
	14	Irregular undulating lowlands with hills	0-2	0 - 6	50-80%
	15	Strongly undulating lowlands with hills	0-2	0 - 6	50-80%
	16	Lowlands with mountains	0-2	0 – 6	50-80%
Open hills, lowlands with moderate to high relief	17	Dune hills with parallel crests and lowlands	0.5-2	0 - 6	20-50%
	18	Hills and lowlands	0.5-2	0 – 6	20-50%
	19	Parallel hills and lowlands	0.5-2	0 - 6	20-50%
	20	Undulating hills and lowlands	0.5-2	0 - 6	20-50%
	21	Mountains and lowlands	0.5-2	0 - 6	20-50%
	22	Undulating mountains and lowlands	0.5-2	0 - 6	20-50%
Closed hills and mountains with moderate and high relief	23	Hills	0.5-2	1.5 - 0.5	< 20%
	24	Parallel hills	0.5-2	1.5 - 0.5	< 20%
	25	Highly dissected hills	2-3.5	10.5 - 13.5	< 20%
	26	Undulating hills	0.5-2	1.5 - 10.5	< 20%
	27	Low mountains	0.5-2	1.5 - 10.5	< 20%
	28	Highly dissected low undulating mountains	2-3.5	10.5 - 13.5	< 20%
	29	High mountains	0.5-2	1.5 - 10.5	< 20%
Mountains with high relief	30	Table-lands (mountain and hill plateau)	0.5-2	1.5 - 10.5	< 80%

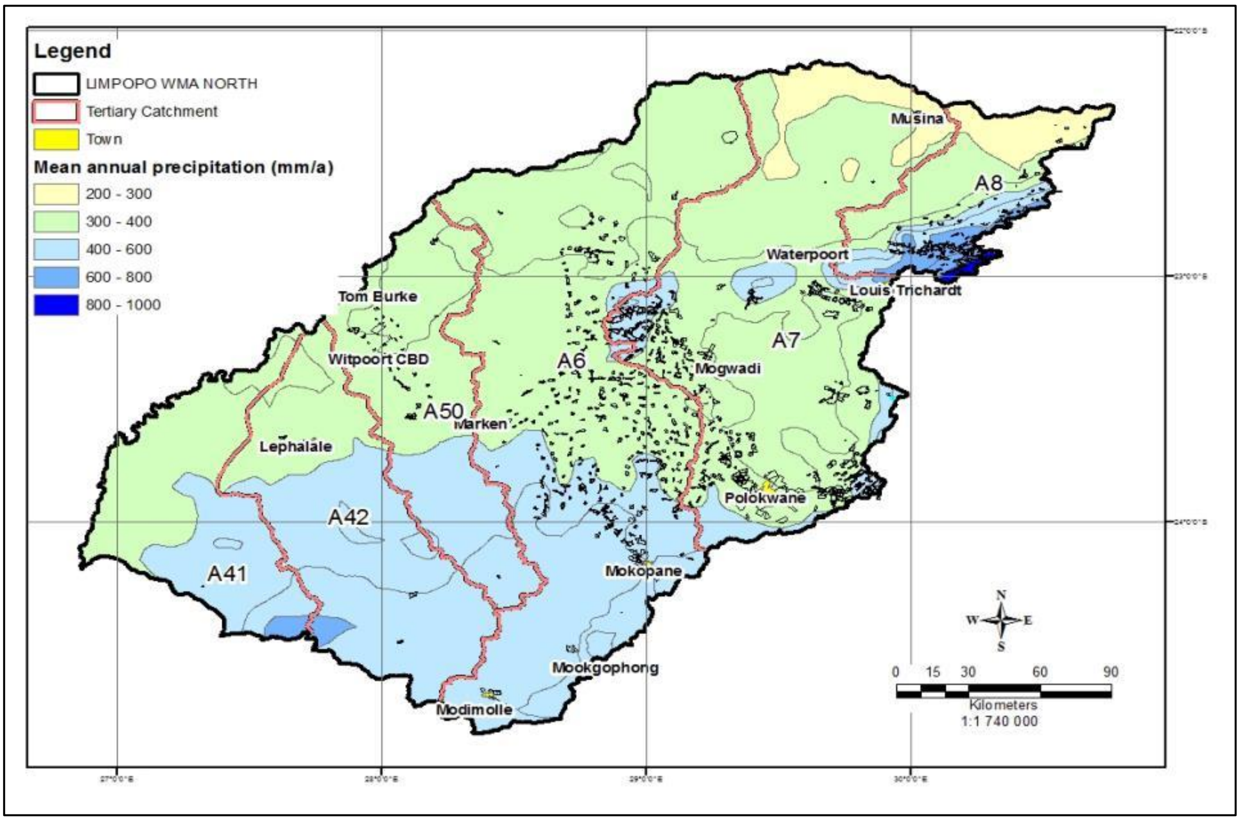


Figure 3.2 Mean annual precipitation

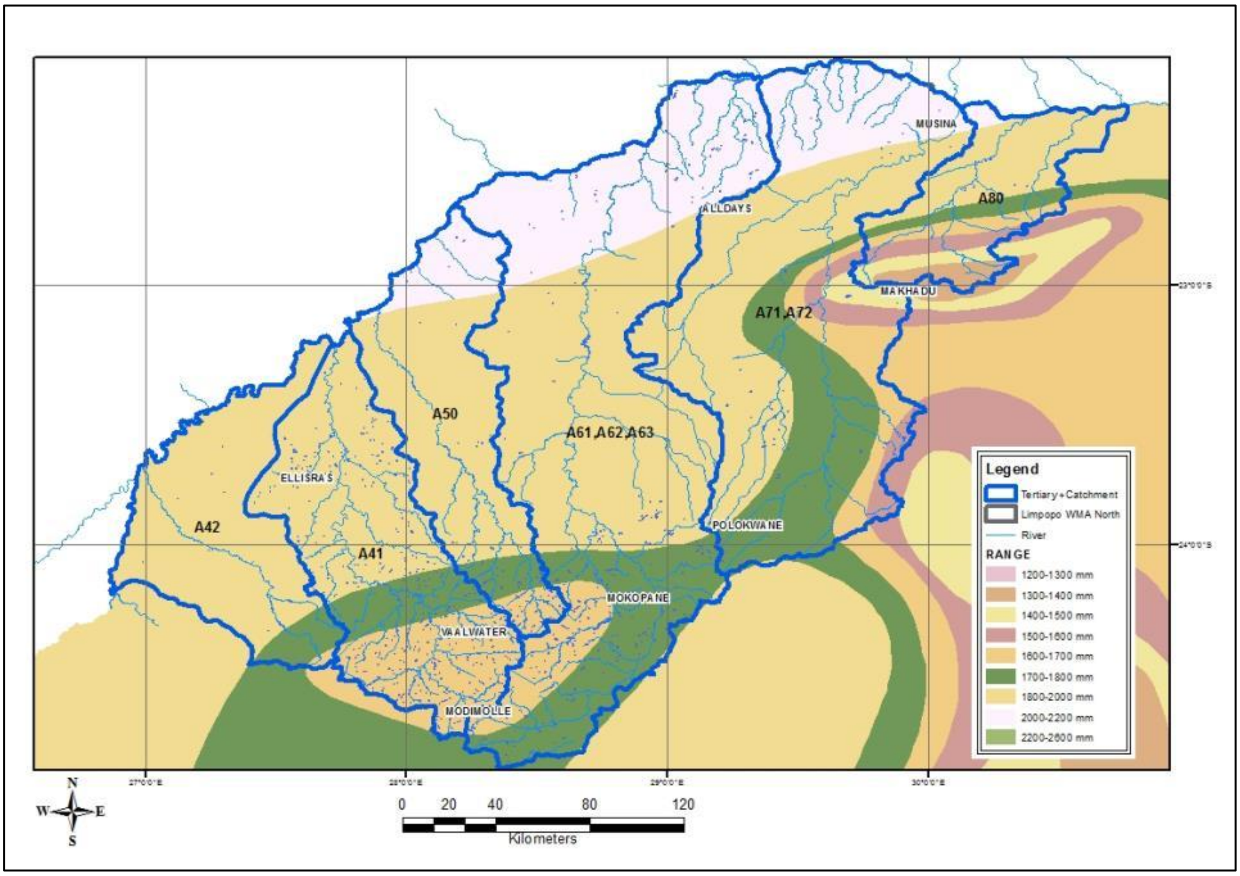


Figure 3.3 Mean annual evaporation

3.5 OVERVIEW OF THE REGIONAL GEOLOGY

3.5.1 Stratigraphy and lithology

The geology underlying the Limpopo WMA North spans the length of the South African geological history and represents some of the major stratigraphic groups of the country. A simplified geological map, included as **Figure 3.4**, was compiled from the 1: 1 000 000 published geological maps and explanatory booklet (Council for Geosciences). The following is an overview of the regional geology, but more detailed information can be obtained from the relevant 1:250 000 geological map series and explanatory brochure.

The upper reaches of the Sand River (south-western section of the WMA) is underlain by a variety of Zwazian basement gneisses, migmatite and accompanying leucogranite collectively known as the Goudplaats gneiss (Z) and to a larger extent by similar rocks of Radian age known as the Hout River gneiss (R). Rocks of the Bandelierkop Complex (Zp) occur as elongated deformed bodies within these gneisses as well as within some of the younger Granitoid Intrusives (Rv) of varied areal extent. The Murchison Sequence (Zp) to the south of these gneisses occurs as an elongated to irregularly shaped north-eastern belt. The Mothiba Formation of the Pietersburg Group dominates, consisting mainly of various schist, amphibolite, serpentinite and iron formation. The lithology shows the typical characteristics of Archaean greenstone belts and is believed to have been developed in a rifting environment or in back-arc basins, (Brandl, The geology of Tzaneen area, Geological map series 1:250 000, Single map and explanation - 2330, 1987).

Rocks of the Beit Bridge Complex (Zl) underlay large sections of the lower reaches of the Lephalala, Mogalakwena, and Sand River basins and to a lesser extent, the lower reaches of the Mokolo and Nzhelele River basins. It is part of the Central zone of the Limpopo Mobile Belt and represents a shelf-type supracrustal sequence consisting of a succession of metasedimentary and metavolcanic rocks. Based on lithology it is divided into the Mount Dove, Malala Drift and Gumbu Groups. Intrusives of Radium age includes the Messina Suite, Madiapala Syenite and the Alldays, Bulai, Sand River and Zoetfontein Gneisses.

Rocks of the Transvaal Supergroup (Vp, Vm) are limited to the upper reaches of the Mogalakwena and Matlabas Rivers; the areal extent is insignificant as it underlay a small percentage of the WMA (±2%). It is of Vaalian age and is divided into the Wolkberg, Chuniespoort, Pretoria and Rooiberg Groups. The Malmani Subgroup (carbonate rocks) of the Chuniespoort Group and the underlying Black Reef Formation was developed as an important well field for Mokopane. Another minor occurrence near Thabazimbi was addressed in the Crocodile West Reconciliation Strategy and is insignificant to this study.

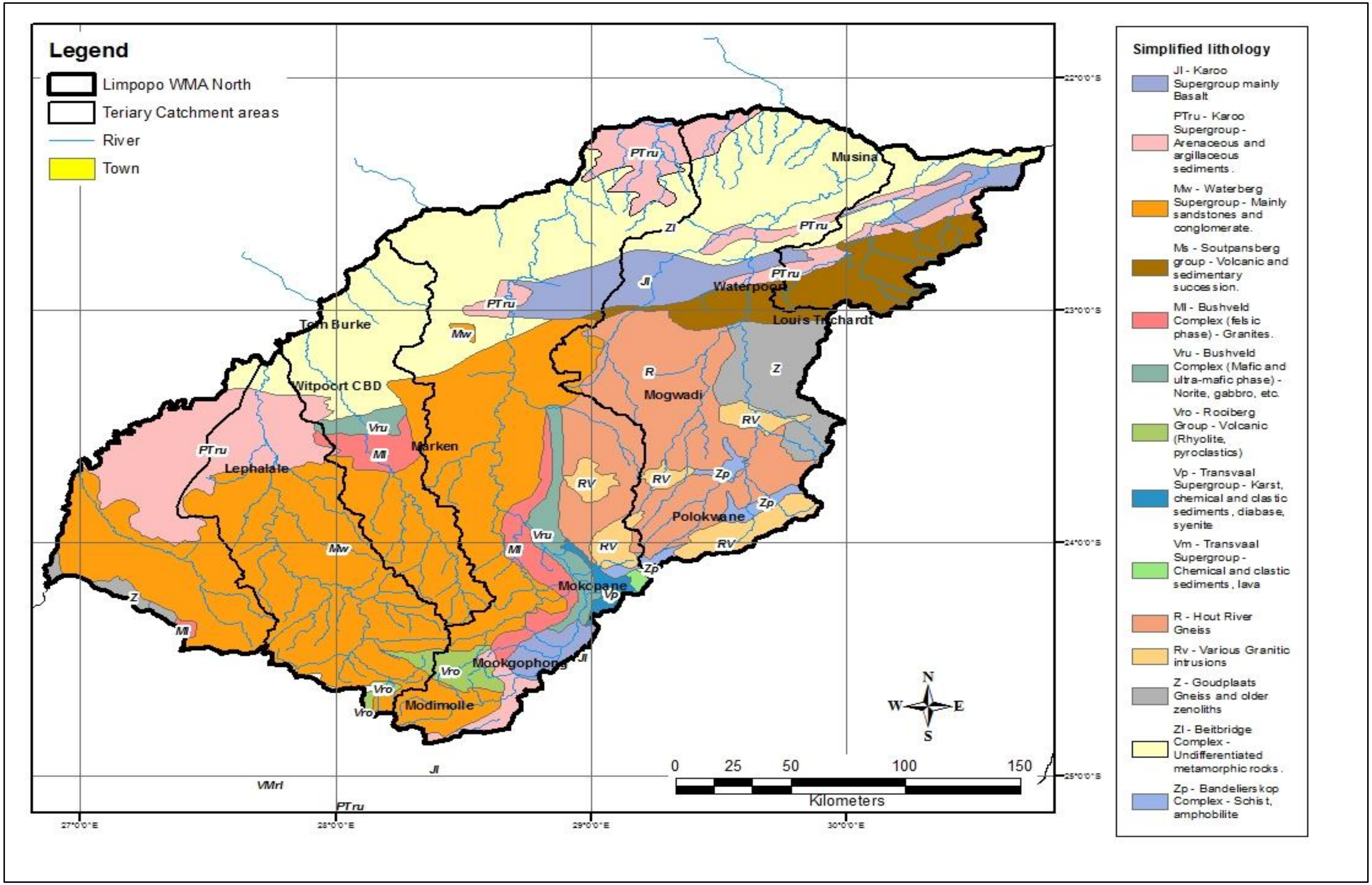


Figure 3.4 Simplified regional geological map

The Bushveld Igneous Complex (BIC) underlies a ‘narrow’ northern striking strip near Mokopane where it underlies 9.5% of the Mogalakwena River basin; another major occurrence is near Villa Nora where it underlay 13.5% of the Lephalale River basin. Near Thabazimbi a small portion of the BIC falls within the boundaries of the Limpopo WMA and is thus insignificant for this strategy. The BIC has been divided into a lower layered ultra-mafic unit, a middle massive gabbro unit, a middle massive gabbro unit and an upper-layered mafic unit termed the Rustenburg Layered Suite (Vru). A younger felsic phase (Ml) followed and is named the Lebowa Granite Suite and the Rashoop Granophyre Suite. The mafic phase is significant for the mining sector (Platinum Group Metals) as well as for groundwater supply. Intrusive diabase sills and dykes that enhance the occurrence of groundwater are from the same period (see Figure 3.5).

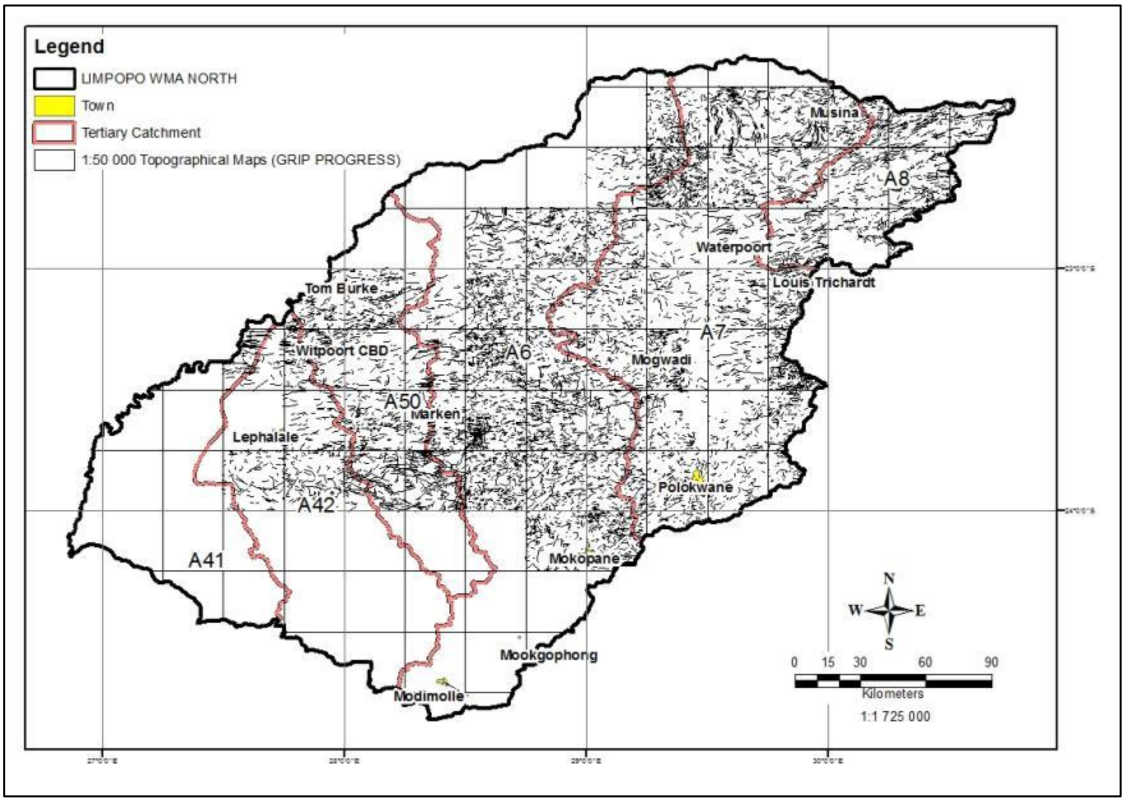


Figure 3.5 Interpreted dykes, Aster imagery interpretation after DWS GRIP

The central to south-western sector of the WMA which includes large sections of the Mogalakwena, Lephalale, Mokolo and Matlabas River basins are underlain by sedimentary rocks of the Waterberg Supergroup (Mw). It underlay a significant portion (42%) of the WMA. The rocks of Mokolian age were deposited within the northern portion of a large shallow intercratonic depression known as the late Waterberg basin. Noticeable plateau intersected by narrow steep valleys are characteristic of outcrop; peak elevations are around 1 300 m, which contrast strongly with the 900 – 1 000 m of adjacent country.

Of similar age but considered slightly older, the rocks of the Soutpansberg Group (Ms) were deposited in an elongated fault bounded depression which developed by rifting along a major zone of weakness between the central and southern marginal zones of the Limpopo Mobile Belt. It is a sedimentary-volcanic succession forming the Soutpansberg Mountain range; it has a thickness of approximately 12 km; an east-south-east extent of approximately 170 km; a north-south extent of 15 to 40 km and is in the form of a wedge dipping to the north. A major centre of volcanic activity was probably located in the Sibasa area and a minor one east of Klein Tshipise. The deposition of arenaceous and argillaceous sediments within fluviatile and shallow-water conditions followed the period of volcanic activity (Brandl, The geology of Messina area, Geological map series 1:250 000, Single map sheet and explanation - 2230, 1981). The areal extent within the WMA is insignificant as it only underlay 50% of the Nzhelele and less than 5% of the Sand catchment. In groundwater terms the area is significant as the rainfall and recharge is high; the water quality is usually ideal to good and the probability of finding high yielding boreholes are high due to the large number of geological lineaments that include major fault zones (see **Figure 3.6**).

The Karoo Supergroup represents a variety of sedimentary environments that reflect the migration of the Gondwana continent from Polar to lower latitudes over a period of 200 million years, (Brandl, The geology of the Alldays area, Geological map series 1:250 000, Single map sheet and explanation - 2228, 2002). The final phase of deposition was terminated by the outflow of basaltic magma [Lebombo Group (Jl)]. The sediments (PTru) were deposited in intercratonic basins of which three are within the WMA. The first is the Ellisras basin near Lephalale that is significant to coal mining and power generation. It underlay 38% of the Matlabas and 21.5% of the Mokolo river basins. The second is the Tuli basin with the largest outcrop along the Limpopo River. This is in an area more or less between the inflow of the Mogalakwena River eastwards up to approximately 20 km from Beit Bridge. Coal mining occurs although some of the mines are under care and maintenance. Lastly is the Tshipise basin which includes all Karoo age rocks south of the Voorburg, Bosbokpoort and Tshipise faults, (Van den Berg, 1980). Large undeveloped coal deposits occur within this basin. Significant for groundwater exploitation in all three basins are the Lebombo Group and Clarens Sandstone Formation.

Quaternary deposits (Q) occur throughout the area. Within the shallow alluvial aquifers, large volumes of groundwater/surface water can be extracted while rivers are flowing, in dry periods the available volume of water decreases over time as the water storage capacity within the sand is approximately 30% per volume of sand within the river. Mining of alluvial diamonds occur along the Limpopo River, mining of significant volumes of sand occur along the Lephalala River.

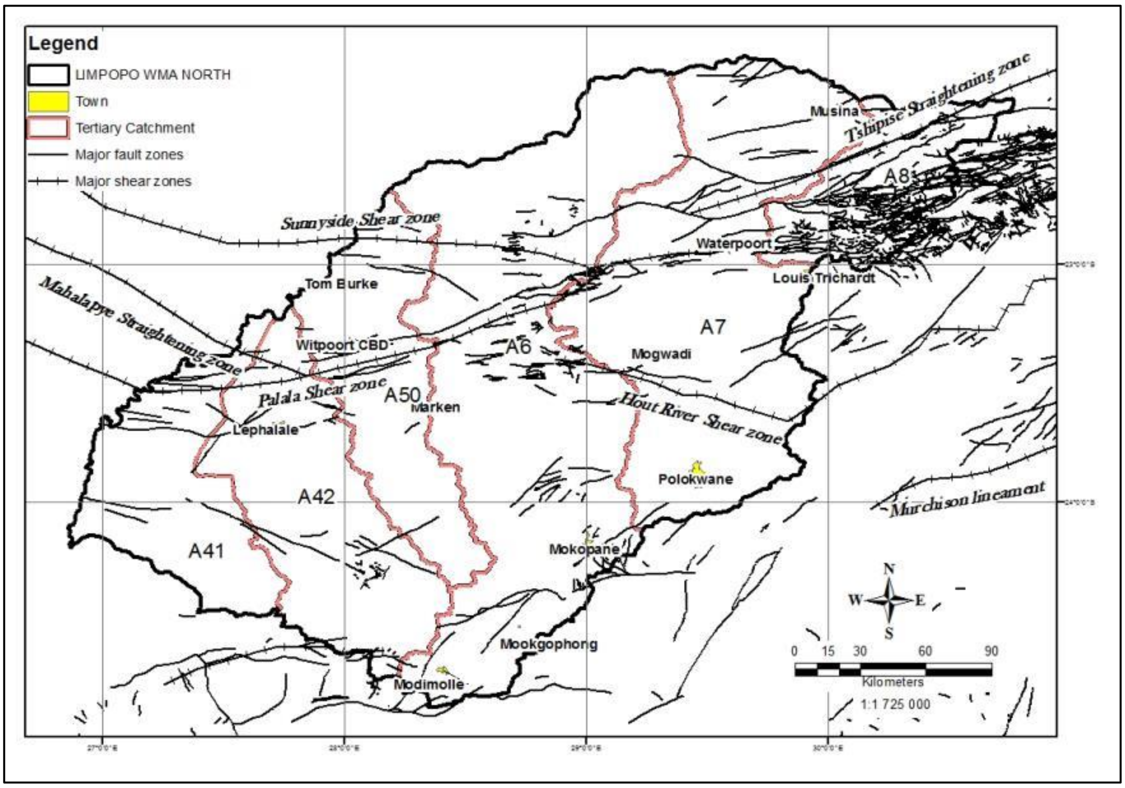


Figure 3.6 Major shear and fault zones

3.5.2 Overview of the structural geology

The southern section of the WMA is located on a stable continental mass, the Kaapvaal Craton. Broadly it consists of granitic material, some true granites, granodiorites, quarts-diorites, gneisses, or a mix with migmatites. Within these rocks remnants of mafic volcanics are present with associated ultramafic volcanics and sediments. Metamorphism of these resulted in the formation of 'greenstones'.

The granitoid-greenstone terranes of the Kaapvaal and Zimbabwe craton are separated by the east-northeast trending Limpopo Mobile belt. Large ductile shear zones is an integral part of the mobile belt, it defines the boundaries between the belt and the adjacent craton and separates internal zones within the belt. The shear zones forming the external (northern, southern, and western) margins of the belt are interpreted as uplift structures of the over thickened crust. The belt is of high-grade metamorphic rocks that have undergone a long cycle of metamorphism and deformation and comprises of three components: the Central Zone, the North Marginal Zone, and the South Marginal Zone. The Hout River Shear Zone define the southern margin of the belt, the ±10 km wide Palala shear zone the southern marginal zone and the central zone as is depicted in Figure 3.6.

a) *Dykes and sills*

Dykes in the basement gneisses are striking predominantly north-east. The presences of these dykes are usually indicated by boulders forming small ridges and spherical weathering patterns in road cuttings. In the search for high yielding boreholes these dykes and contacts with the host rocks are generally regarded as poor targets.

Fewer dyke intrusions occur in the WMA underlain by rocks of the Beit Bridge Complex; these are not considered good targets in the search for groundwater. The presence of these lineaments is mostly concluded from the interpretation of remote sensing data as the area is covered by overburden. Strikes are predominantly northeasterly and to a lesser extend to the east, north, and north-west.

In the area underlain by rocks of the Soutpansberg Supergroup, diabase sills and dykes occur mainly in the upper formations of the Supergroup in an area bounded approximately by the Klein Tshipise Fault in the north, the Mufungudi Fault in the southwest, the Thengwe Fault in the south and the Lavhurala Fault in the southeast. The strike length of these dykes are extensive, the trend being mainly east-north-east and to a lesser extent west-north-west and north-north-west. The diabase intrusions generally predate the main period of faulting. South of the Klein Tshipise Fault a few north-east-trending diorite dykes occurs (Brandl, The geology of Messina area, Geological map series 1:250 000, Single map sheet and explanation - 2230, 1981).

In the areas underlain by rocks of the Waterberg Group diabase sills and dykes occur throughout the area, the strike is predominantly east, north and north-east. If dykes and sills are ignored, the groundwater potential of the Waterberg Group is generally low with 79% of yields < 2 ℓ/s, (Du Toit & Sonnekus, Explanation of the 1:500 000 Hydrogeological map 2127, 2010).

Rocks of the Karoo Supergroup are underlying three geographical areas within the map area with minor outliers consisting of the older formations occurring in down-faulted blocks between the Tuli and Tshipise basins. Dolerite dykes are most prominent in the Tuli basin striking easterly to north-north-easterly with minor north to north westerly trends. Within the Tshipise basin dolerite dykes are less developed. In the vicinity of the Taaibosch Fault, exploration drilling into and adjacent to dolerite dykes produced disappointing borehole yields with no conclusive results obtained (Fayazi & Orpen, Development of water supply for Alldays from groundwater resources associated with the Taaibos fault. - Report no. GH3664, 1989). In the Ellisras basin faulting is dominant, dykes are less develop; the trend is more or less west to east.

b) Faults

In the south-eastern sector of the WMA, geological lineaments are predominantly related to dyke intrusions. Minor faults occur within the area but these are confined to a zone around the contact between the Gneiss and the Sibasa Formation. The faults are trending northerly with almost 2/3 of the strike length within the basalt and 1/3 within the gneiss.

The regional grain of the north-western part of the map underlain by rocks of the Beit Bridge Complex is defined by large-scale north-trending folds and large closed structures. Geological lineaments occurring in the area underlain by these rocks were predominantly concluded from the interpretation of remote sensing data and are believed to be mostly related to dyke intrusions. Regionally the trends are predominantly north-easterly and easterly and to a lesser extent southerly.

A number of brittle shear zones are developed in the WMA trending east-northeast or easterly. They are generally normal faults with a downthrown to the south. The most prominent faults are the Bosbokpoort, Tshipise and Voorburg faults with estimated vertical displacements of approximately 500 m. The Bosbokpoort fault was investigated near Sigonde village for water supply. The fault was drilled without finding any water. The fault needs to be investigated further. The Tshipise fault was successfully drilled in the past for water supply for various villages. The Senotwane fault, just north of the Blouberg in contrast with the above mentioned fault zones have a northerly downthrow. The displacement is approximately 1 500 m in the west decreasing to approximately 600 m near Soutpan 459MS and disappearing within the Karoo sediments further east. Near Musina the Dowe-Tokwe fault and the Messina fault are strike-slip shear zones with a right-lateral displacement. Displacement by the Dowe-Tokwe fault at Schoonoord 230MS is approximately 1 800 m as seen in the displacement of a prominent north-trending magnetite quartzite outcrop. The near vertical fault zone interpreted as a strike-slip shear forms a 200 m wide breccia zone in the Limpopo River on Eersteling 138MR (Brandl, The geology of the Alldays area, Geological map series 1:250 000, Single map sheet and explanation - 2228, 2002). The country rock adjacent to the Dowe-Tokwe fault is referred to as a grey granitic-gneiss. The fault itself is commonly evident on the surface and recognized by the occurrence of brecciated, epidotisation and chloritic gneiss, quartz and epidote. Within the fault various coloured feldspathic quartzite, hydrothermal quartz, epidote and pyrite are typical. The fault is commonly intruded by amphibolite and dolerite and in places by younger granites (Orpen & Fayazi, Assessment of the ground water resources in the proximity to Messina with particular reference to the Dowe-Tokwe fault - Report no. GH3260, 1983).

Within the Soutpansberg Group, fault zones occur more frequently. Two intersecting fault systems are described. The first is trending east-northeast, parallel to the regional strike, delineating major horst-and-graben structures and responsible for the frequent structural repetition of the Soutpansberg Formations. The Klein Tshipise fault is a typical example. The second fault system is oblique to the regional strike and has faults trending west-northwest to north-west. The most prominent fault of this system is the Siloam fault with an estimated vertical displacement of 1 500 m (Brandl, The geology of Messina area, Geological map series 1:250 000, Single map sheet and explanation - 2230, 1981). Within the Tshipise basin intense block-faulting caused the development of a series of stepped half-grabens resulting in the repeatedly occurring narrow strips of Karoo rocks.

The northeast trending Taaibosch fault is an important regional aquifer for water rural villages and Alldays town. The Dzundwini fault, an east west striking fault within the Soutpansberg Supergroup was investigated in the past for water supply. Only one borehole with a yield of 15 ℓ/s is listed on the databank near this fault, more exploration needs to be done. Numerous faults occur within the Mokolo basin such as the Eenzaamheid, Daarby and Zoetfontein fault zones. Exploration around Lephalale resulted in water strikes between 120-250 m ranging in yields of between 0.2 to >20 ℓ/s.

4 OVERVIEW OF THE CHARACTERISTICS OF THE GROUNDWATER RESOURCE

4.1 DELINEATION OF GROUNDWATER UNITS BASED ON HYDROGEOLOGICAL CRITERIA

The 1:500 000 hydrogeological map series used the major stratigraphic units as basis for the delineation of the hydrological units that were chosen according to geohydrological similarities. The boundaries of the hydrological units do not always follow the geological boundaries and the map symbols used do not always correspond to the geological map series, (Du Toit & Sonnekus, Explanation of the 1:500 000 Hydrogeological map 2326, 2010). The section gives an overview of the hydrogeological properties of these units; more detailed information can be obtained from the relevant explanatory brochures for each of the hydrogeological maps. Maps depicting the character and location of the aquifer units within each quaternary catchment can be obtained in **Appendix A**. The major stratigraphic units used are as follows:

4.1.1 Basement Complex

Rocks grouped under the Basement Complex occur in the northern and eastern portions of the WMA and consist of gneiss, banded gneiss, granite gneiss with infolded xenoliths of mafic to ultra-mafic material and migmatite associated with leucocratic granite [Goudplaats gneiss (Zgo)], greenstones [Bandelierkop Complex (Zga) and Pietersburg Group (Zp)], undifferentiated metamorphic rocks [Mount Dove Group (Zbo), Malala Drift Group (Zba), Gumbu Group (Zbg)], intrusive layers and lenses of ultramafic and anorthositic to gabbroic rocks [Messina Suite (Zbm)], migmatite gneiss [Hout River Gneiss (Rho)] and Unnamed Swazian Rocks (Zz). The Pietersburg Group (Zp) occurs within the south eastern section of the WMA within the gneiss (Zgo and Rho) as a south-west striking belt of steeply folded material ranging from ultra-mafic to mafic lavas, acidic lavas, arenaceous sediments and chemical sediments such as banded iron formation and chert. The sequence was subjected to low-grade (green schist facies) metamorphism.

While most of the Basement Complex hydrological units are poor to moderate in terms of quality and quantity the Goudplaats and Hout River Gneisses are considered good to very good aquifers.

4.1.2 Granite intrusives

The Basement Complex has been intruded by numerous younger granites such as Geyser (Rge), Hugomond (Rhu), Matok (Rma), Moletsi (Rmo), Lunsklip (Rlu), Uitloop (Rui), Utrecht (Rut), Matlala (Rat), and Turfloop Granite (Vtu).

The Granite intrusives are generally poor aquifers with the Matlala granite having slightly better yields.

4.1.3 Transvaal Supergroup

The Transvaal Supergroup occurs as steeply dipping strata in the southern part of the WMA underlying the upper reaches of the Mogalakwena and Matlabas Rivers. The Sequence consists of a basal quartzite, shale and basalt layer [Wolkberg Group (Vw)] followed by rocks formed during a period of chemical sediment deposition consisting of a lower banded iron formation and chert layer [Black Reef Formation (Vbl)], followed by a thick sequence of dolomite with interlayered chert [Chuniespoort Group (Vh)]. Chemical deposition of the Chuniespoort Group was followed by cyclic episodes of quartzite and shale deposition [Pretoria Group (Vp)]. A capping of acidic lava [Rooiberg Group (Vb)] marks the end of Transvaal deposition and the beginning of the intrusion of the Bushveld Complex. Of significance in this unit are the Weenen and Planknek wellfields (in dolomites) that supply Mokopane.

4.1.4 Bushveld Complex

Rocks of the Bushveld Complex consist of a mafic unit [Rustenburg Layered Suite (Vr)] capped by a red granite and granophyre unit [Lebowa Granite Suite (Mle) and the Rashoop Granophyre Suite (Vrg)]. The Palala Granite (Mpa) located intermittently along the Abbottspoort and Melinda faults, is related to the Bushveld Complex.

The mafic unit of the complex is regarded as a moderate to good aquifer while the granitic units are poor.

4.1.5 Soutpansberg and Waterberg Groups

The Bushveld Complex intrusion was followed by the deposition of the Soutpansberg (Ms) and Waterberg (Mw) Groups. The Waterberg Group includes the Koedoesrand Formation (Mko). In the south-western part of the WMA a plug consisting of carbonatites and biotite pyroxenite intruded the Waterberg Group, named Glenover (Mge) after the farm on which it occurs. In the centre of the northern part a series of unnamed Mokolian Rocks (Mz) intruded the Soutpansberg Group.

Numerous faults and dykes in the Soutpansberg Group, combined with higher rainfall in the area, contributes to moderate to very good aquifers, while the Waterberg group is considered a poor aquifer due to limited faulting, but where dykes and sills occur higher yields can be found.

4.1.6 Karoo Supergroup

The Supergroup consists of lower diamictite of probable glacial origin Dwyka (C-Pd) overlain by shale (at places carbonaceous), mudstone, and sandstone horizons [Ecca Group (Pe)], Permian-Triassic (P-Tr) formations consisting of the Solitude (P-Trs) and undifferentiated Ecca Group and Clarens Formation (P-Trc), Triassic (Tr) formations consisting of the Bosbokpoort (Trb) mudstone and siltstone grading into an upper sandstone layer Clarens Formation (Trc) and capped by a thick sequence of basalt [Lebombo Group (Jl)]. Intrusive rocks include Dolerite (Jd) dykes and sills.

The lower units of the Supergroup are poorer aquifers due to the fine grained nature of the rocks while the upper units Clarens and Lebombo are considered good aquifer, with the Lebombo having slightly inferior water quality (TDS and nitrate).

4.1.7 Quaternary deposits

The youngest strata are thin sequences of Quaternary to Tertiary Aeolian Kalahari sand (not shown on map) and alluvial sand deposits (Q) along the major drainages in the area. Significant to water supply is the shallow alluvium deposits in the major rivers, these aquifers are fully saturated during surface flow. During dry periods, surface flow is limited and the potential abstraction of wells within the alluvial decreases.

4.2 OVERVIEW GROUNDWATER QUALITY

Water chemistry data was obtained from the WMS data base, GRIP Limpopo data base as well as from various consultancies. For data points with time series chemistry data was averaged using the Pivot table function in Excel. The electrical conductivity (EC) values were contoured using a 1 km x 1 km grid to give a regional overview of the water quality of the WMA. High fluoride concentrations within the WMA relate mostly to granitoid intrusive rocks, like at Mookgopong where fluorspar (commercial name for the mineral fluorite) was mined in the past. Fluorite occurs naturally in the area and leads to the higher concentrations of fluoride visible on the map.

The poor water quality in the Nzhelele catchment in the vicinity of the Siloam Hospital can be attributed to anthropogenic origins. Higher nitrate concentrations are natural in certain areas due to underlying geology, but can also relate to irrigation and human settlements. Interventions to limit possible nitrate pollution in human settlements will be to use sealed environmentally friendly toilets in the rural areas

4.3 MAXIMUM YIELDS

The maximum yields were subdivided using the same ranges as depicted on the 1:500 000 hydrogeological map series. The production ranges are divined as follows:

- High borehole yields, generally greater than 5 ℓ/s, can be used for urban and rural water supply, industry or large-scale irrigation.
- Moderate borehole yields generally, 2 ℓ/s – 5 ℓ/s, can be used for urban and rural water supply to small towns, industry or small-scale irrigation.
- Low borehole yields generally, 0.5 ℓ/s – 2 ℓ/s, can be used for domestic and livestock watering supply to rural settlements, hospitals and health centres or small-scale irrigation at community vegetable gardens.

- Very low borehole yields generally, 0.1 ℓ/s - 0.5 ℓ/s, can be used for domestic supply to single homesteads, schools, police stations, clinics, small rural villages (250 persons) or livestock watering. Boreholes in this group are mostly equipped with hand, submersible or wind pumps.
- Un-economical borehole yields generally, 0.0 ℓ/s - 0.1 ℓ/s. Non-reticulated water supply for isolated households or for monitoring in certain cases. Suitability dependable on factors such as construction, objective of monitoring, location, and geological setting.

4.4 Groundwater levels

Groundwater level data was obtained from the NGA and the GRIP Limpopo database. The distribution of water levels obtained from the period 1960 to date corresponds well with the distribution on previous large-scale DWS groundwater projects. From 1995 the data distribution suggests a clear shift towards projects in rural areas. Available groundwater data from the NGA decreases from 1995 when the final GRA1 maps were produced, no time series data for water levels was available from the NGA for the period after 2003. The information on the GRIP Limpopo database is updated up to March 2015 when the data was extracted for analysis. Natural fluctuations of the static water levels vary on a seasonal basis (short periods) as well as over dry and wet cycles (long periods).

Contouring of water levels is a means to evaluate the status of the groundwater source on a regional scale provided that data is adequate and well distributed. The method used for contouring was the "heatmap" method which uses a grid to average water levels in each grid cell. The grid spacing is critical to reduce the influence of localized very deep or very shallow water levels of single boreholes. It was found that a 15 km grid spacing produced good results with the available data. A series of "heatmaps" was produced for the periods 1960 – 1979, 1980 – 1989, 1990 – 1994, 1995 – 1999 and 2000 – present, these maps are given in **Appendix F**. The point distribution was also shown to compare the availability of water level data and therefore the reliability of the contouring results. Several water level points were also labelled with the used water level and often shows deeper water levels in generally shallow water level areas and the other way round.

The 1960 to 1979 map shows deep water levels over most of the region with a localized spot (35 mbgl) in the Lephalala catchment. The map for the next period 1980 to 1989 shows more localized zones with deep water levels and also indicates the increased abstraction in the Sand River basin near Mogwadi (Dendron). The deep water levels on both of these two maps are related to irrigation.

The period 1990 to 1994 shows three localized zones similar to the previous period. The following maps representing the periods 1995 to 1999 and 2000 to present indicate deeper water levels especially in the Sand River catchment which are due to irrigation and the increasing population in the rural areas. The areas affected by irrigation migrated over the WMA over time which gives a clear indication of changes in farming due to the cost related to abstract deep water for irrigation. Large scale farming enterprises migrated to areas with access to shallower water sources such as the Weipe area along the Limpopo River

The final map gives an indication of the period when the water levels were measured. The availability of data relates to areas where regional groundwater projects occurred in the WMA. The distribution of the majority of water levels measured during the period 1994 to recent corresponds with the distribution of rural settlements.

While water level contour maps provide a regional overview of an area, time series data provides an accurate picture at a certain point within the catchment. Plotting time series water levels with rainfall data gives a picture of the short time changes over the seasons as well as the long-term trend of the water level with dry and wet cycles that represent changes over long periods. Abstraction exceeding the recharge due to rainfall will result in a decrease in water level over time. In some of the graphs the water level seems to stabilize and recover after a long period of deterioration, this might be that the pumping rates decreased due to practical and financial problems associated with over pumping. The high rainfall event in 2000 shows recharge to some of the areas.

The cumulative rainfall departures method (CRD) was used as it reflects the outcome of the natural balance of groundwater due to the combined effects of both recharge and losses from a system. It is accepted that under natural conditions (no extraction from pumping) a dynamic balance exists between recharge and drainage in an aquifer. This implicates that if the rainfall is greater than the average rainfall water levels will rise and if the rainfall is lower than the average the depth to the groundwater level will increase. Losses from the system vary in proportion to the average precipitation. Given in **Appendix E** are the time series plots of water levels (as discussed above).

5 QUANTIFICATION OF THE GROUNDWATER RESOURCE

5.1 RECHARGE

Groundwater is the world's most extracted raw material, but unlike other raw materials it is constantly being replenished under natural conditions. Recharge is defined as the addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers. Recharge is crucial for the ongoing replenishment of aquifers and is influenced by various factors. On a local scale some can be changed by human activities but on a regional scale nature is the controlling factor. Previous groundwater studies established that recharge takes place under effective rainfall conditions. Research on global warming suggests rainfall events to be more irregular and more intensive which might influence recharge. The character of the subsurface conditions including overburden and the weathered zone also influence the infiltration of water to the groundwater.

Recharge contours and recharge per quaternary catchment in the WMA are depicted in **Appendix H**, **Figure H.1**.

5.2 HARVEST AND EXPLOITATION POTENTIAL

The harvest potential is the maximum volume of groundwater that can be abstracted per square kilometre per annum without depleting the aquifers ($m^3/km^2/a$), The Groundwater Harvest Potential (Vegter, 1995) was used as the basis for calculations done for the report and depicted in **Figure H.1** of **Appendix** H. The objective of the harvest potential was to present a safe yield that can be used by resource managers as it gives an indication of the maximum potential of an aquifer, (DWS groundwater dictionary on the DWS groundwater website). The available storage is the volume of water stored in the aquifer. The thickness of an aquifer changes seasonally due to the fluctuation of water levels, the harvest potential on the map sheet gives an upper and lower limit.

As it is not possible to abstract all the available groundwater stored in the aquifer due to practical, financial and natural limitations, the exploitation potential is used when calculating available volumes in an aquifer. The exploitation potential is thus defined as the volume of harvest potential that can practically be exploited. It will always be less than the harvest potential **Figure H.2** of **Appendix H** illustrates the study areas exploitation potential.

6 GROUNDWATER UTILISATION

6.1 GROUNDWATER USE QUATERNARY SCALE

Table 6.1 presents the estimated groundwater use of agricultural, domestic, mining and industry users per quaternary catchment in the WMA. A figure of 5 000 million m³/a was estimated as unregistered irrigation (DWA, 2013a).

Table 6.1 Estimated groundwater use per quaternary catchment

Quaternary	Registered irrigation and stock watering	Agriculture		Domestic			Mining & Industry	Groundwater use assessment
		Un-registered irrigation	Schedule 1: Grazing	Un-registered Community (GRIP-tested & equipped boreholes)	Registered community water use	Schedule 1	Registered	TOTAL (10^6 m^3/a)
A41A	0.19	0.00	0.08	0.00	0.00	0.18	0.00	0.45
A41B	0.00	0.00	0.04	0.00	0.00	0.07	0.00	0.11
A41C	0.00	0.00	0.12	0.00	0.00	0.20	0.00	0.32
A41D	1.81	0.00	0.22	0.00	0.00	0.54	0.01	2.58
A41E	0.00	0.00	0.22	0.00	0.00	0.43	0.00	0.65
A42A	0.52	0.00	0.06	0.00	0.00	0.64	0.14	1.36
A42B	0.35	0.00	0.04	0.00	0.00	0.36	0.00	0.75
A42C	0.96	0.00	0.06	0.09	0.00	0.82	0.01	1.94
A42D	0.00	0.00	0.05	0.00	0.00	0.10	0.00	0.15
A42E	0.73	0.00	0.10	0.10	0.03	0.49	0.00	1.45
A42F	0.62	0.00	0.12	0.09	0.00	0.33	0.02	1.18
A42G	0.00	0.00	0.14	0.00	0.00	0.44	0.00	0.58
A42H	0.00	0.00	0.12	0.01	0.00	0.45	0.00	0.58
A42J	0.00	0.00	0.20	0.00	0.00	0.57	3.60	4.37
A50A	0.01	0.00	0.03	0.00	0.00	0.11	0.00	0.15
A50B	0.00	0.00	0.04	0.00	0.00	0.13	0.01	0.18
A50C	0.00	0.00	0.04	0.05	0.00	0.14	0.00	0.23
A50D	0.08	0.00	0.07	0.00	0.00	0.14	0.00	0.29
A50E	0.02	0.00	0.07	0.00	0.00	0.15	0.00	0.24
A50F	0.00	0.00	0.04	0.00	0.00	0.06	0.00	0.10
A50G	0.60	0.00	0.08	1.12	0.00	0.22	0.00	2.02

Quaternary	Registered irrigation and stock watering	Agriculture		Domestic			Mining & Industry	Groundwater use assessment
		Un-registered irrigation	Schedule 1: Grazing	Un-registered Community (GRIP-tested & equipped boreholes)	Registered community water use	Schedule 1	Registered	TOTAL (10^6 m^3/a)
A50H	0.00	0.00	0.19	2.80	0.00	0.67	0.00	3.66
A50J	0.00	0.00	0.13	0.00	0.00	0.35	0.40	0.88
A61A	1.11	0.00	0.03	0.10	0.15	0.53	0.12	2.04
A61B	0.20	0.00	0.03	0.01	0.00	0.37	0.00	0.61
A61C	2.26	0.00	0.06	0.11	0.00	0.66	0.17	3.26
A61D	2.24	0.00	0.04	0.38	1.07	0.70	0.23	4.66
A61E	8.78	0.00	0.05	0.00	0.01	0.44	0.04	9.32
A61F	1.18	0.00	0.08	1.73	1.08	1.15	0.77	5.99
A61G	0.32	0.00	0.07	2.89	0.01	0.32	0.76	4.37
A61H	0.73	0.00	0.05	0.00	0.00	0.34	1.46	2.58
A61J	0.96	0.00	0.08	0.07	0.00	0.60	0.01	1.72
A62A	0.45	0.00	0.04	0.10	0.00	0.11	0.00	0.70
A62B	0.00	0.00	0.06	0.50	0.00	0.13	0.00	0.69
A62C	0.00	0.00	0.03	0.19	0.00	0.04	0.00	0.26
A62D	0.64	0.00	0.06	0.27	0.02	0.21	0.00	1.20
A62E	0.00	0.00	0.03	2.30	0.00	0.18	0.00	2.51
A62F	2.28	0.00	0.05	2.09	0.00	0.19	0.00	4.61
A62G	0.00	0.00	0.04	0.66	0.00	0.09	0.00	0.79
A62H	0.00	0.00	0.04	2.00	0.05	0.31	0.05	2.45
A62J	0.31	0.00	0.08	0.19	0.00	0.21	0.00	0.79
A63A	17.39	0.00	0.17	0.60	0.07	0.49	0.00	18.72
A63B	1.50	0.00	0.14	0.89	0.00	0.28	0.00	2.81
A63C	0.00	0.00	0.13	0.00	0.05	0.34	0.00	0.52
A63D	2.89	0.00	0.13	0.90	0.00	0.36	0.00	4.28
A63E	0.00	0.00	0.17	0.00	0.02	0.32	4.39	4.90
A71A	32.27	0.00	0.08	2.52	1.21	3.44	4.36	43.88
A71B	6.78	0.00	0.04	2.49	0.00	1.03	0.02	10.36
A71C	23.62	0.00	0.12	2.68	0.06	0.78	1.13	28.39

Quaternary	Registered irrigation and stock watering	Agriculture		Domestic			Mining & Industry	Groundwater use assessment
		Un-registered irrigation	Schedule 1: Grazing	Un-registered Community (GRIP-tested & equipped boreholes)	Registered community water use	Schedule 1	Registered	TOTAL (10^6 m^3/a)
A71D	5.44	0.00	0.10	0.00	0.00	0.38	0.01	5.93
A71E	5.26	0.00	0.05	2.24	0.00	0.32	0.00	7.87
A71F	6.12	0.00	0.04	0.89	0.00	0.23	0.02	7.30
A71G	9.59	0.00	0.08	1.71	0.00	0.38	0.00	11.76
A71H	1.02	0.00	0.10	1.58	1.16	0.97	0.00	4.83
A71J	15.42	0.00	0.11	0.02	0.00	0.44	0.50	16.49
A71K	3.12	0.00	0.14	0.03	3.48	0.99	0.13	7.89
A71L	0.00	0.00	0.15	0.06	0.01	0.33	0.01	0.56
A72A	14.97	0.00	0.13	7.95	0.00	0.57	0.01	23.63
A72B	3.16	0.00	0.15	0.12	0.00	0.28	0.00	3.71
A80A	0.00	0.00	0.01	0.24	0.01	0.11	0.00	0.37
A80B	0.17	0.00	0.01	0.22	0.00	0.12	0.00	0.52
A80C	0.00	0.00	0.02	0.31	0.01	0.03	0.00	0.37
A80D	0.00	0.00	0.01	0.00	0.00	0.05	0.00	0.06
A80E	0.82	0.00	0.02	0.02	0.00	0.19	0.00	1.05
A80F	0.32	0.00	0.06	0.04	0.00	0.14	0.03	0.59
A80G	2.53	0.00	0.11	0.30	0.01	0.33	0.07	3.35
A80H	0.00	0.00	0.02	0.29	0.02	0.01	0.00	0.34
A80J	0.00	0.00	0.08	0.65	0.04	0.35	0.00	1.12
Total	**179.74**	**0.00**	**5.55**	**44.60**	**8.57**	**27.43**	**18.48**	**284.37**
%	**63.2%**	**0.0%**	**2.0%**	**15.7%**	**3.0%**	**9.6%**	**6.5%**	**100.0%**

6.2 GROUNDWATER USE WATER SCHEMES

The information used for the water schemes were obtained from DWS Limpopo, the small town study reports and from data supplied by AECOM. The information on the boreholes within each scheme was obtained from the Limpopo groundwater data bank (GRIP).

6.2.1 Rural groundwater development

a) *Historic development*

The historic development of groundwater followed the approach to develop the source within a reasonable distance (500 m) from the settlement. This was when the settlements were smaller and had a lower water demand. Over time the settlements became larger, the water demand increased and the radius of investigation needed to be expanded (500 to 2 000 m) as the best groundwater options close to the villages were already developed. Unfortunately this approach is still followed in some of the rural areas due to budget restrictions and community demands that the source must be within the village boundary. This approach was and is not necessarily the best hydrogeological option available as the occurrence of groundwater relates to specific favourable subsurface conditions regarding geology, structural geology and recharge potential. Although this approach resulted in the successful development of groundwater in many of the areas, it also resulted in large numbers of low yielding production boreholes. The better long term approach should be to limit maintenance costs by reducing the number of production boreholes. This can only be achieved by a regional approach with large exploration budgets. Only the highest yielding boreholes need to be equipped to lower the extraction cost per litre of water.

b) *Water schemes, groundwater development*

Groundwater developments for water schemes usually results in a larger (2 to 5 km) area available for exploration. The objective of the hydrogeologist is to develop the most favourable position for high yielding production boreholes within the area. This approach is more successful to develop less production boreholes with higher yields provided that the budget does not restrict adequate exploration.

c) *Regional groundwater development*

The most favourable groundwater development approach is when the hydrogeologist has a very large area available for the investigation and sufficient budget for adequate exploration. This approach is currently followed by the Mogalakwena Local Municipality. The Municipal area is divided into an urban and peri-urban water supply zone (functional part) and a rural settlement supply zone consisting of approximately 114 villages. The rural area is currently predominantly supplied by single sources within a short (1 km) distance from each village. Surface water from the Flag Boshielo Dam is planned to supplement groundwater, but this might only reach the furthest villages in 2020.

The master plan of the municipality is to develop the most favourable areas for groundwater thus limiting the number of production boreholes. After this development the positions of the main surface water supply lines will be finalized. A comparison between the local development and the regional approach was made in Table 6.2. It shows that the average daily available volume per borehole using the regional development approach is 204 m³/d compared to the 55 m³/d that were developed in the past using the > 2 km development approach. If the success achieved during the first phase of new source development using the regional approach can be repeated it will result in 75% less equipped boreholes. The maintenance cost to extract groundwater in the municipal area will be drastically reduced.

Table 6.2 Comparison between the local development and the regional approach

Development method	Total boreholes tested	Average yield (m³/d)	Number of boreholes equipped	Volume available (m³/day)	Comment
Develop within a 2 km radius from the village	220	55(1)	178	121 159	Volume not verified-GRIP info
Regional approach	33	204(2)	33	6 734	Verified volume

Note Water quality ignored, the regional approach will lead to less boreholes thus limiting maintenance cost on production boreholes.

(1) Estimated

(2) Not yet equipped

6.2.2 Dominant groundwater users

Groundwater extraction volumes were obtained from various sources. This included the small town study reports for the domestic use for the major towns, the Limpopo groundwater data base (GRIP) for the rural villages and water schemes, irrigation data from the verification project and the WARMS data set for mines and industries. Extraction estimates for “schedule 1 domestic” and “schedule 1 grazing” were obtained from DWS Limpopo. Figure 6.1 depicts the current dominant water use for each quaternary catchment. The mixed farming description includes areas where livestock watering and irrigation in combination dominates the groundwater use. In similar maps these were previously indicated under the description 'no dominant use'. Comparing the map with a study done in 2005 indicates that irrigation dominance decreased and domestic use increased. Listed volumes from the shallow alluvial aquifers along the Limpopo River were not included as groundwater in the compilation of the map resulting in a change in dominant use for some of the adjacent quaternary catchments.

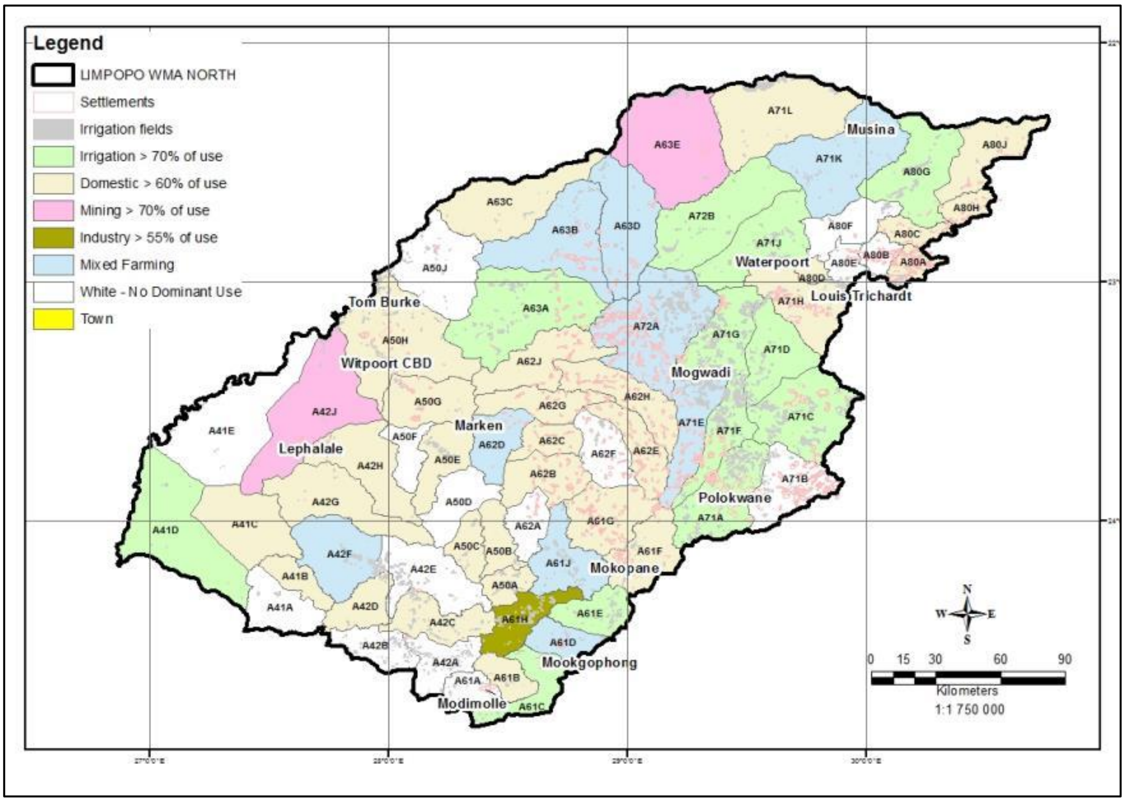


Figure 6.1 Dominant groundwater use per quaternary

6.3 COST ESTIMATES

6.3.1 Water schemes, evaluation of the maximum potential versus current development to plan actions for cost estimates

The exploitation potential for the water schemes was calculated using the polygon area extent as per DWS lists (LP-settlements form G13, March 2015) and presented in Figure H.2. The population figures for 2010 and the estimated population for 2040 was used to calculate a maximum volume that can be developed for each scheme calculated as litres/capita/day (ℓ/c/d). All boreholes within each scheme (tested and delivering more than 25 m^3/d), even boreholes without known equipment, and the available surface sources were used to calculate the available volume per person/day. It was assumed that only 70% of the listed groundwater abstraction is actually pumped. As the GRIP database is dependent on regular updates (which unfortunately are not always available) it was assumed that all of the higher yielding boreholes are in production. For this unregistered community borehole use a total tested available volume was calculated per person using the population of 2010 and 2040. Comparing the calculated volumes leads to the proposed interventions (last column in table) for each scheme.

The exploitation potential calculation for the schemes using the GIS is obviously based on the size of the actual polygon representing the scheme. One must keep in mind that this calculation might not be representative of the actual potential as the size of the polygon is not necessarily correct and groundwater is drawn in from outside the polygon or transferred across polygon boundaries from/to other schemes. Therefore a lot of factors can play a role in the calculation and the results may not even closely resemble the reality.

Therefore the water balance per quaternary catchment should be used as well as the average water table in the area for a better estimation. If the water table in the area is not stressed (no or little drawdown compared to the surrounding areas) it means that the production boreholes are not used to capacity or that more water is available than the estimated volume. Monitoring and management is therefore a key aspect to evaluate the optimum use of groundwater in each scheme.

6.3.2 Water schemes, maintenace and equiping cost existing boreholes

Information regarding the existing borehole infrastructure was obtained from the Limpopo database (GRIP). Groundwater extraction volumes were obtained from various sources, including the small town study reports for the domestic use for the major towns, the Limpopo groundwater database (GRIP) for the rural villages and water schemes, irrigation data from the verification project and the WARMS data. The following describes the findings as listed in **Table** .

Operation and Maintenance (O&M) cost was estimated at R122 000 for existing equipped and tested production boreholes. For tested boreholes with no equipment a cost estimate of R422 000 was used which include O&M cost for one year. The cost to pump 1 kℓ of water for all listed production boreholes equipped and tested above 25 m³/d is R2.20. The same calculation for all production boreholes equipped and tested yielding less than 25 m³/d was done. The cost is R13.54/1 000 l. This differs slightly from area to area due to the average available yield of the boreholes. The same comparison was done for tested but unequipped boreholes. The estimated cost is R5.93 for yields above 50 m³/d and R34.92 for yields between 25 to 50 m³/d. To minimize O&M costs in areas where the hydrogeological conditions are favourable boreholes should only be equipped if the recommended daily extraction is above 50 m³/day. Water quality was not included as a cost factor when the calculations were done.

7 WATER BALANCE

Using GIS tools the exploitable volume per quaternary catchment was calculated using the harvest potential from the maps produced by (Seward, Baron, & Seymour, 1998) and the exploitation factor multiplied with the surface extent of the quaternary catchment (see maps in Figure 7.1 and Figure 7.2) and the water balance summary tables are found under Appendix J. The exploitation potential does not take into account the groundwater quality. For the water schemes the same methodology was used. The calculation was more complex as some of the schemes fall within more than one quaternary catchment boundary. For the schemes water balance only the domestic available water extraction as listed on the Limpopo groundwater data base (GRIP) or as reported in the small town study reports or water master plans from the municipalities was used. The water balance on quaternary scale does not make provision for water use growth for irrigation and livestock watering. Where available the water demand growth for mines and industries over time was included, especially in the Mogalakwena quaternary catchments. In the Mogalakwena municipality master plan provision is made for possible growth in water demand for these industries. Domestic demand was increased as per expected population growth and includes unregistered "schedule one" use.

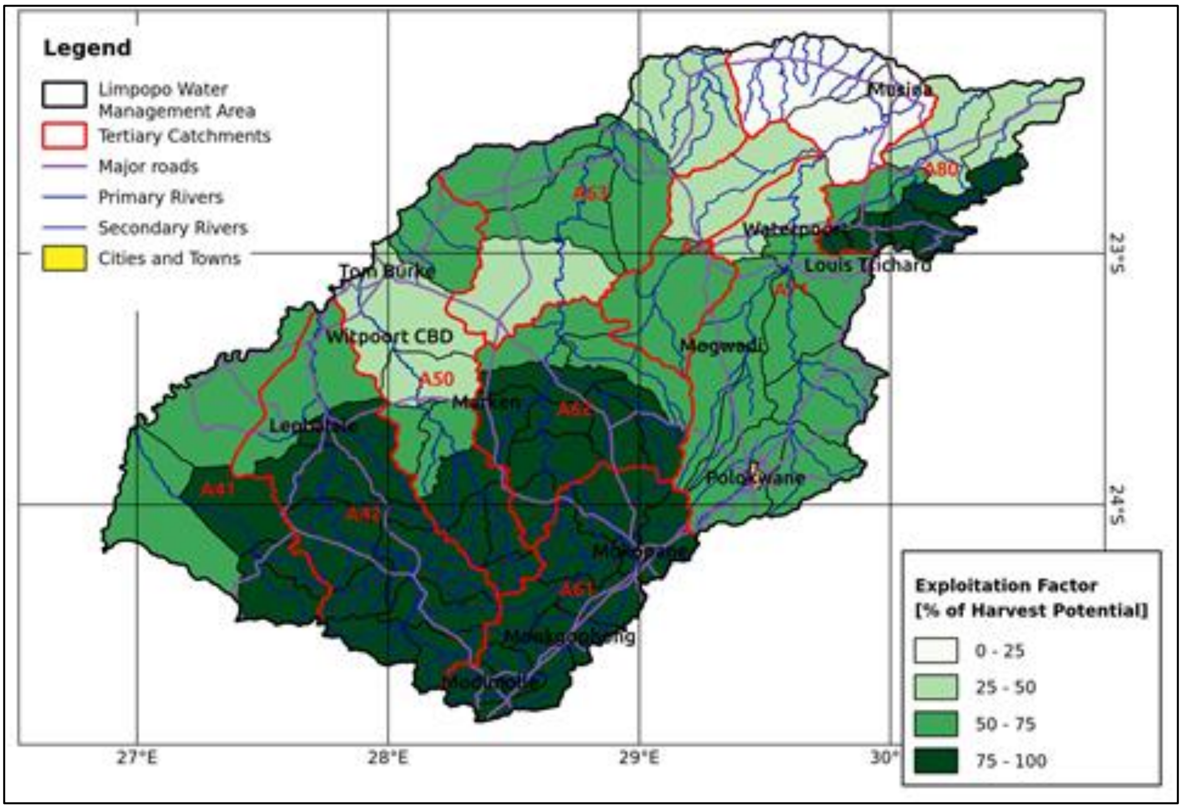


Figure 7.1 Exploitation factor

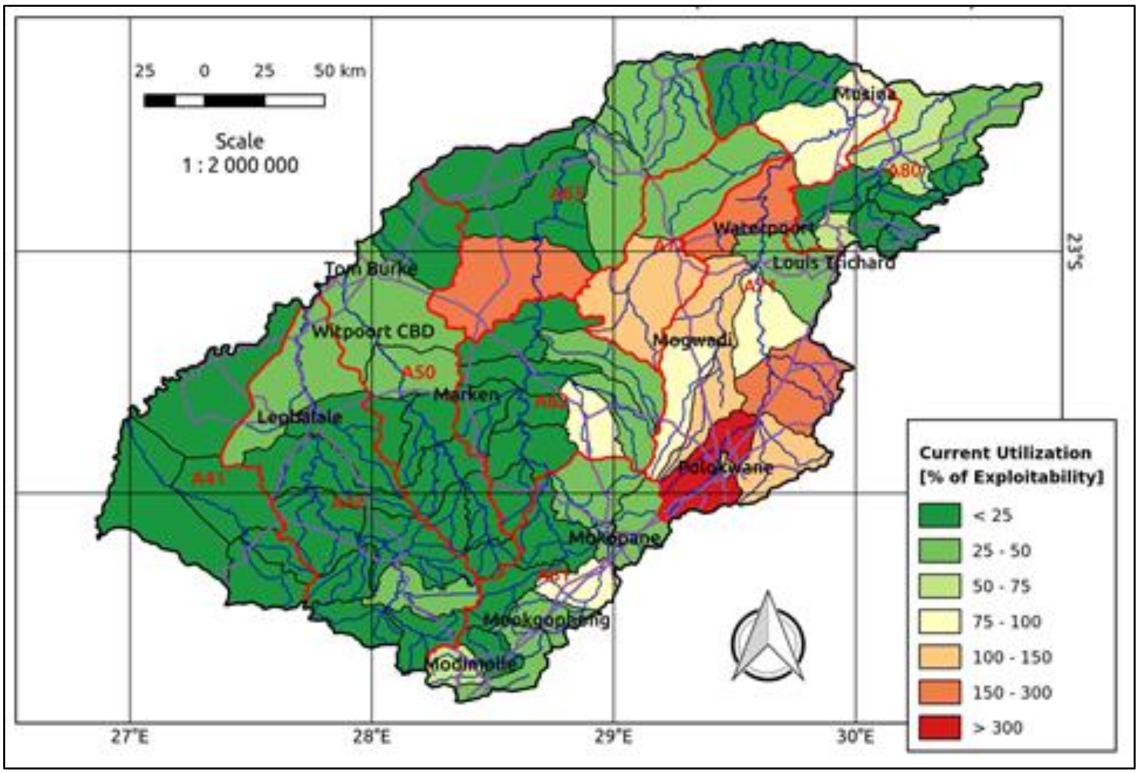


Figure 7.2 Current utilisation as a percentage of exploitability

8 RECONCILIATION OF GROUNDWATER REQUIREMENTS AND AVAILABILITY

From the water balance calculations it can be seen that there are some of the water schemes that are under stress regarding groundwater and surface water use. On a quaternary scale the central zone of the WMA is using more water than it receives from recharge. The current utilisation of groundwater as a percentage of exploitation is used in Figure 7.2 to evaluate usage versus availability. The water level "heat maps" (Appendix F from Figure F.1 to Figure F.3Figure F.) give an indication of the water level response. As rainfall is also a factor to take into consideration before making assumptions that deeper water levels are caused by pumping, long term time series water level data were compared with analysed rainfall data (Appendix E from Figure E.1 to Figure E.9). The transfer of water from other catchments or from outside the WMA was not included in the calculation, for instance the Sand River basin receives considerable recharge from treated sewerage water which originates from outside the WMA.

8.1 PROPOSED INTERVENTION MEASURES

8.1.1 Groundwater management

Groundwater data capturing on the NGA (formally NGDB) shows a decline in data entry since 1997 on national level, from 2002 data capturing devolved to regions (Review GRA1 and 2, 2009). This poses serious problems for future groundwater management. Groundwater monitoring and the availability of historic and current data is a key aspect of groundwater management. The following interventions are proposed:

- Enforcement of the compulsory groundwater monitoring as required by law for authorized water users.
- This data as well as all other available groundwater information must be added to the GRIP data base which is the database on a provincial level. The advantages of a good database on provincial level will ensure commitment on all levels of government. The quality of input data reflects the quality of output data, data capturing should thus be done with a high level of accuracy.
- The continuation of the Limpopo GRIP database is an essential tool for future groundwater management.
- The core of groundwater information is the NGA and provincial data must be exported on a regular basis.
- The spatial distribution of the provincial groundwater monitoring network must be constantly improved.
- The evaluation of current available water level data for the strategy was not in depth and further research work must be done.

- Chloride measurements of rainfall and groundwater at static level in the same area must be obtained as these form part of the harvest potential determination. The harvest potential map should then be updated using the same methodology as used in the first map completed in 1996.
- Different methodologies to determine the harvest potential during other studies need to be compared with the chloride methodology.

8.1.2 Artificial recharge

Dams and reservoirs act as surface storage of water while water in the subsurface is stored in micro pores and cracks. The openings represent a small percentage of a volume of solid rock. In order to increase subsurface storage large underground openings in the subsurface are needed. These are available due to mining activities, but unfortunately come with a negative impact: The main problem using old mines is the formation of acidic water (pH <5.0), laden with iron, sulphate and other metals, that form under natural conditions when geologic strata containing pyrite and other minerals are exposed to the atmosphere or oxidizing environments. Decanting of this water may pose serious environmental problems to river systems.

One old mine in the WMA that needs to be investigated as a storage facility is the old copper mine in Musina. The topography in the area is flat and there are no surface dam sites nearby. Possible pollution of the water during storage is a factor to take in consideration although the regional water quality is already poor. The static water level in the area is deep and decanting will not be a problem. Availability of water in Musina during very dry periods will be ranked higher than poor quality. The cost of water purification is linked to power use and research in solar technology can make this a viable option in future.

This solution for Musina will be considerably cheaper than a dam/pipeline option in Zimbabwe or Mozambique, but needs the following feasibility studies:

- The volume of the old dumps will give an indication of the available storage below surface, but this information may already be available from the mine's records.
- The cost to pump water to the mine from the Limpopo River in high flood times, which is the source. The cost of a solar farm to supply power needs to be investigated for this.
- The likelihood and intensity of acid mine drainage, which takes time, and which is more problematic with the introduction of oxygen and the fluctuation of the water level. The formation of acid water may be reduced by sealing the most problematic walls inside the mine, if at all possible.

Another such storage option is the old tin mine at Modimolle, where previous investigations have suggested a possible natural inflow of 60 ℓ/s into the mine. Modimolle obtains water from the Roodeplaat Dam, and the reuse of treated sewage needs to be ascertained as possible source for storing underground and then used to supply Mokopane and Polokwane. Again, the power source can be a solar farm, which is the largest cost for the treatment and supply.

The third, maybe less controversial, storage option is the area around Mahodi in the Dendron area. It is a large natural aquifer within the gneiss. The aquifer consists of a weathered and fractured zone to approximately 40 m with the natural static water level around 5-10 m below ground level, and a fractured zone associated with pegmatite and diabase dykes. During pumping tests the inflow into some of the boreholes proved to be more than 20 ℓ/s, which implies that an artificial recharge of around 20 ℓ/s per hole can be added to the aquifer with water that needs to be obtained from outside the catchment. The runoff at Ebenezer dam, the run-off of the Sand River as near as possible to the Mahodi area and the sewerage treatment works of Polokwane need to be investigated as possible sources. This would recharge the area over time. Irrigation would become an option again and the economy would be revitalized. Water can then be used for all the rural villages in the area of which some have large populations, like Senwarbarwana (Bochum), Mogwadi (Dendron) and Mahodi. Again solar farms as power source must be investigated.

The fourth area to be investigated is the dolomite aquifer at Weenen and Planknek. It is now pumped at approximately 8 Mℓ/d, although higher abstraction rates had been recommended during previous investigations, which in the end were not sustainable. Higher recharge, e.g. from treated effluent at Mokopane, could make this aquifer an artificial/natural reservoir with higher abstraction rates possible again.

Over and above artificial and natural underground reservoirs alluvial riverbeds can provide substantial water storage areas that obtain regular and large volume recharge. One example is the Mogalakwena River, where caissons (galleries or well points) were built and used. These are very effective as up to 30 ℓ/s can be achieved from these sources. Generally two pumps are installed: A big pump for the rainy season when “unlimited” volumes can be pumped while the river is in flow, and a smaller pump for abstraction of the water that is stored in the sand during dry periods. Again treated effluent could be pumped into the river to artificially keep the river in flow. These sand well points could thus be used at a higher pumping rate for a longer period of the year.

8.1.3 Water borne / dry system sewarage

Water borne sewerage uses large volumes of water. For large urban areas there is no other practical alternative. The re-use of water is linked to purification with cost implications. For rural areas where the density of the population is lower, dry sealed sewage units are the most effective system to protect the groundwater from possible pollution.

8.1.4 Development of additional sources for rural domestic supply

For the development of groundwater the most favourable approach is a regional approach with sufficient budget for exploration. This will result in fewer borehole installations to be maintained, as only the highest yielding boreholes will be equipped. It will also prevent over-abstraction within a limited area around the villages. Nitrate problems are associated with poor or incorrect rural village sanitation infrastructure and therefore production boreholes further from the villages will not carry the pollution risk.

9 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made with regard to the groundwater in the study area:

- The availability of surface and groundwater sources plays an ever-increasing role in decisions that can influence future economic growth for the Province. This is especially true for the Limpopo WMA North of which a large part (±30%) has a MAP of less than 400 mm/a.
- Water balance calculations indicate that some of the water schemes are under stress. It must be taken into account that the calculations used the polygon area as per DWS information and groundwater is not controlled by this arbitrary boundary. The calculations could be influenced by the position of the source which might be used for an adjacent water scheme.
- Water balance calculations for the quaternary catchments indicate possible over-utilisation in the central zone of the WMA. These areas have large groundwater extractions for domestic and irrigation. The regional water level maps indicating declined water levels confirm the stress on the resource.
- There are areas available for further groundwater development from which water can be transferred to areas under stress. Other interventions will include the possibility of artificial recharge, re-use of water and transfer schemes.
- Management of groundwater is essential and this must include the constant measuring of water levels, extraction and chemistry. The availability of data, for instance monitoring data from registered users such as mines, needs to be improved.
- A centralized groundwater database is essential for the whole province. The continuation of the Limpopo groundwater database is essential for future groundwater evaluations on a regional scale. The DWS groundwater monitoring network should be extended and the data updated so that time series groundwater level data from the NGA after 2003 becomes available.
- No extraction is monitored from production boreholes within the water schemes and assumptions were made in the calculations using the data on recommended sustainable yields listed on the GRIP database. The equipment status on the database is not updated regularly and therefore assumptions were made that all higher yielding boreholes are in production. In addition, it was assumed that only 70% of the tested volume is abstracted due to maintenance and power constraints. Teamwork is needed between the technical managers at the municipalities and DWS to update the database on a regular basis.

- Water user authorization requires monitoring of abstraction, water levels and chemistry. This data should be obtained and added to the Limpopo database and NGA.
- The difference in harvest potential and exploitation potential between the GRA2 and the recalculated datasets (as applied in this study) needs to be analysed and reassessed, using recharge figures from pending research (DWS and Potchefstroom University).

10 REFERENCES

ARC. (2003). *Land types of the maps 2228 Alldays & 2230 Messina.* Pretoria, South Africa: ARC-Institution for soil, Climate and Water.

Brandl, G. (1981). *The geology of Messina area, Geological map series 1:250 000, Single map sheet and explanation - 2230.* Messina, South Africa: Council of Geoscience.

Brandl, G. (1986). *The geology of Pietersburg area, Geological map series 1:250 000, Single map and explanation - 2328.* Pietersburg, South Africa: Council of Geoscience.

Brandl, G. (1987). *The geology of Tzaneen area, Geological map series 1:250 000, Single map and explanation - 2330.* Tzaneen, South Africa: Council of Geoscience.

Brandl, G. (2002). *The geology of the Alldays area, Geological map series 1:250 000, Single map sheet and explanation - 2228.* Alldays, South Africa: Council of Geoscience.

Bush, R. (1987). *Preliminary findings of geohydrological investigations of the area Swartwater-Platjan, as aids to the siting of successful boreholes. - Report no. GH3547.* Northern Transvaal: Directorate Geohydrology, Department of Water Affairs.

Bush, R. (1989). *A Geohydrological Assessment of the Swartwater and Beauty Areas - GH Report no. GH3577.* N.W. Transvaal: Directorate Geohydrology, Department of Water Affairs.

CGS. (1984). *1:1 000 000 Scale geological map and explanation brochure.* South Africa: Council of Geoscience.

De Klerk, M., & Wiegmans, F. (1990). *Geophysical Investigation of the Alluvial Aquifer (Limpopo River) on the farm Greefswald 37 MS - Report no. GH3689.* Pretoria, South Africa: Directorate Geohydrology, Department of Water Affairs.

De Villiers, S. (1968). *Verslag oor die beskikbare Grondwatervoorraad by die warmbron Tshipise - GH1579.* Pietersburg, South Africa: Geologiese opname.

Du Toit, A. (1939). *The geology of South Africa, Second Edition.* South Africa.

Du Toit, W., & Sonnekus, C. (2010). *Explanation of the 1:500 000 Hydrogeological map 2127.* Musina, South Africa.

Du Toit, W., & Sonnekus, C. (2010). *Explanation of the 1:500 000 Hydrogeological map 2326.* Polokwane, South Africa.

Du Toit, W., Whitehead, R., & Maluleke, T. (2007). *The groundwater potential of the Tshipise Sanadstone on the farm Kromhoek 438MS as a source of supply to the town of Alldays - Report no. GH4044.* South Africa: Directorate Water Resources Management, Department of Water Affairs.

Du Toit, W., Whitehead, R., & Maluleke, T. (2008). *Groundwater Resources Assessment of the Melinda fault region: The availability of groundwater for the Water Supply to the villages of My Darliing, Springfileds, Ga-Kgatha, Larochelle and Les-Fontein in the Blouberg Municipal area - Report no. GH4052.* Limpopo, South Africa: Directorate Water regulation and use, Department of Water Affairs and Forestry.

DWA. (2013a). *Validation and Verification Study for the Limpopo WMA North.* Prepared by Schoeman & Vennote, Department of Water Affairs, Pretoria, South Africa.

Enslin, J. (1970). *Die gronwaterpotensiaal van Suid-Afrika.* South Africa: Konvensie: Water vir die toekoms.

Fayazi, M. (1995). *Potential targets for groundwater development for a community water supply to Kutama and Sinthumule areas - Report no: GH3856.* Northern Transvaal, South Africa: Directorate: Geohydrology, Department of Water Affairs and Forestry.

Fayazi, M., & Orpen, W. (1989). *Development of water supply for Alldays from groundwater resources associated with the Taaibos fault. - Report no. GH3664.* Pretoria, South Africa: Department of Water Affairs and Forsetry.

Fayazi, M., Smith, C., & Meyer, P. (1981). *A geohydrological investigation in the area between Mopane and Tshipise, Mesina District - Report no. GH3185.* Messina, South Africa: Directorate Geohydrology, Department of Water Affairs.

Frommurze, H. (1937). *The water-bearing properties of the more important formations in the Union of South Africa.* South Africa.

Hem, J. (1970). *Study and interpretation of the chemical characteristics of natural water, Second edition.* U.S Geol Surey.

HRU. (1981). *Surface water resources of South Africa - Volume 1. Drainage regions A & B - The Limpopo Olifants - Report no. 9/81.* South Africa: Hydrogeological Research Unit.

Johnson, J. (1975). *Hydrochemistry in groundwater exploration.* Bulawayo, Zimbabawe.

Johnson, M., Anhaeusser, C., & Thomas, R. (2006). *The geology of South Africa. Geological society of South Africa.* Pretoria, South Africa: Council of Geoscience.

Kok, T. (1976). *Voorlopige evaluasie van die Grondwaterpotensial van seker plase tussen Dendron en Alldays Distrikte Pietersburg en Soutpanssberg - Report no. GH2885.* South Africa: Division of Geohydrology, Department of Environmental Affairs.

Kruger, G. (1983). *Terrain morphological map of South Africa.* Pretoria, South Africa: Soil and Irrigation research institute, Department of Agriculture.

Midgley, D., Pitman, W., & Middleton, B. (1994). *Surface water resources of South Africa - Report no: 298/1.1/94, Vol 1.* South Africa: Water Research Commision.

Mulder, M. (1973). *Water supply from Riversrand Limpopo River at Messina - Report no. GH3237.* Messina, South Africa.

Norman, N., & Whitfield, G. (2006). *Geological journeys. A traveller's guide to South Africa's rocks and landforms.* Pretoria, Soutrh Africa: Struiks publishers & Council of Geosciences.

Opren, W. (1994). *A recommended map legend and mapping methodology for the compilation of regional hydrogeological maps of the Republic of South Africa at a scale of 1:500 000. - Upublished report.* South Africa: Directorate Geohydrology, Department of Water Affairs and Forestry.

Orpen, W. (1985). *Development of groundwater supplies for the municipality of Louis Trichardt - Report no: GH3414.* South Africa: Directorate Geohydrology, Department of Water Affairs and Forestry.

Orpen, W. (1985). *Possible groundwater resources within a radius of about 20km of Louis Trichardt - Report no: GH3409.* South Africa: Directorate Geohydrology, Department of Water Affairs and Forestry.

Orpen, W., & Fayazi, M. (1983). *Assessment of the ground water resources in the proximity to Messina with particular reference to the Dowe-Tokwe fault - Report no. GH3260.* South Africa: Division of Geohydrology, Department of Environmental Affairs.

Parsons, P., & Wentzel, J. (2006). *Groundwater resource Directed Measures-GRDM Manual.* South Africa: Water Research Commission.

Seward, P., Baron, J., & Seymour, A. (1998). *The grounwater harvest potential map of the Republic of South Africa - Report no. GH3917.* South Africa: Directorate Geohydrology, Department of Water Affairs and Forestry.

Simonic, M. (1995). *National groundwater quality assessment.* South Africa.

Van den Berg, H. (1980). *Die sedimentologie van die Soutpansberg steenkoolveld met spesiale verwysing na steenkoolvorming.* South Africa: University of the Free State.

van der Westhuizen, C. (1983). *Beit Bridge Border control post abstraction of groundwater from the Limpopo River - Report no. GH3314.* South Africa: Division of Geohydrology, Department of Environmental Affairs.

van Wyk, E. (2002). *Sustainable development of Groundwater Resources - Draft report.* Pretoria, South Africa: Department of Water Affairs and Forestry.

Vegter, J. (1995). *Groundwater Resource of South Africa: An Explanation of a set of National Groundwater Maps - Report no. TT74/95: A-B33.* Pretoria, South Africa: Water Research Commission.

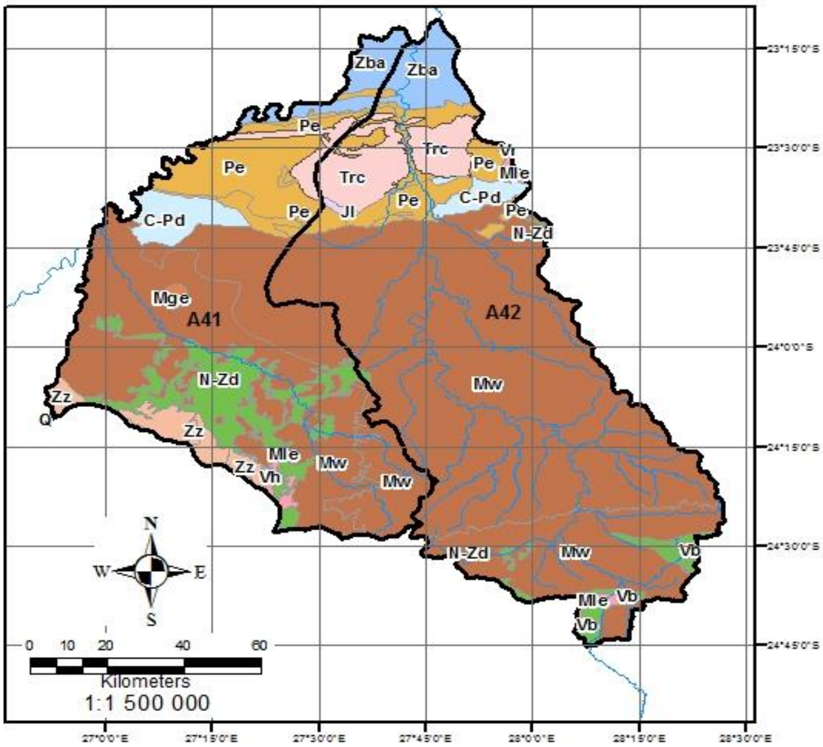
Visser, D. (1989). *Explanation of the 1:1 000 000 Geological map, fourth edition, 1984: The geology of the republic of South Africa, Transkei, Bophuthatswana, Venda and Ciskeiand the kingdoms of Lesotho and Swziland.* South Africa: Department of Mineral and Energy Affairs.

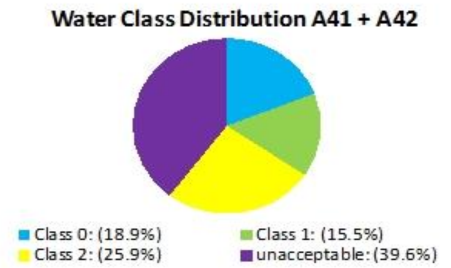
WRC. (1998). *Quality of domestic water supplies. Volume 1 - Report no: TT101/98.* South Africa: Water Research Commision.

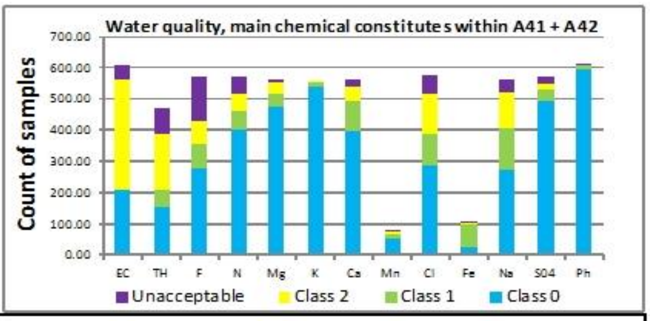
Zaporozec, A. (1972). *Graphical interpretation of water quality data.* South Africa: Ground water Journal Vol 10, No 2.

Appendix A

Aquifer units and lithology maps

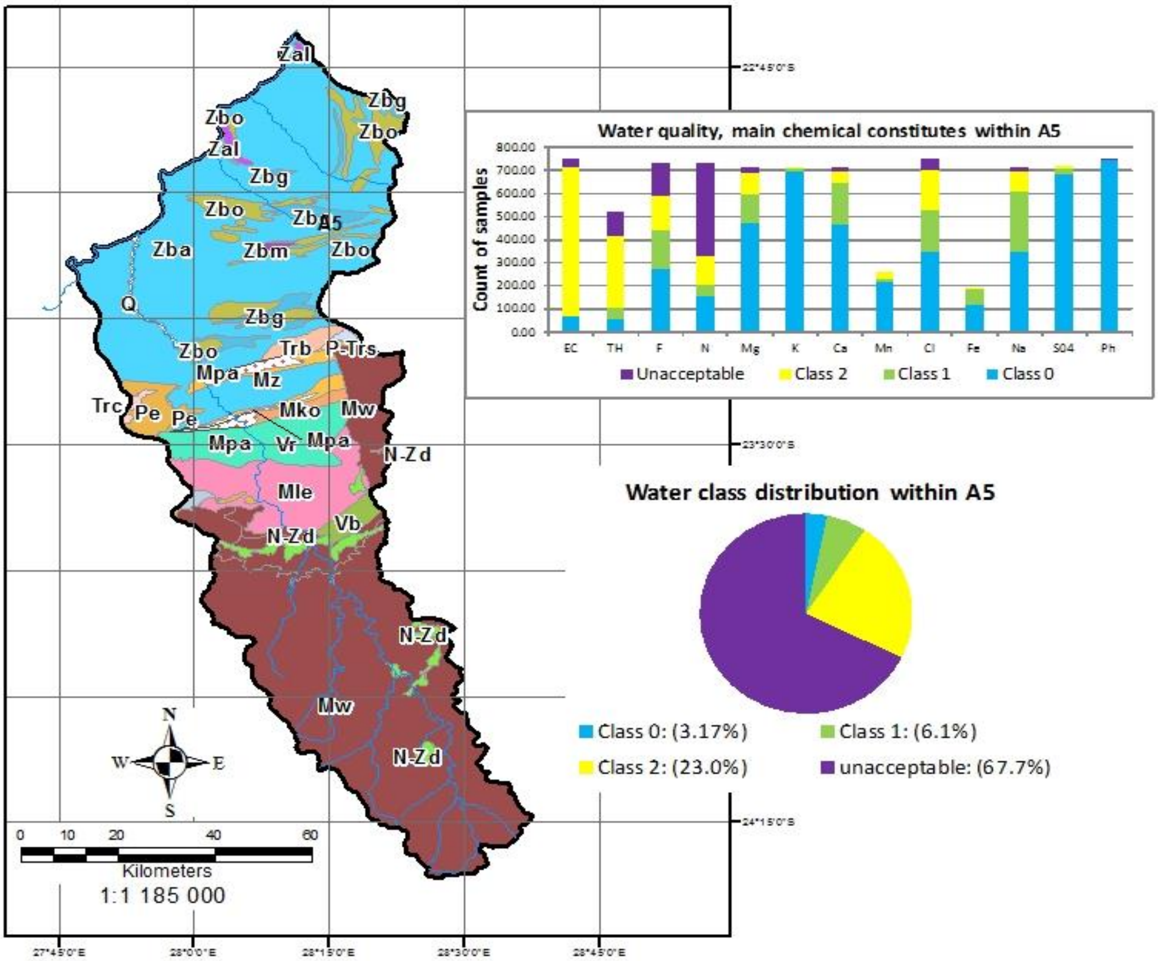






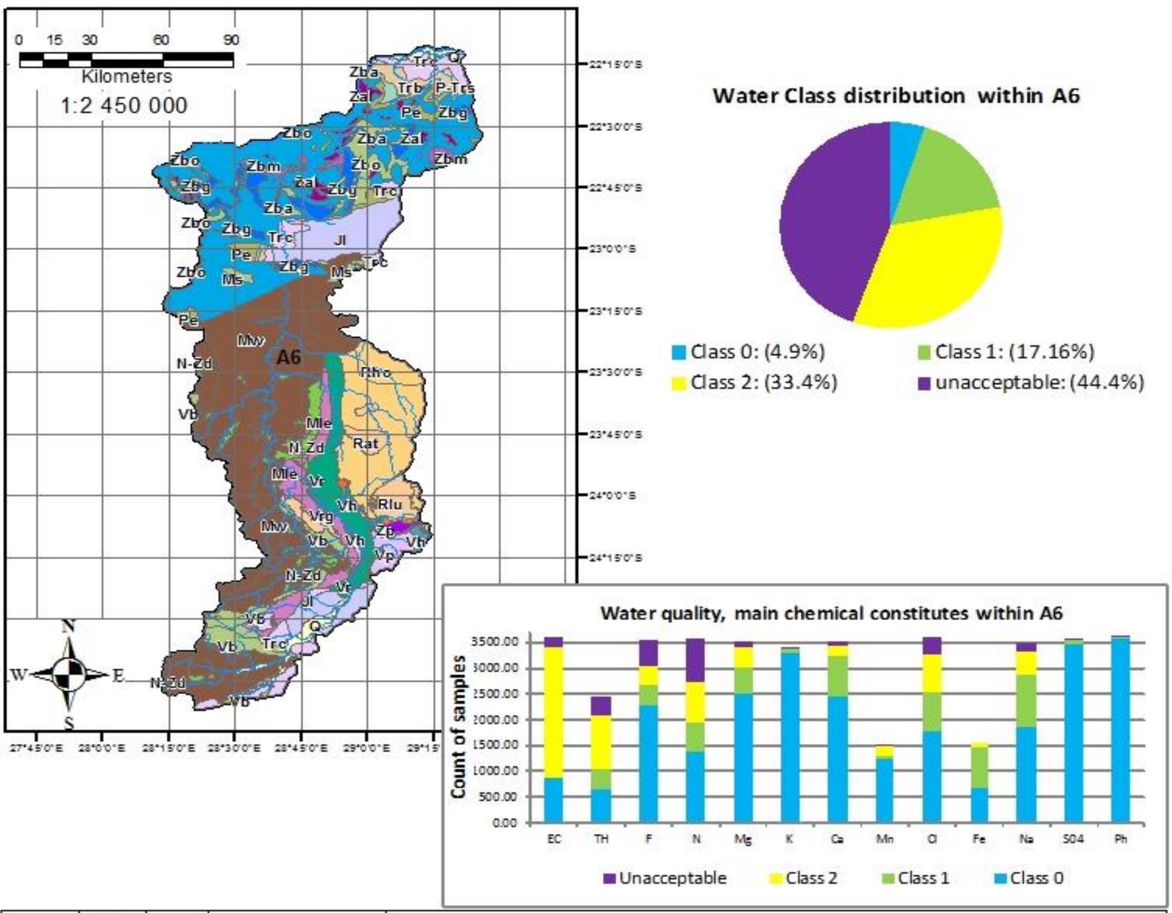
Symbol	Area surface (km2)	% Unit	Aquifer unit	Lithology
Q	0.7	0.00%	Alluvium	Alluvium (clay, sand, gravel, boulders)
JI	19.6	0.14%	Lebombo Group	Mafic/ultra mafic extrusive rocks (basalt, andesite)
Trc	723.5	5.00%	Clarens Formation	Predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose)
Pe	1406.3	9.73%	Ecca Group	Argillaceous and arenaceous rocks (approximately equal proportions)
C-pd	405.7	2.81%	Dwyka Group	Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
N-Zd	814.5	5.63%	Diabase	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite, hornblendite, carbonatite)
Mge	34.7	0.24%	Glendower C	Undifferentiated rocks and various mixed lithologies
Mw	9824.8	67.95%	Waterberg Group	Argillaceous and arenaceous rocks (approximately equal proportions)
Mle	100.8	0.70%	Lebowa Suite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Vr	7.5	0.05%	Rustenburg Suite	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite, hornblendite, carbonatite)
Vb	204.3	1.41%	Rooiberg Group	Undifferentiated rocks and various mixed lithologies
Vh	15.6	0.11%	Chuniespoort Group	Predominantly calcareous rocks (limestone, dolomite, calcarenite)
Zba	582.5	4.03%	Malala Drift Group	Undifferentiated rocks and various mixed lithologies
Zz	317.5	2.20%	Jnnamed Swazian Rock	Undifferentiated rocks and various mixed lithologies

Figure A.1 Delineation of aquifer units and lithology and chemistry (Matlabas and Mokolo)



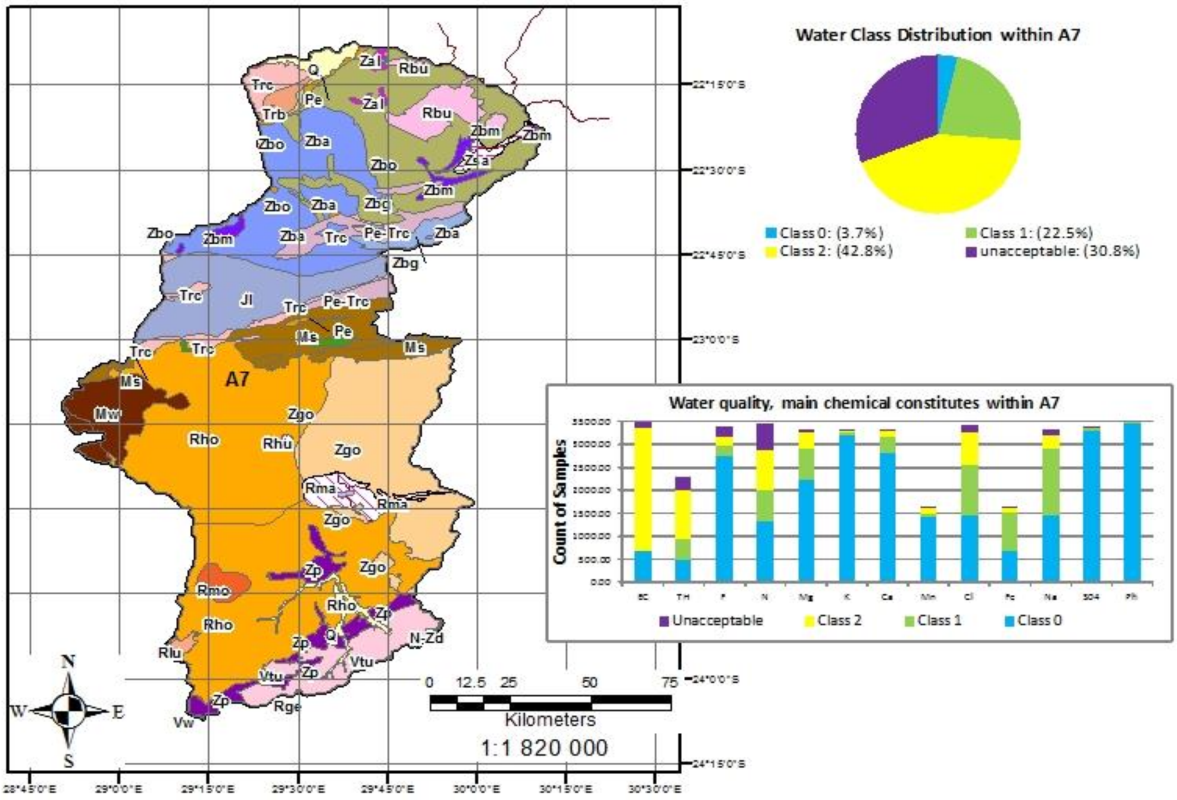
Symbol	Area surface (km2)	% Unit	Aquifer unit	Lithology
Q	21.4	0.32%	Alluvium	Alluvium (clay, sand, gravel, boulders)
Trc	14.1	0.21%	Clarens Formation	Predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose)
Trb	53.6	0.79%	Bosbokpoort Formation	Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
P-Trs	13.7	0.20%	Solitude Formation	Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
Pe	118.3	1.75%	Ecca Group	Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)Argillaceous and arenaceous rocks (approximately equal proportions)
C-pd	14.4	0.21%	Dwyka Group	Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
N-Zd	119.1	1.77%	Diabase	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite, hornblendite, carbonatite)
Mw	2595.5	38.46%	Waterberg Group	Argillaceous and arenaceous rocks (approximately equal proportions)
Mz	72.9	1.08%	Unnamed Mokolian rocks	Undifferentiated rocks and various mixed lithologies
Mko	37.0	0.55%	Koedeoesrand F	Undifferentiated rocks and various mixed lithologies
Mpa	70.2	1.04%	Palala Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Mle	415.4	6.16%	Lebowa Suite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Vr	305.8	4.53%	Rustenburg Suite	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite, hornblendite, carbonatite)
Vb	57.3	0.85%	Rooiberg Group	Acid/intermediate/alkaline extrusive rocks (rhyolite, felsite, quartzporphyry)
Zal	21.4	0.32%	Alldays Gneiss	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zbm	9.6	0.14%	Messina Suite	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite, hornblendite, carbonatite)
Zbo	299.3	4.44%	Mount Dowe Group	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zba	2354.9	34.90%	Malala Drift Group	Undifferentiated rocks and various mixed lithologies
Zbg	154.3	2.29%	Gumbu Group	Predominantly meta-calcareous rocks (marble, calc-silicate)

Figure A.2 Delineation of aquifer units and lithology and chemistry (Lephalala)



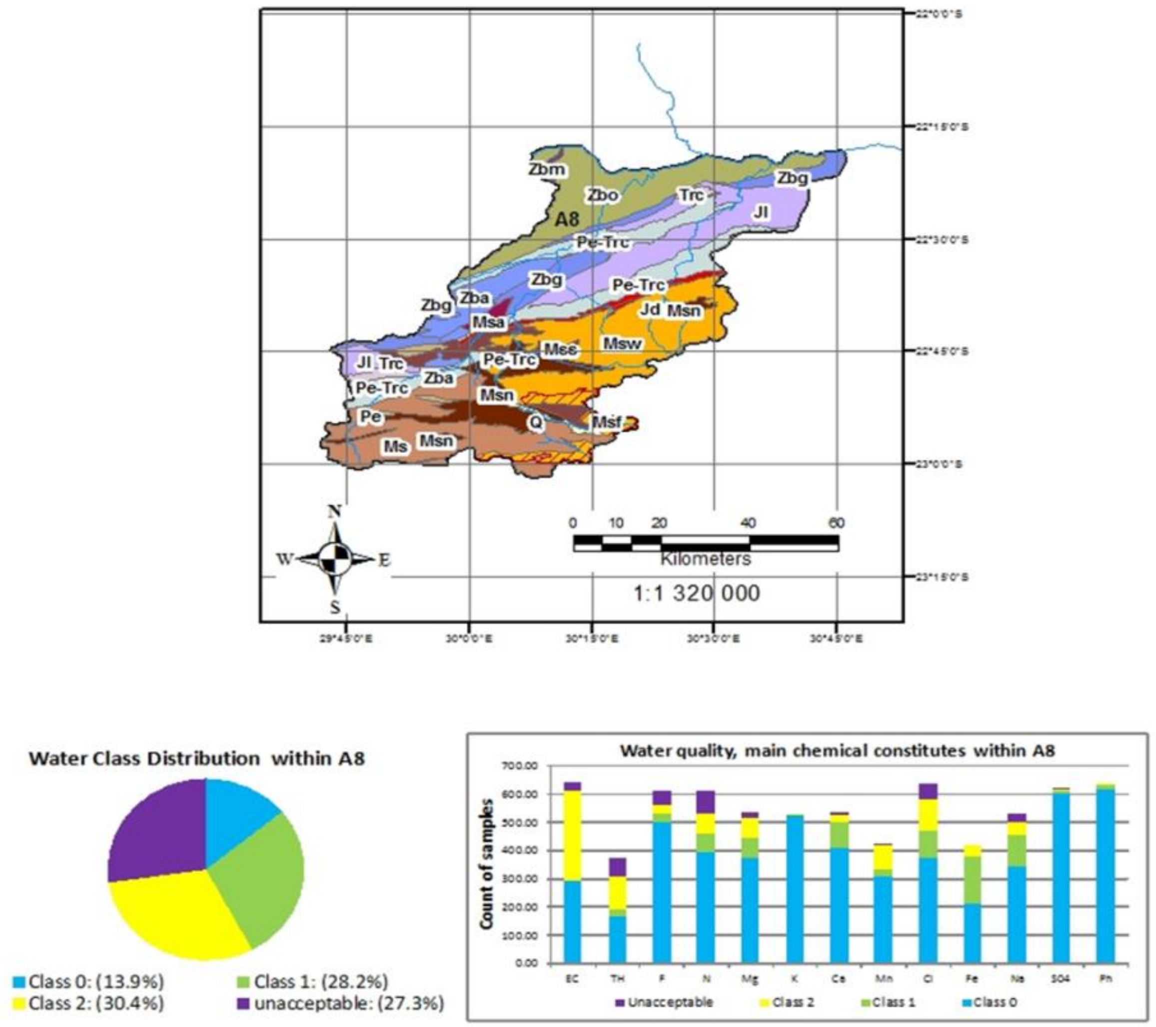
Symbol	Area surface (km2)	% Unit	Aquifer unit	Lithology
Q	14775.5	43.67%	Alluvium	Alluvium (clay, sand, gravel, boulders)
Jl	1110.9	3.28%	Lebombo Group	Mafic/ultra mafic extrusive rocks (basalt, andesite)
Trc	734.2	2.17%	Clarens Formation	Predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose)
Trb	303.0	0.90%	Bosbokpoort Formation	Predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose)
P-Trs	106.8	0.32%	Solitude Formation	Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
Pe	320.1	0.95%	Ecca Group	Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
N-Zd	447.0	1.32%	Diabase	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite)
Ms	80.7	0.24%	Soutpansberg Group	Mafic/ultra mafic extrusive rocks (basalt, andesite)
Mw	5708.0	16.87%	Waterberg Group	Argillaceous and arenaceous rocks (approximately equal proportions)
Mle	715.4	2.11%	Lebowa Suite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Vr	810.4	2.40%	Rustenburg Suite	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite)
Vb	630.0	1.86%	Rooiberg Group	Undifferentiated rocks and various mixed lithologies
Vrg	108.4	0.32%	Rashoop S	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Vp	241.6	0.71%	Pretoria Group	Undifferentiated rocks and various mixed lithologies
Vh	99.3	0.29%	Chuniespoort Group	Predominantly calcareous rocks (limestone, dolomite, calcarenite)
Vbl	9.2	0.03%	Black Reef Formation	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Vw	5.6	0.02%	Wolkberg Group	Undifferentiated rocks and various mixed lithologies
Rat	158.4	0.47%	Matlala Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rut	12.9	0.04%	Utrecht Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rlu	249.0	0.74%	Lunsklip Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rui	28.2	0.08%	Uitloop Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rge	7.9	0.02%	Geyser Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rho	1651.1	4.88%	Houtrivier Gniess	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zal	227.8	0.67%	Alldays Gneiss	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zbm	169.5	0.50%	Messina Suite	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite)
Zma	9.9	0.03%	Madiapala Syenite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Zbo	528.5	1.56%	Mount Dowe Group	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zba	3947.8	11.67%	Malala Drift Group	Undifferentiated rocks and various mixed lithologies
Zbg	590.4	1.74%	Gumbu Group	Predominantly meta-calcareous rocks (marble, calc-silicate)
Zp	45.1	0.13%	Pietersburg Group	Predominantly meta-argillaceous rocks (slate, phyllite, meta-pelite, schist, serpentine, amphibolite, hornfels)

Figure A.3 Delineation of aquifer units and lithology and chemistry (Mogalakwena)



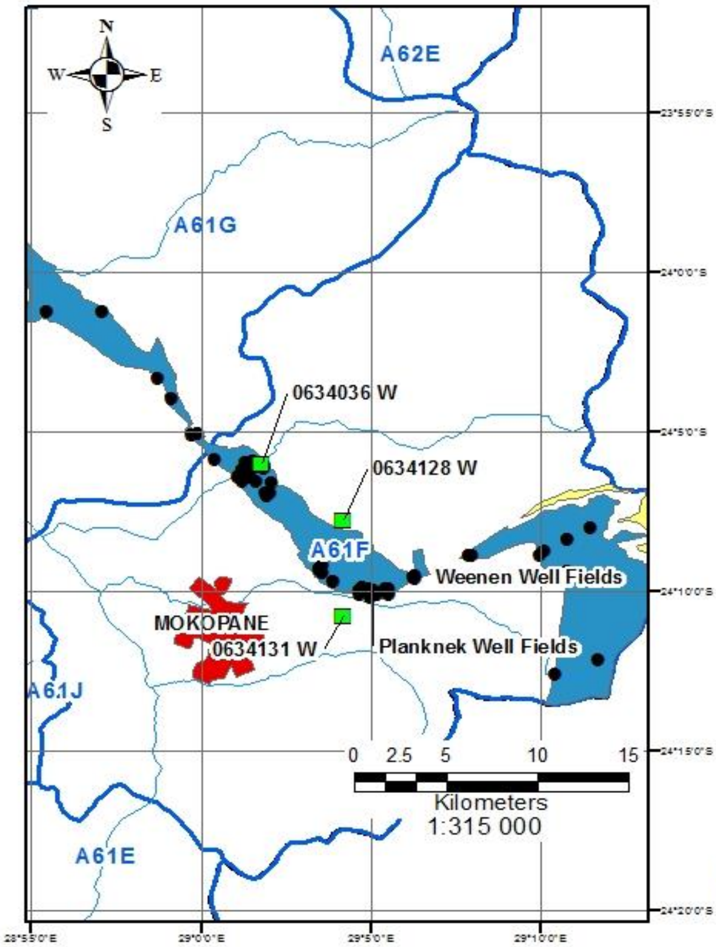
Symbol	Area surface (km2)	% Unit	Aquifer unit	Lithology
Q	223.7	1.43%	Alluvium	Alluvium (clay, sand, gravel, boulders)
Jl	1075.1	6.86%	Lebombo Group	Mafic/ultra mafic extrusive rocks (basalt, andesite)
Trc	376.5	2.40%	Clarens Formation	Predominantlyarenaceous rocks (sandstone, feldspathic sandstone, arkose)
Trb	92.1	0.59%	Bosbokpoort Formation	Predominantlyargillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
P-Trs	22.4	0.14%	Solitude Formation	Predominantlyargillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
Pe-Trc	414.0	2.64%	Undifferentiated Ecca Group	Undifferentiated rocks and various mixed lithologies
Pe	76.3	0.49%	Ecca Group	Predominantlyargillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
N-Zd	39.5	0.25%	Diabase	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite)
Ms	764.5	4.88%	Soutpansberg Group	Predominantlymeta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Mw	531.3	3.39%	Waterberg Group	Argillaceous and arenaceous rocks (approximatelyequal proportions)
Vbl	0.0	0.00%	Black Reef Formation	Predominantlymeta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Vw	1.4	0.01%	Wolkberg Group	Undifferentiated rocks and various mixed lithologies
Vz	0.8	0.01%	Unnamed Vaalian rocks	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Vtu	584.9	3.73%	Turfloop Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rma	233.3	1.49%	Matok Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rhu	4.6	0.03%	Hugomond Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rlu	46.1	0.29%	Lunsklip Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rui	0.5	0.00%	Uitloop Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rge	0.6	0.00%	Geyser Granite	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Rho	4921.8	31.39%	Houtrivier Griess	Predominantlymeta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Rbu	353.7	2.26%	Bulai Gneiss	Predominantlymeta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zal	42.6	0.27%	Alldays Gneiss	Predominantlymeta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zsa	88.5	0.56%	Sand River Gneiss	Predominantlymeta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zbm	141.1	0.90%	Messina Suite	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite)
Zbo	1775.9	11.33%	Mount Dowe Group	Predominantlymeta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zba	1444.8	9.22%	Malala Drift Group	Undifferentiated rocks and various mixed lithologies
Zbg	152.8	0.97%	Gumbu Group	Predominantly meta-calcareous rocks (marble, calc-silicate)
Zga	9.8	0.06%	Bandelierskop Complex	Acid/Intermediate/Alkaline intrusive rocks (various granitoids)
Zp	406.3	2.59%	Pietersburg Group	Predominantlymeta-argillaceous rocks (slate, phyllite, meta-pelite, schist, serpentine, amphibolite)
Zgo	1853.7	11.82%	Goudplaats Gneiss	Predominantlygneissoid rocks with xenoliths of undifferentiated metamorphic rocks

Figure A.4 Delineation of aquifer units and lithology and chemistry (Sand)



Symbol	Area surface (km2)	% Unit	Aquifer unit	Lithology
Q	21.4	0.51%	Alluvium	Alluvium (clay, sand, gravel, boulders)
Jl	543.4	12.92%	Lebombo Group	Mafic/ultra mafic extrusive rocks (basalt, andesite)
Jd	65.6	1.56%	Dolorite	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, pyroxenite, norite, carbonatite)
Trc	47.7	1.13%	Clarens Formation	Predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose)
Pe-Trc	548.9	13.05%	Undifferentiated Ecca Group	Undifferentiated rocks and various mixed lithologies
Pe	36.8	0.87%	Ecca Group	Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
Ms	585.1	13.91%	Soutpansberg Group	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Msn	322.8	7.67%	Nzehelele Formation	Predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose)
Msw	668.7	15.89%	Wyllies Poort Formation	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Msf	115.5	2.75%	Fundudzi Formation	Predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose)
Mss	154.9	3.68%	Sibasa Formation	Mafic/ultra mafic extrusive rocks (basalt, andesite)
Msa	26.8	0.64%	Stayt Formation	Mafic/ultra mafic extrusive rocks (basalt, andesite)
Zsa	1.5	0.03%	Sand River Gneiss	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zbm	11.8	0.28%	Messina Suite	Mafic/ultra mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite, hornblendite, carbonatite)
Zbo	591.2	14.05%	Mount Dowe Group	Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
Zba	186.5	4.43%	Malala Drift Group	Undifferentiated rocks and various mixed lithologies
Zbg	278.6	6.62%	Gumbu Group	Predominantly meta-calcareous rocks (marble, calc-silicate)

Figure A.5 Delineation of aquifer units and lithology and chemistry (Nzhelele)



Abstraction from the karst aquifer		
period	Planknek well field m³/month	Weenen well field m³/month
Nov 2013	57340.0	193105.0
Dec 2013	57940.0	114091.0
Jan 2014	47542.7	179654.9
Feb 2014	52662.7	263060.0
Mar 2014	56550.0	195250.0
Apr 2014	76830.0	195320.0
Total m³	348865.4	1140480.9
m³/ a	697730.9	2280961.7
Mm³ /a	0.698	2.281

Symbol	Aquifer unit	Lithology
Vh	Chuniespoort Group	Predominantly calcareous rocks (limestone, dolomite, calcarenite)
Vw	Wolkberg Group	Undifferentiated rocks and various mixed lithologies

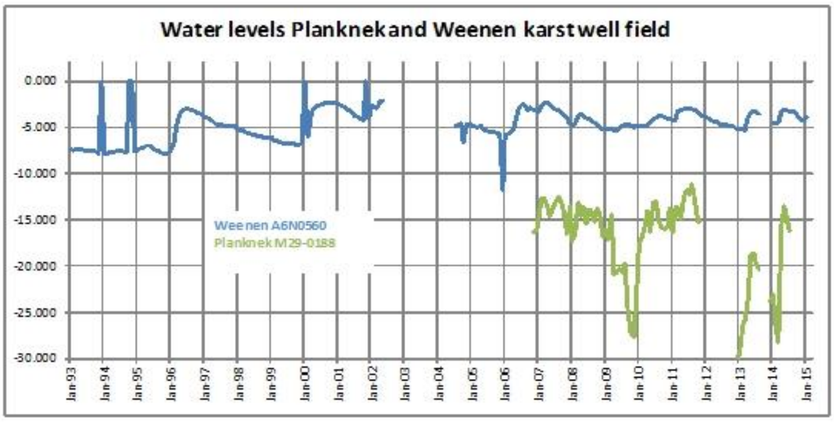


Figure A.6 Karst aquifer unit, abstraction, water levels and chemistry (Mokopane)

Appendix B

Groundwater chemistry maps

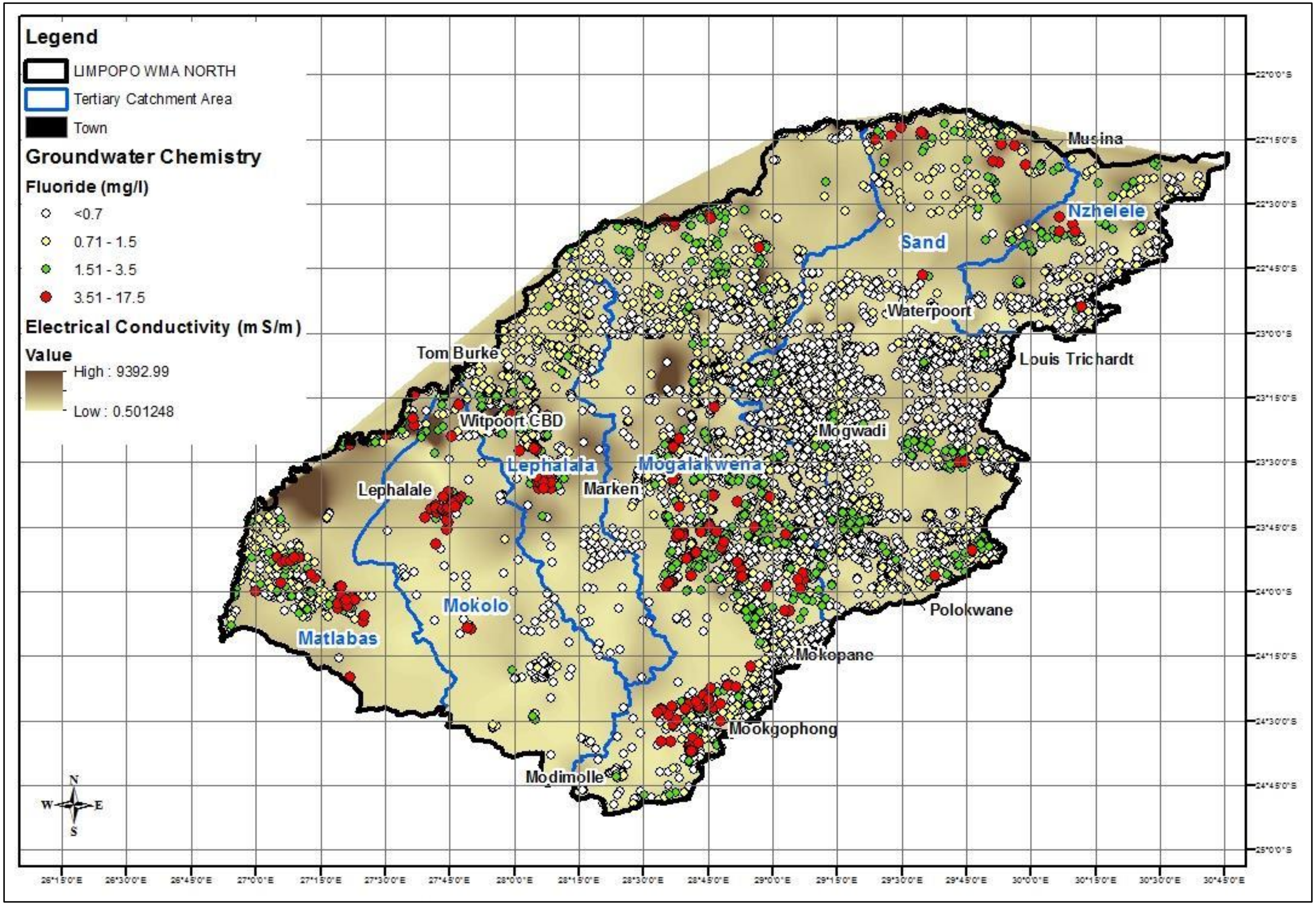


Figure B. 1 Groundwater quality, contoured EC and fluoride

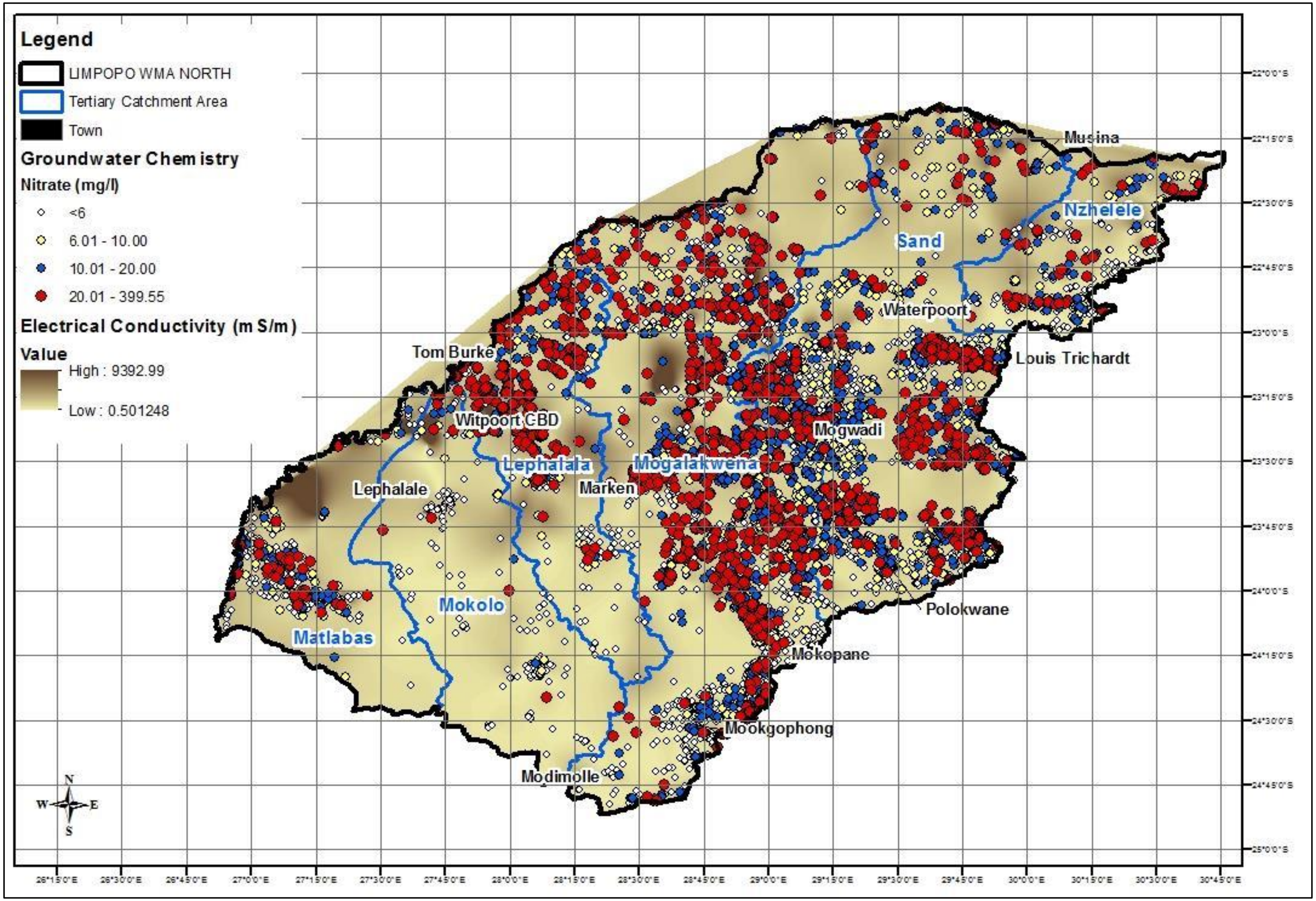


Figure B. 2 Groundwater quality, contoured EC and nitrate

Appendix C

Groundwater chemistry tables

Table C.1 Water chemistry, distribution of the major cations in the intergranular, fractured and karst aquifer units

Cationes		Calcium Ca (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Sodium Na (mg/l)			
Symbol	Number of samples	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un- accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un- accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un- accept-able
Limit Ranges		80	150	300	>300	25	50	100	>100	30	70	100	>100	100	200	400	>400
Category A: Intergranular aquifers																	
Q	227	80.2%	11.0%	6.2%	3.1%	98.5%	1.0%		0.5%	39.7%	39.7%	7.1%	13.7%	61.2%	24.7%	10.6%	3.5%
Category B: Fractured aquifers																	
Jd	2	100.0%				100.0%				100.0%				100.0%			
Trb	3	66.7%	33.3%			100.0%				33.3%	33.3%		33.3%	33.3%			66.7%
P-Trs	1	100.0%				100.0%					100.0%				100.0%		
Pe Trc	46	54.4%	32.6%	6.5%	6.5%	93.3%	2.2%	4.4%		13.0%	41.3%	26.1%	19.6%	34.8%	37.0%	10.9%	17.4%
Pe	100	74.0%	17.0%	3.0%	6.0%	100.0%				28.0%	63.0%	3.0%	6.0%	46.0%	34.0%	14.0%	6.0%
C-Pd	33	48.5%	36.4%	15.2%		50.0%	6.7%	20.0%	23.3%	33.3%	20.0%	26.7%	20.0%		6.7%	53.3%	40.0%
Mge	9	77.8%	11.1%	11.1%		100.0%					66.7%	11.1%	22.2%	66.7%	33.3%		
Ms	57	91.2%	7.0%	1.8%		100.0%				45.6%	35.1%	12.3%	7.0%	80.7%	14.0%	3.5%	1.8%
Msn	87	59.8%	32.2%	8.1%		100.0%				28.7%	28.7%	20.7%	21.8%	52.9%	25.3%	14.9%	6.9%
Msw	72	93.6%	6.9%			100.0%				77.8%	12.5%	4.2%	5.6%	87.5%	12.5%		
Msf	16	100.0%				100.0%				93.8%	6.3%			100.0%			
Mw	1277	63.8%	21.7%	10.1%	4.5%	95.7%	3.6%	0.5%	0.2%	37.8%	30.9%	13.6%	17.8%	49.6%	23.2%	17.5%	9.8%
Mpa	21	66.7%	19.1%	14.3%		95.2%		4.8%			38.1%	52.4%	9.5%	4.8%	76.2%	9.5%	9.5%
Mz	16	75.0%	25.0%			100.0%				6.3%	68.8%	25.0%		75.0%	18.8%	6.3%	
Vb	107	92.6%	6.3%	1.1%		100.0%				88.4%	10.5%	1.1%		96.8%	3.2%		
Vrg	2	100.0%				100.0%				100.0%				100.0%			
Vbl	1	100.0%				100.0%				100.0%				100.0%			
Category C : Karst aquifers																	
Vh	16	87.5%	12.5%			100.0%				18.8%	56.3%	25.0%		100.0%			

Table C.2 Water chemistry, distribution of the major cations in the intergranular and fractured aquifer units

Cationes		Calcium Ca (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Sodium Na (mg/l)			
Symbol	Number of samples	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un- accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un- accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un- accept-able
Limit Ranges		80	150	300	>300	25	50	100	>100	30	70	100	>100	100	200	400	>400
Category D: Intergranular and Fractured aquifers																	
Jl	512	78.3%	16.8%	3.7%	1.4%	99.1%	0.7%		0.2%	39.1%	44.2%	9.6%	7.1%	68.4%	24.7%	4.7%	2.2%
Jd	9	77.8%	11.1%	11.1%		100.0%				44.4%	33.3%		22.2%	77.8%	22.2%		
Trc	157	81.5%	14.0%	3.2%	1.9%	99.3%	0.7%			51.6%	31.9%	10.2%	6.4%	62.4%	22.3%	8.3%	7.0%
Pe	14	100.0%				100.0%				100.0%				28.6%		71.4%	
N-Zd	137	56.4%	22.6%	19.6%	1.5%	98.5%	1.5%			20.3%	44.4%	13.5%	21.8%	41.4%	30.8%	24.1%	3.8%
Ms	88	85.9%	12.9%	1.2%		98.8%	1.2%			31.8%	50.6%	15.3%	2.4%	88.1%	10.7%	1.2%	
Mss	38	86.8%	13.2%			100.0%				44.7%	42.1%	10.5%	2.6%	97.4%	2.6%		
Mle	204	75.0%	19.1%	5.9%		97.5%	2.5%			60.3%	26.5%	8.3%	4.9%	52.9%	29.4%	12.8%	4.9%
Vr	394	76.1%	19.8%	3.6%	0.5%	99.5%	0.5%			13.5%	30.2%	37.1%	19.3%	51.4%	23.7%	24.9%	
Vp	86	88.4%	8.1%	3.5%		100.0%				23.3%	52.3%	15.1%	9.3%	95.4%	3.5%	1.2%	
Vtu	142	95.6%	4.4%			99.3%	0.7%			46.0%	37.2%	16.1%	0.7%	59.9%	27.7%	11.7%	0.7%
Rat	60	78.3%	8.3%	11.7%	1.7%	98.3%	1.7%			51.7%	28.3%	8.3%	11.7%	18.3%	28.3%	28.3%	25.0%
Rbu	29	65.5%	20.7%	6.9%	6.9%	96.6%	3.5%			6.9%	44.8%	31.0%	17.2%	20.7%	55.2%	6.9%	17.2%
Rmo	77	97.4%	2.6%			96.1%	2.6%	1.3%		87.0%	10.4%	1.3%	1.3%	52.0%	48.1%		
Rma	64	59.7%	33.9%		6.5%	88.7%	11.3%			16.1%	62.9%	16.1%	4.8%	3.2%	59.7%	29.0%	8.1%
Rlu	68	94.1%	5.9%			98.5%	1.5%			86.8%	11.8%		1.5%	82.4%	13.2%	2.9%	1.5%
Rut	7	85.7%	14.3%			100.0%				42.9%	57.1%			28.6%	28.6%	42.9%	
Rho	2476	90.2%	7.8%	1.9%	0.2%	96.6%	2.4%	0.7%	0.2%	23.8%	41.4%	27.6%	7.2%	48.9%	42.5%	8.1%	0.6%
Zal	17	70.6%	17.7%		11.8%	100.0%				5.9%	64.7%	17.7%	11.8%	23.5%	64.7%		11.8%
Zbm	5	40.0%	40.0%	20.0%		100.0%				20.0%	40.0%	20.0%	20.0%	40.0%	0.0%	60.0%	
Zgo	550	89.3%	8.4%	2.4%		98.9%	1.1%			16.0%	49.8%	23.4%	10.9%	35.7%	55.7%	8.1%	0.6%
Zbg	69	63.8%	23.2%	10.1%	2.9%	91.3%	7.3%	1.5%		14.5%	39.1%	11.6%	34.8%	33.3%	39.1%	11.6%	15.9%
Zba	794	61.1%	28.2%	6.6%	4.2%	98.6%	1.4%			11.0%	53.7%	18.6%	16.7%	47.8%	35.8%	11.3%	5.1%
Zbo	149	76.5%	18.8%	4.7%		96.6%	3.4%			7.4%	54.4%	19.5%	18.8%	40.9%	34.2%	16.8%	8.1%
Zp	68	97.1%	2.9%			100.0%				23.5%	66.2%	8.8%	1.5%	70.6%	26.5%	2.9%	
Zz	40	80.6%	11.1%	5.6%	2.8%	97.2%	2.8%			66.7%	13.9%	2.8%	16.7%	5.6%	72.2%	5.6%	16.7%

Table C.3 Water chemistry, distribution of the major anions in the intergranular, fractured and karst aquifer units

Aniones		Chloride Cl (mg/l)				Nitrate NO2 + NO3 as N (mg/l)				Sulphate SO4 (mg/l)			
Symbol	Number of samples	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limit Ranges		100	200	600	>600	6	10	20	>20	200	400	600	>600
Category A: Intergranular aquifers													
Q	227	56.4%	19.4%	15.9%	8.4%	76.0%	8.4%	12.0%	3.6%	91.2%	74.5%	0.4%	0.9%
Category B: Fractured aquifers													
Trb	3	33.3%			66.7%	100.0%				33.3%	66.7%		
P-Trs	1	100.0%				100.0%				100.0%			
Pe Trc	46	19.6%	39.1%	26.1%	15.2%	70.7%	17.1%	9.8%	2.4%	82.6%	4.4%	2.2%	10.9%
Pe	100	53.0%	18.0%	22.0%	7.0%	48.0%	21.0%	22.0%	9.0%	92.0%	4.0%		4.0%
C-Pd	33		6.7%	40.0%	53.3%	33.3%	10.0%	26.7%	30.0%	100.0%			
Mge	9	66.7%	22.2%	11.1%		22.2%		22.2%	55.6%	100.0%			
Ms	57	70.2%	19.3%	7.0%	3.5%	78.6%	3.6%	10.7%	7.1%	96.5%	3.5%		
Msn	87	48.3%	11.5%	24.1%	16.1%	58.3%	9.5%	14.3%	17.9%	100.0%			
Msw	72	80.6%	9.7%	9.7%		87.0%	2.9%	2.9%	7.3%	100.0%			
Msf	16	93.8%	6.3%			93.8%		6.3%		100.0%			
Mw	1277	44.2%	15.0%	24.6%	16.3%	52.8%	10.3%	18.3%	18.6%	94.2%	2.9%	1.4%	1.6%
Mpa	21	19.1%	47.6%	23.8%	9.5%	14.3%	9.5%	4.8%	71.4%	95.2%			4.8%
Mz	16	75.0%	6.3%	18.8%		6.3%			93.8%	93.8%	6.3%		
Vb	107	96.8%	2.1%	1.1%		84.0%	1.1%	3.2%	11.7%	100.0%			
Vrg	2	100.0%				100.0%				100.0%			
Vbl	1	100.0%				100.0%				100.0%			
Category C : Karst aquifers													
Vh	16	100.0%				68.8%	18.8%	6.3%	6.3%	100.0%			

Table C.4 Water chemistry, distribution of the major anions in the intergranular and fractured aquifer

Aniones		Chloride Cl (mg/l)				Nitrate NO2 + NO3 as N (mg/l)				Sulphate SO4 (mg/l)			
Symbol	Number of samples	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limit Ranges		100	200	600	>600	6	10	20	>20	200	400	600	>600
Category D: Intergranular and Fractured aquifers													
Jl	512	64.8%	20.4%	10.4%	4.5%	31.8%	18.2%	25.8%	24.3%	98.0%	1.6%	0.2%	0.2%
Jd	9	44.4%	33.3%	11.1%	11.1%	87.5%			12.5%	100.0%			
Trc	157	56.1%	19.1%	17.8%	7.0%	57.4%	12.9%	15.5%	14.2%	95.5%	1.9%	2.6%	
N-Zd	137	35.3%	27.1%	18.8%	18.8%	40.6%	22.6%	24.1%	12.8%	97.0%	0.8%		2.3%
Ms	88	82.4%	12.9%	3.5%	1.2%	50.6%	29.4%	10.6%	9.4%	98.8%	1.2%		
Mss	38	86.8%	10.5%	2.6%		51.4%	20.0%	22.9%	5.7%	100.0%			
Mle	204	58.8%	13.2%	21.6%	6.4%	51.7%	10.3%	19.7%	18.2%	98.0%	2.0%		
Vr	394	46.5%	18.8%	31.5%	3.3%	29.7%	11.4%	25.4%	33.5%	98.5%	1.5%		
Vp	86	90.7%	3.5%	5.8%	0.0%	87.2%	8.1%	1.2%	3.5%	97.7%	1.2%		1.2%
Vtu	142	67.2%	22.6%	9.5%	0.7%	64.2%	16.8%	11.7%	7.3%	98.5%	1.5%		
Rat	60	30.0%	31.7%	25.0%	13.3%	26.7%	13.3%	20.0%	40.0%	98.3%	1.7%		
Rbu	29	10.3%	48.3%	24.1%	17.2%	24.1%	17.2%	37.9%	20.7%	72.4%	13.8%	3.5%	10.3%
Rmo	77	74.0%	24.7%	1.3%		23.4%	24.7%	31.2%	20.8%	100.0%			
Rma	64	21.0%	29.0%	43.6%	6.5%	12.5%	7.8%	21.9%	57.8%	93.6%			6.5%
Rlu	68	88.2%	5.9%	5.9%		51.5%	19.1%	19.1%	10.3%	95.6%	2.9%	1.5%	
Rut	7	42.9%	28.6%	28.6%		71.4%			28.6%	100.0%			
Rho	2476	42.4%	36.3%	19.9%	1.4%	47.4%	22.6%	21.1%	8.8%	97.4%	1.5%	0.5%	0.7%
Zal	17	47.1%	29.4%	11.8%	11.8%	41.2%	11.8%	29.4%	17.7%	88.2%			11.8%
Zbm	5	40.0%	20.0%	20.0%	20.0%	20.0%		40.0%	40.0%	80.0%		20.0%	
Zgo	550	29.6%	49.6%	18.6%	2.2%	53.3%	12.9%	16.6%	17.3%	98.9%	0.7%	0.4%	
Zbg	69	40.6%	15.9%	23.2%	20.3%	36.8%	20.6%	16.2%	26.5%	85.5%	8.7%	1.5%	4.4%
Zba	794	48.1%	24.2%	18.5%	9.2%	21.7%	13.1%	23.3%	41.9%	91.1%	3.9%	3.1%	1.9%
Zbo	149	44.3%	25.5%	24.8%	5.4%	22.8%	22.8%	24.2%	30.2%	88.6%	6.7%	3.4%	1.3%
Zp	68	85.3%	11.8%	2.9%		36.8%	26.5%	23.5%	13.2%	100.0%			
Zz	40	2.8%	69.4%	8.3%	19.4%	83.3%	11.1%	5.6%		75.0%	19.4%	5.6%	

Table C.5 Water chemistry, distribution of the EC, pH and fluoride in the intergranular, fractured and karst aquifer units

Physical requirements		Conductivity (mS/m)				pH (pH units)				Flouride F (mg/l)			
Symbol	Number of samples	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Ideal	Class 1 '5-6 acidic 9-9.5 alcalic	Class 2 '4-5 acidic 9.5-10	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limits Ranges		70	150	370	>370	6.0-9.0	acceptable	acceptable	>10 & <4	0.7	1	1.5	>1.5
Category A: Intergranular aquifers													
Q	227	35.2%	42.7%	16.3%	5.7%	98.67%	0.88%			73.7%	13.4%	4.0%	8.9%
Category B: Fractured aquifers													
Trb	3	33.3%			66.7%	100.0%						66.7%	33.3%
P-Trs	1		100.0%			100.0%					100.0%		
Pe Trc	46	6.5%	52.2%	26.1%	15.2%	97.8%	4.4%			62.5%	7.5%	22.5%	7.5%
Pe	100	2.0%	70.0%	21.0%	7.0%	97.0%	2.0%	0.2%		63.6%	11.1%	12.1%	13.1%
C-Pd	33	3.2%	19.4%	35.8%	41.9%	100.0%				60.0%	3.3%		36.7%
Mge	9		66.7%	33.3%		100.0%				11.1%		11.1%	77.8%
Ms	57	54.4%	35.1%	8.8%	1.8%	96.5%	3.5%	0.2%		92.9%	3.6%	1.8%	1.8%
Msn	87	32.2%	25.3%	32.2%	10.3%	100.0%				83.5%	6.3%	5.1%	5.1%
Msw	72	76.4%	15.3%	8.3%		94.1%	5.9%	0.2%		85.5%	2.9%	11.6%	
Msf	16	93.8%	6.3%			100.0%				100.0%			
Mw	1277	30.6%	29.3%	29.4%	10.7%	98.5%	1.4%	0.2%		70.4%	10.5%	7.9%	11.3%
Mpa	21		61.9%	33.3%	4.8%	100.0%				19.1%	4.8%	4.8%	71.4%
Mz	16		81.3%	18.8%		100.0%				6.3%	50.0%	37.5%	6.3%
Vb	107	80.4%	13.1%	5.6%	0.9%	99.1%	0.9%			57.9%			42.1%
Vrg	2	100.0%				100.0%					50.0%		50.0%
Vbl	1	100.0%				100.0%				100.0%			
Category C: Karst Aquifers													
Vh	16	68.8%	31.3%			100.0%				81.3%		18.8%	

Table C.6 Water chemistry, distribution of the EC, pH and fluoride in the intergranular and fractured aquifer units

Physical requirements		Conductivity (mS/m)				pH (pH units)				Flouride F (mg/l)			
Symbol	Number of samples	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Ideal	Class 1 '5-6 acidic 9-9.5 alcalic	Class 2 '4-5 acidic 9.5-10	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limits Ranges		70	150	370	>370	6.0-9.0	acceptable	acceptable	>10 & <4	0.7	1	1.5	>1.5
Category D: Intergranular and Fractured aquifers													
Jl	512	28.3%	55.3%	14.1%	2.3%	97.9%	1.6%	1.0%		77.0%	11.0%	8.2%	3.7%
Jd	9	33.3%	44.4%	22.2%		100.0%				100.0%			
Trc	157	41.4%	38.2%	15.9%	4.5%	99.4%	1.3%			52.9%	12.4%	13.1%	21.6%
N-Zd	137	14.6%	48.9%	21.9%	14.6%	99.3%			0.7%	35.3%	15.0%	10.5%	39.1%
Ms	88	50.0%	39.8%	8.0%	2.3%	96.6%	2.3%	0.2%		97.7%	1.2%	1.2%	
Mss	38	52.6%	36.8%	10.5%		93.4%	4.8%	0.8%		90.9%			9.1%
Mle	204	44.6%	31.9%	19.1%	4.4%	99.0%	1.0%			16.7%	9.8%	11.8%	61.8%
Vr	394	14.7%	41.9%	42.4%	1.0%	100.0%				53.1%	13.3%	18.5%	15.1%
Vp	86	51.2%	40.7%	8.1%		98.8%	1.2%			83.7%	11.6%	3.5%	1.2%
Vtu	142	27.5%	61.3%	9.2%	2.1%	99.3%	0.7%			58.4%	13.9%	13.9%	13.9%
Rat	60	16.7%	30.0%	46.7%	6.7%	100.0%				21.7%	10.0%	6.7%	61.7%
Rbu	29	3.5%	51.7%	27.6%	17.2%	100.0%	3.5%			10.3%	10.3%	41.4%	37.9%
Rmo	77	29.9%	67.5%	2.6%		100.0%				33.8%	9.1%	23.4%	33.8%
Rma	64	0.0%	42.2%	51.6%	6.3%	100.0%				14.5%	8.1%	16.1%	61.3%
Rlu	68	72.1%	23.5%	4.4%		100.0%				23.5%	5.9%	11.8%	58.8%
Rut	7	14.3%	57.1%	28.6%		100.0%				57.1%	14.3%	14.3%	14.3%
Rho	2476	17.1%	62.7%	19.7%	0.5%	99.3%	0.6%		0.1%	88.4%	6.1%	3.4%	2.1%
Zal	17	0.0%	70.6%	17.7%	11.8%	100.0%				5.9%	35.3%	5.9%	52.9%
Zbm	5	0.0%	40.0%	60.0%		100.0%				40.0%	20.0%		40.0%
Zgo	550	13.3%	59.8%	25.6%	1.3%	99.8%	0.4%			80.6%	12.6%	4.7%	2.2%
Zbg	69	5.8%	50.7%	29.0%	14.5%	100.0%				42.0%	20.3%	15.9%	21.7%
Zba	794	6.1%	58.9%	28.0%	7.1%	99.4%	0.6%			33.6%	24.0%	26.6%	15.8%
Zbo	149	3.4%	58.4%	34.2%	4.0%	99.3%	0.7%			24.8%	22.8%	27.5%	24.8%
Zp	68	36.8%	58.8%	4.4%		100.0%				76.5%	7.4%	5.9%	10.3%
Zz	40	7.5%	62.5%	17.5%	12.5%	100.0%				8.3%	5.6%	8.3%	77.8%

Appendix D

Maximum yield tables

Table D.1 Maximum yields for the intergranular, fractured and karst aquifer units-after DWS

Aquifer Unit	Count dry boreholes	Count wet boreholes	% dry boreholes	Maximum yield distribution as %				
				0-0.01 (ℓ/s)	0.1-0.5 (ℓ/s)	0.5-2 (ℓ/s)	2-5 (ℓ/s)	>5 (ℓ/s)
Category A: Intergranular aquifers								
Q	19	303	5.9%	4.9%	10.2%	22.7%	20.4%	41.5%
Category B: Fractured aquifers								
Trb	9	99	8.3%	36.0%	25.0%	25.0%	13.0%	1.0%
P-Trs	0	21	0.0%	12.0%	24.0%	20.0%	12.0%	32.0%
Pe Trc	36	231	13.5%	12.0%	17.0%	32.0%	20.0%	20.0%
Pe	33	364	8.3%	8.0%	13.0%	26.0%	38.0%	15.0%
C-Pd	10	81	10.9%	18.5%	18.5%	39.5%	17.3%	6.2%
Mge	0	6	0.0%	16.7%		66.7%	16.7%	
Ms	9	19	47.3%	16.0%	26.0%	37.0%	5.0%	16.0%
Msn	31	135	18.7%	5.0%	14.0%	36.0%	31.0%	14.0%
Msw	86	383	18.3%	7.0%	26.0%	30.0%	19.0%	18.0%
Msf	25	193	11.5%	6.0%	12.0%	42.0%	27.0%	13.0%
Mw	814	4198	19.3%	16.8%	26.8%	35.2%	15.0%	6.2%
Mko	1	1	0.0%			100.0%		
Mpa	4	19	17.4%	15.8%	21.1%	26.3%	26.3%	10.5%
Mz	8	8	50.0%		37.5%	50.0%		12.5%
Vb	34	300	10.2%	13.0%	26.3%	38.7%	17.0%	5.0%
Vrg	16	34	32.0%	11.8%	20.6%	44.1%	23.5%	
Vp	4	8	66.6%	0.0%	25.0%	50.0%	25.0%	
Vh	17	23	42.5%	13.0%	26.0%	35.0%	9.0%	17.0%
Vbl	0	9	0.0%			44.0%	44.0%	11.0%
Vw	13	51	20.3%	10.0%	10.0%	33.0%	31.0%	16.0%
R-Vbo	not sufficient data							
Rp	4	18	18.2%		25.0%	50.0%	25.0%	
Category C: Karst aquifers								
Vh	81	207	28.1%	28.0%	15.0%	28.0%	16.0%	13.0%

Aquifer Unit	Count dry boreholes	Count wet boreholes	% dry boreholes	Maximum yield distribution as %				
				0-0.01 (ℓ/s)	0.1-0.5 (ℓ/s)	0.5-2 (ℓ/s)	2-5 (ℓ/s)	>5 (ℓ/s)
Category D: Intergranular and Fractured aquifers								
Jl	184	2778	6.6%	3.7%	10.0%	23.0%	24.2%	38.9%
Jd	11	27	28.9%	11.1%	3.7%	18.5%	25.9%	40.7%
Trc	129	1091	11.0%	9.5%	25.8%	31.3%	17.0%	16.5%
N-Zd	101	348	22.4%	14.4%	25.9%	36.5%	15.8%	7.5%
Msp	7	14	33.3%			29.0%	21.0%	50.0%
Ms	26	106	19.6%	9.4%	12.3%	30.2%	25.5%	22.6%
Mss	43	293	12.8%	5.0%	20.0%	36.0%	23.0%	16.0%
Msa	4	11	27.0%	9.0%	27.2%	27.2%	27.2%	9.0%
Mle	288	638	31.1%	23.0%	26.0%	32.0%	11.0%	8.0%
Vr	224	464	32.5%	12.5%	17.7%	31.3%	19.4%	19.2%
Vp	129	487	20.9%	17.5%	21.2%	30.2%	15.8%	15.4%
Vtu	21	156	11.9%	12.0%	24.0%	40.0%	15.0%	10.0%
Rat	4	19	17.4%	5.6%	5.6%	50.0%	11.1%	27.8%
Rbu	16	42	28.0%	12.0%	17.0%	36.0%	21.0%	14.0%
Rmo	4	48	7.7%	4.2%	14.6%	22.9%	43.8%	14.6%
Rma	13	34	27.7%	35.3%	20.6%	14.7%	26.8%	2.9%
Rhu	not sufficient data							
Rlu	7	41	14.6%	46.3%	26.8%	22.0%	4.9%	
Rut	7	8	46.6%	25.0%	50.0%	12.5%	12.5%	
Rui	0	5	0.0%	60.0%	40.0%			
Rge	4	18	18.2%	16.7%	33.3%	33.3%	11.1%	5.6%
Rho	140	2266	5.8%	4.0%	5.1%	17.2%	19.8%	54.0%
Zal	8	66	11.0%	12.0%	29.0%	33.0%	15.0%	11.0%
Zbm	1	79	1.0%	25.0%	38.0%	29.0%	5.0%	3.0%
Zma	0	6	0.0%	50.0%	17.0%	33.0%		
Zbm	not sufficient data							
Zsa	not sufficient data							
Zgo	339	1519	18.0%	9.0%	18.0%	34.0%	26.0%	14.0%
Zbg	56	214	20.7%	11.7%	30.4%	35.1%	13.1%	9.8%
Zba	270	2039	11.7%	14.8%	25.5%	34.3%	15.9%	9.5%
Zbo	83	407	16.9%	14.5%	27.8%	33.7%	17.2%	6.9%
Zga	not sufficient data							
ZP	13	134	8.8%	3.7%	5.2%	28.4%	20.9%	41.8%
ZZ	556	938	37.2%	28.1%	19.7%	35.6%	12.2%	4.4%
Total	3942	21007	15.8%					

Appendix E

Groundwater level graphs

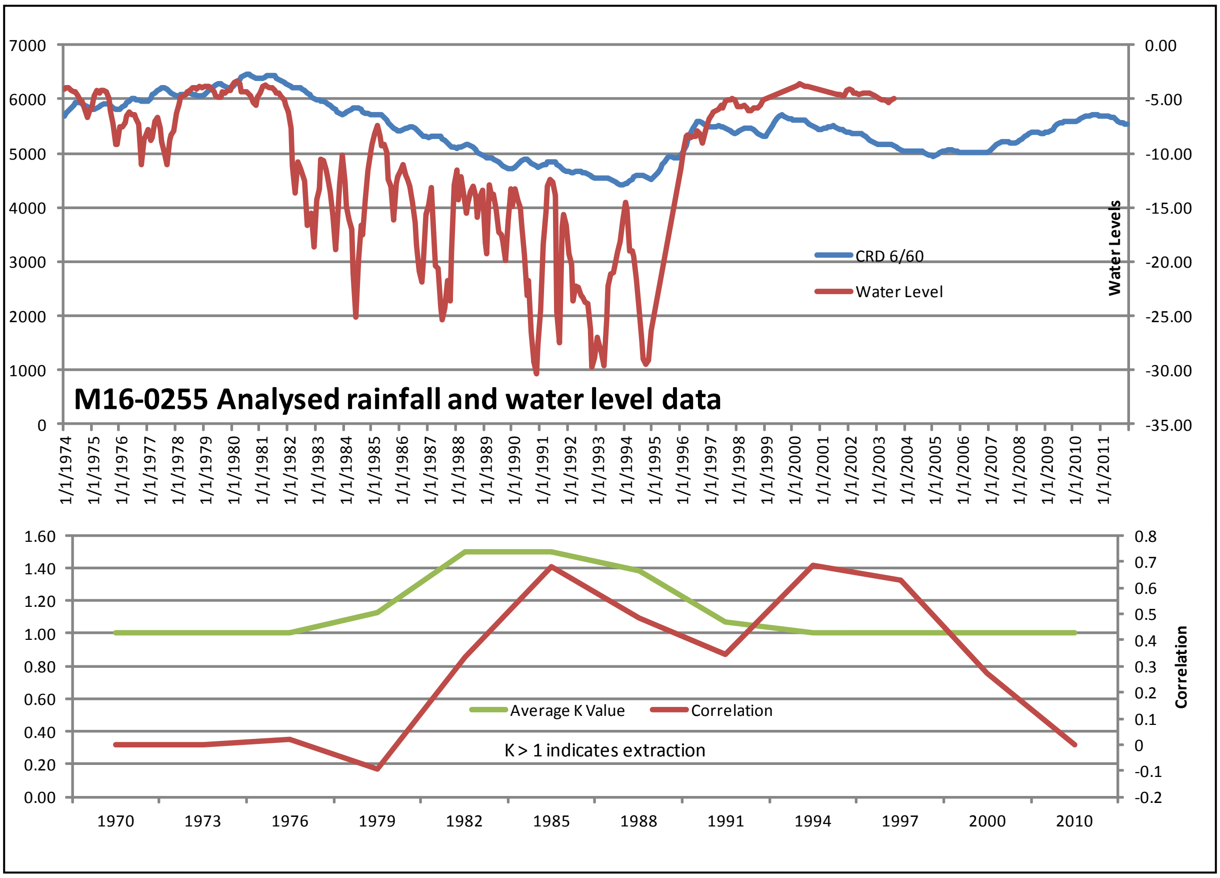


Figure E.1 Analysed rainfall and water level data (M16-0255)

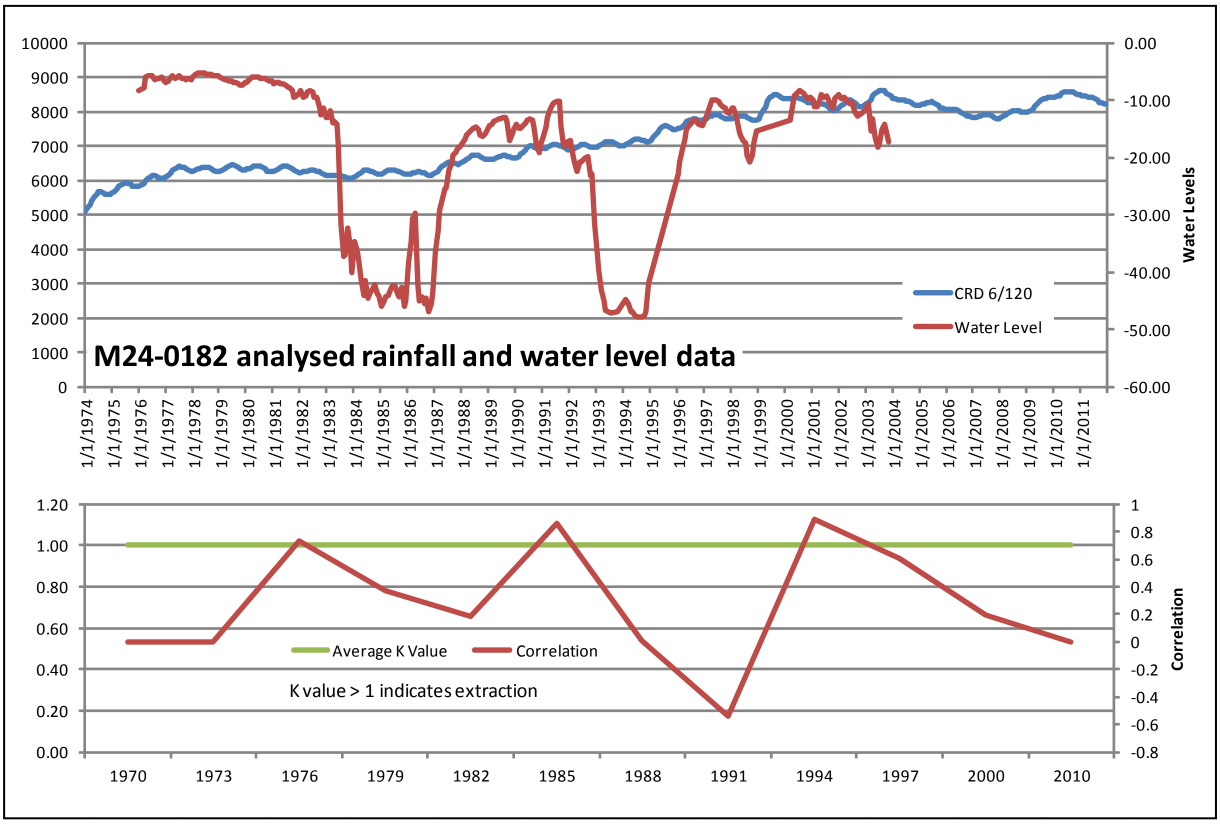


Figure E.2 Analysed rainfall and water level data (M24-0182)

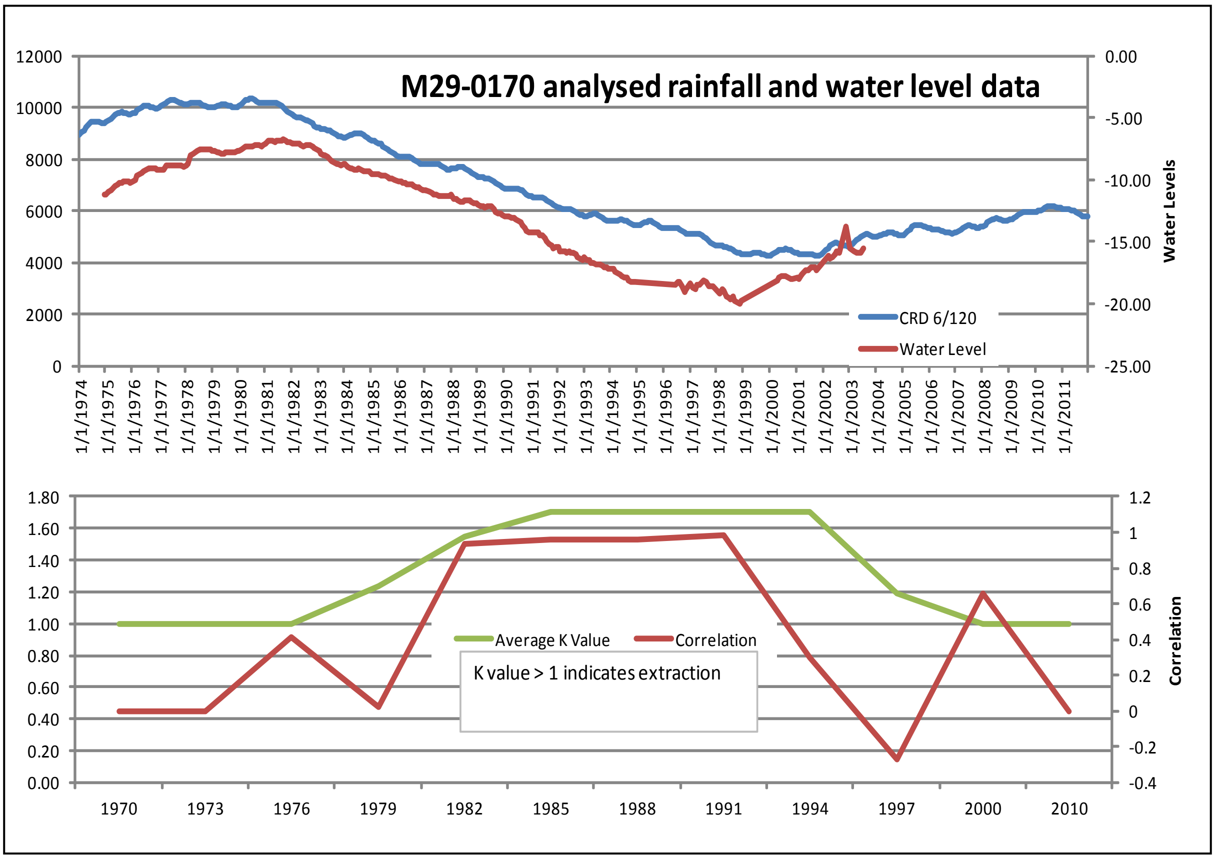


Figure E.3 Analysed rainfall and water level data (M29-0170)

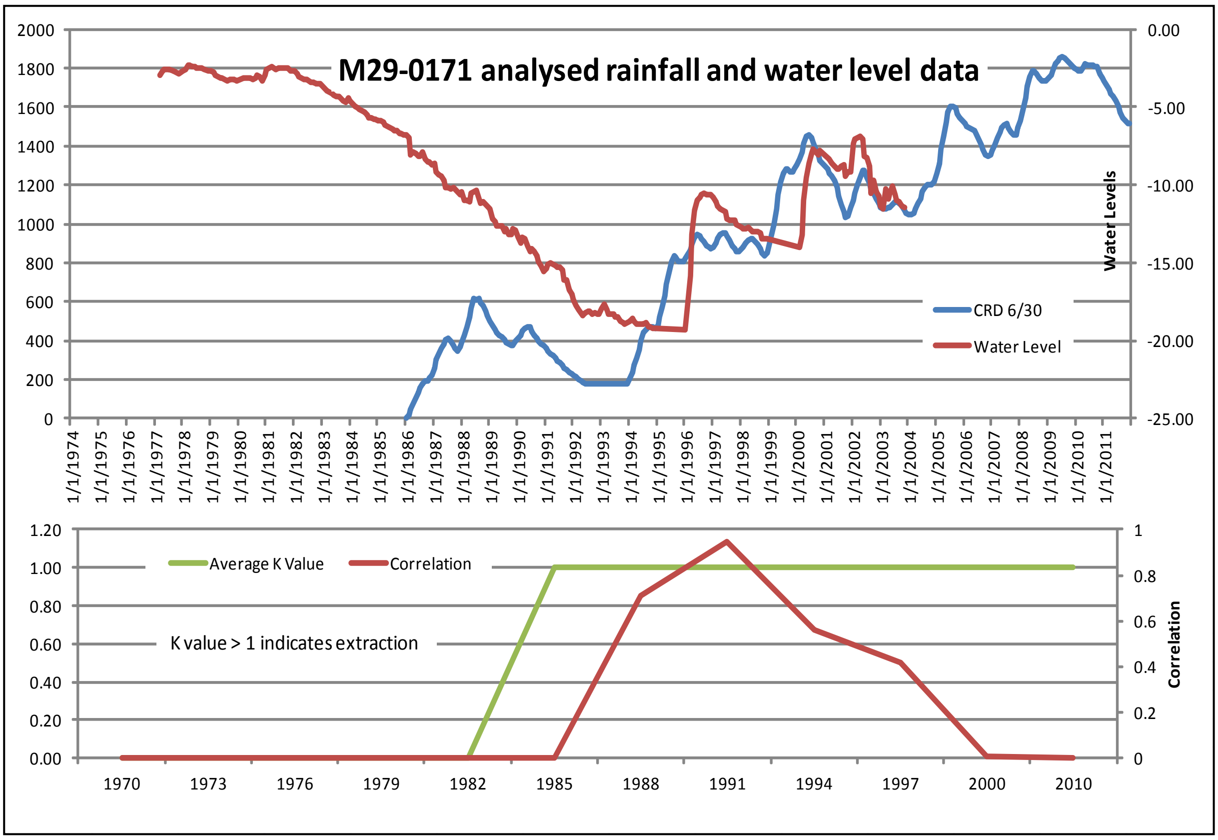


Figure E.4 Analysed rainfall and water level data (M29-0171)

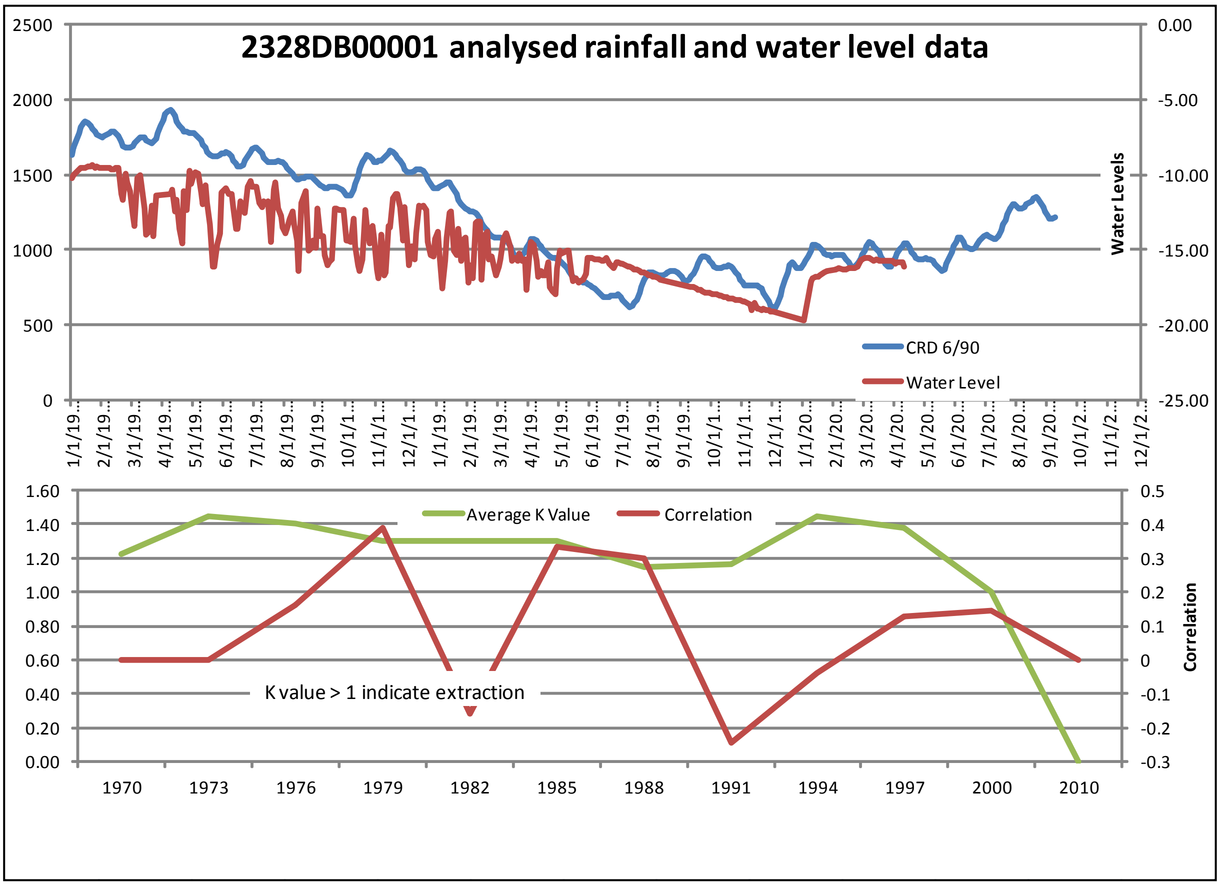


Figure E.5 Analysed rainfall and water level data (2328DB00001)

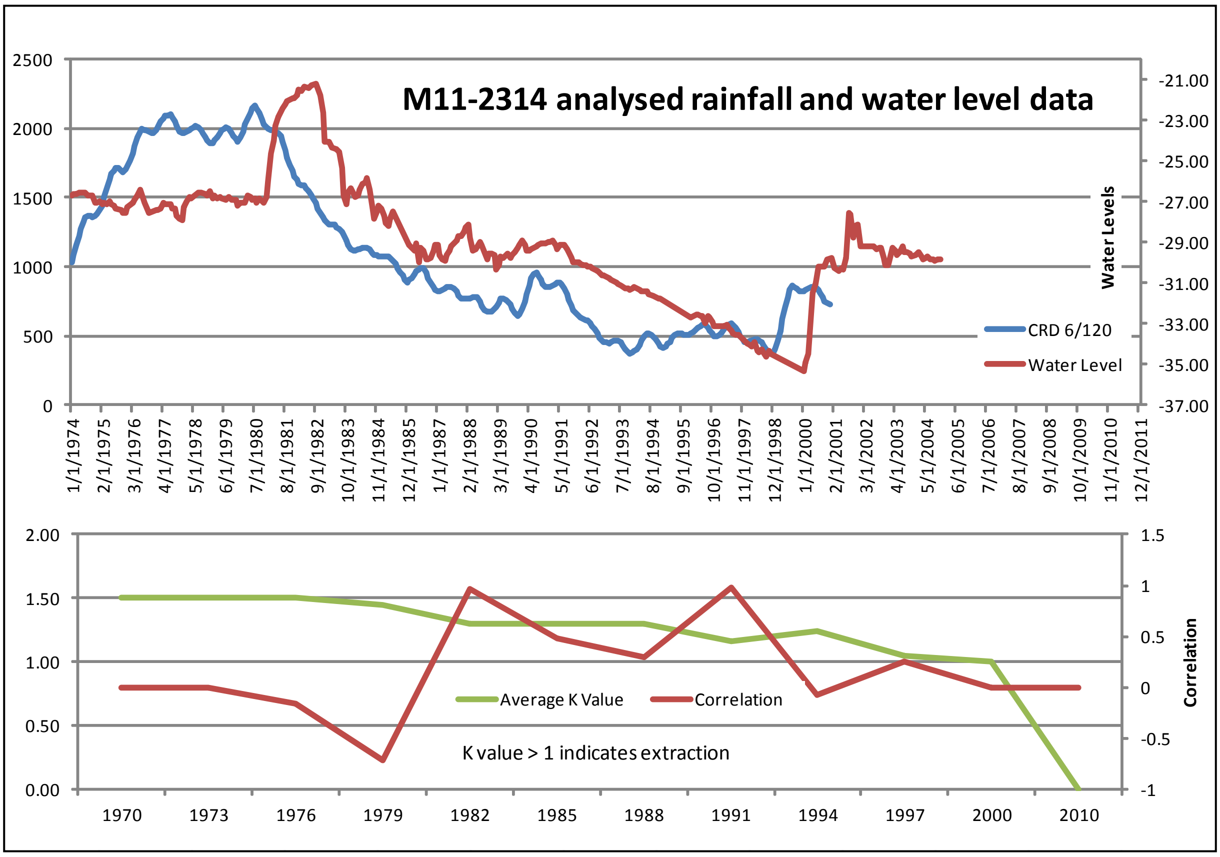


Figure E.6 Analysed rainfall and water level data (M11-2314)

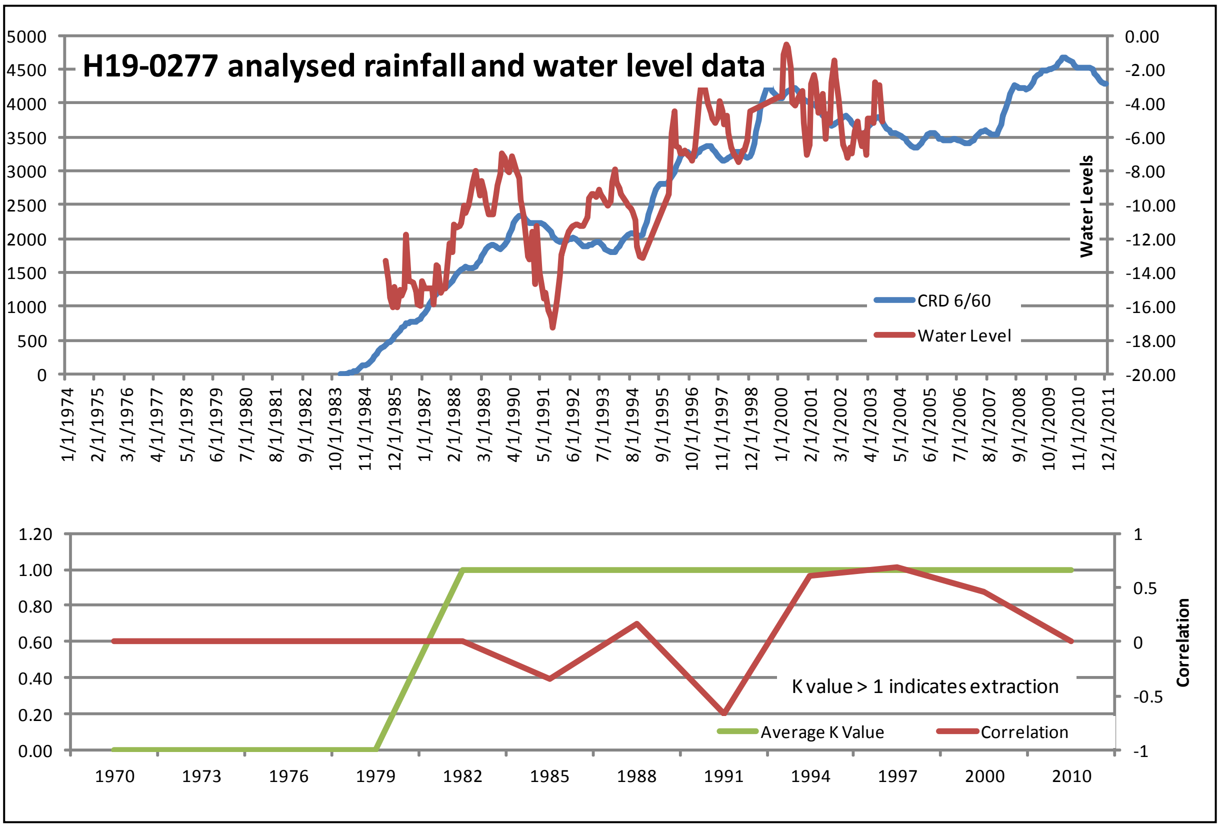


Figure E.7 Analysed rainfall and water level data (H19-0277)

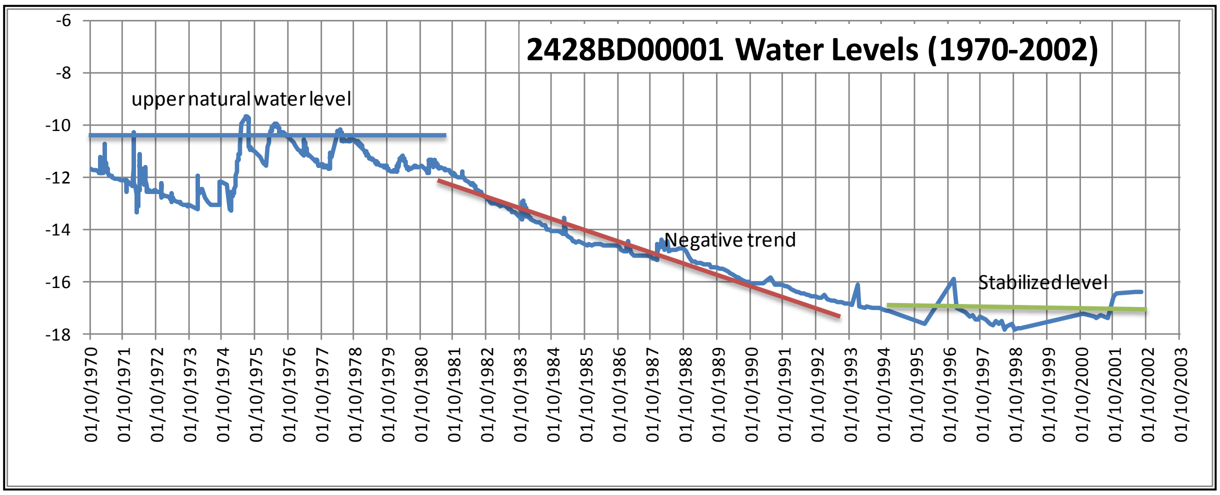


Figure E.8 Water levels 1970 to 2002 (2428BD0001)

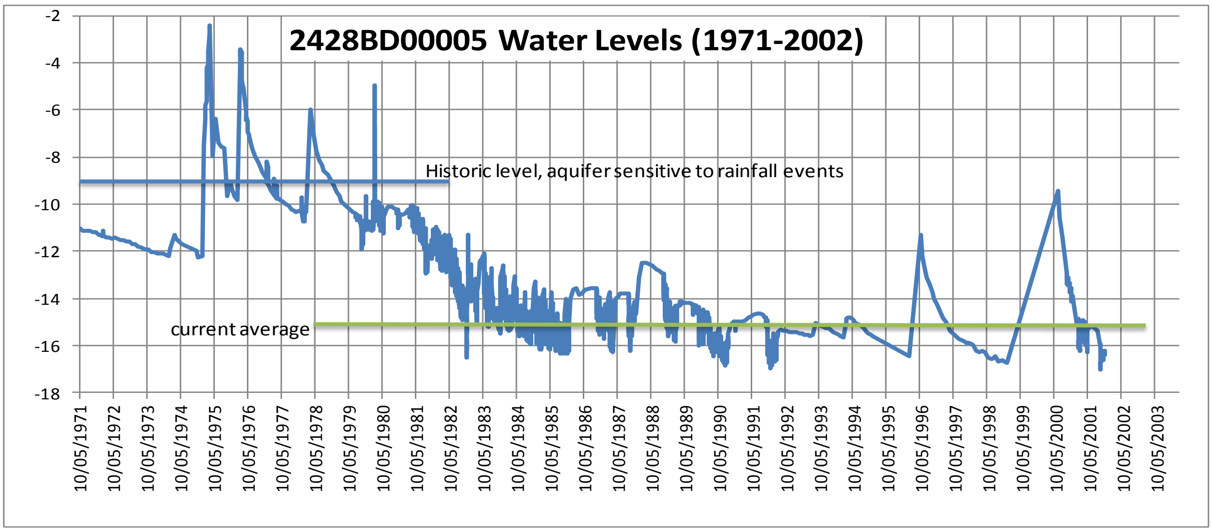


Figure E.9 Water levels 1971 to 2002 (2428BD0005)

Appendix F

Water levels (“Heatmaps”) maps

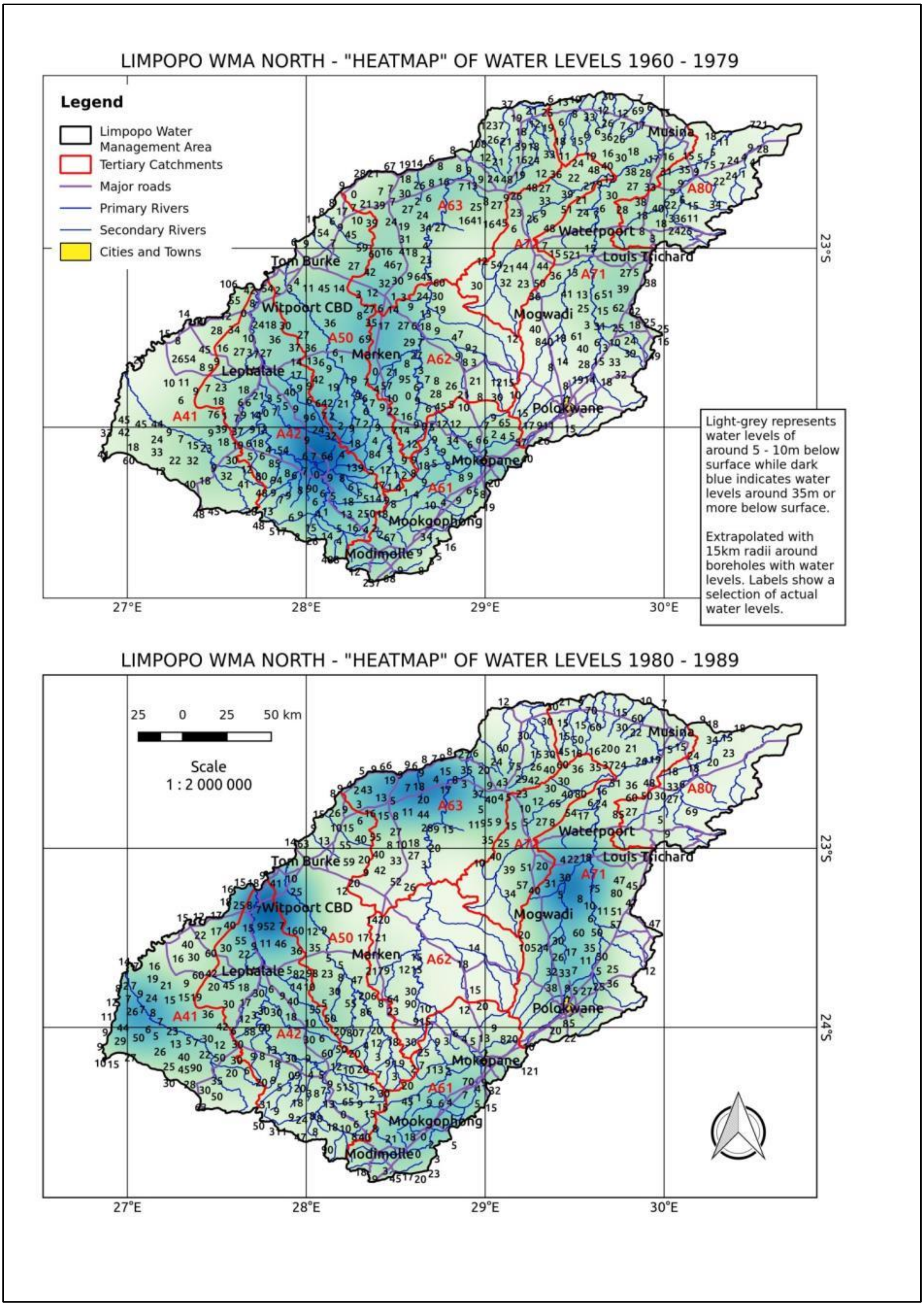


Figure F.1 "Heat map" of water levels 1960 to 1997 and 1980 to 1989

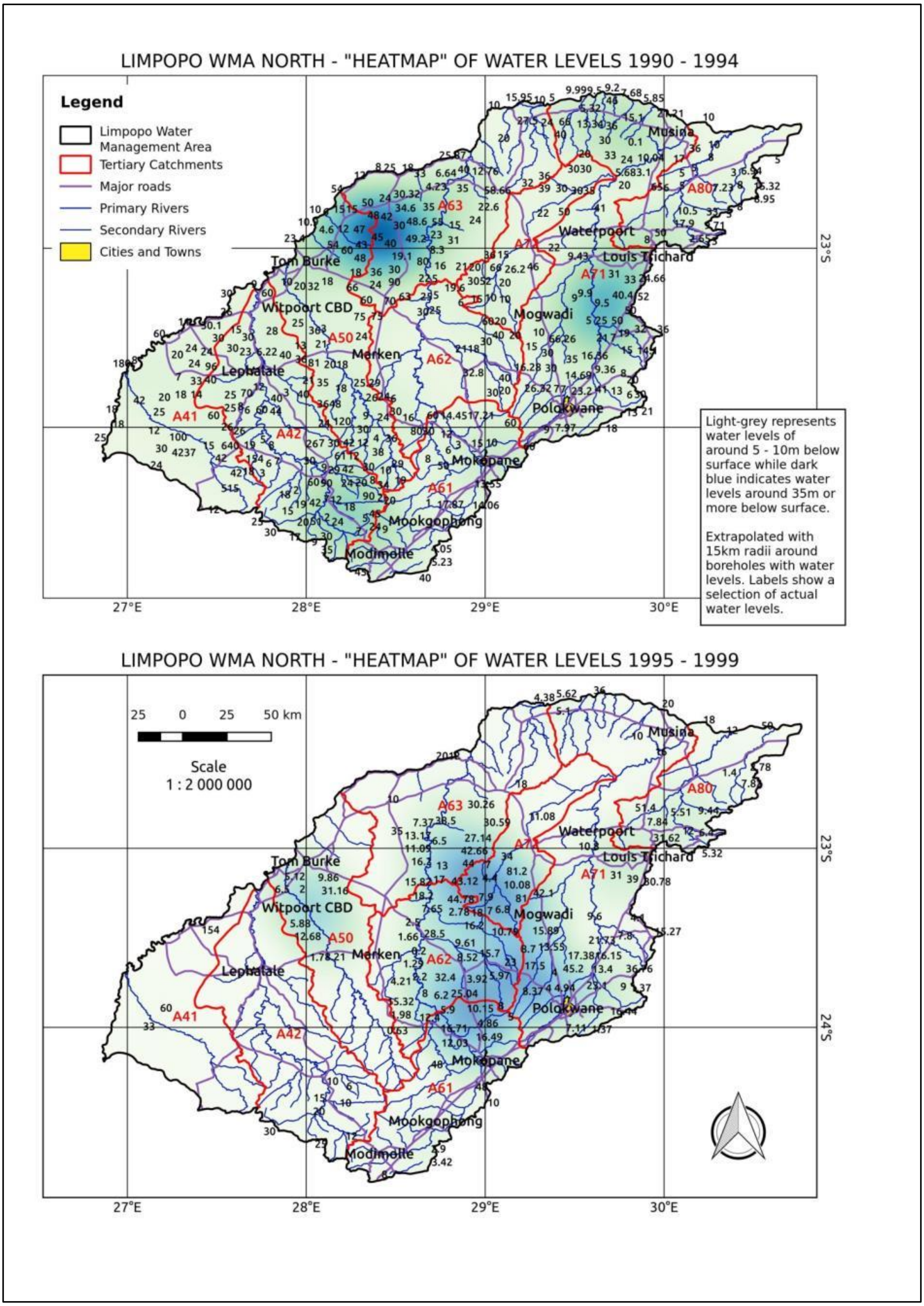


Figure F.2 ‘’Heat map of water levels 1990 to 1994 and 1995 to 1999

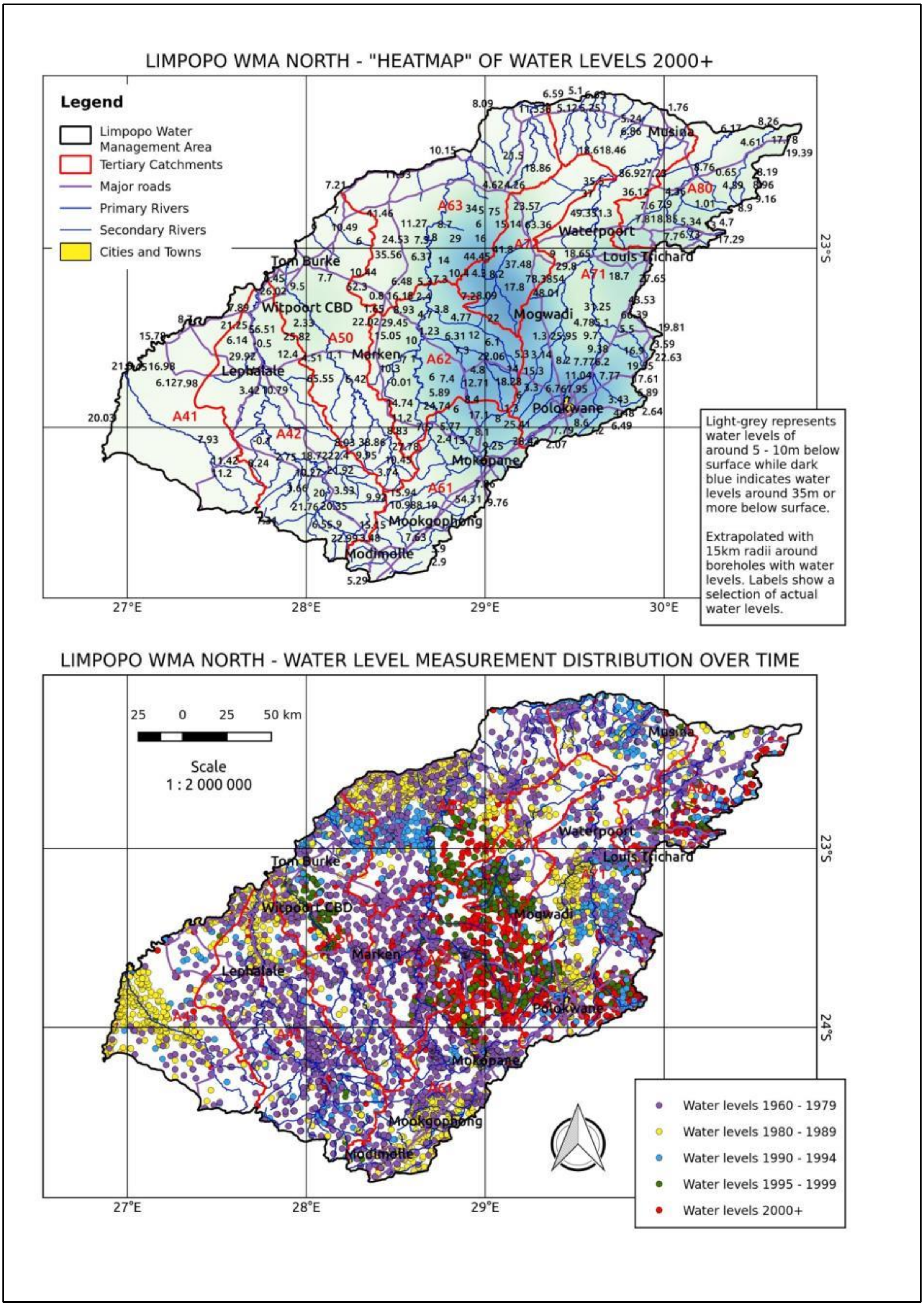


Figure F.3 “Heatmap” > 2000 and the distribution of water levels over time

Appendix G

GRA 2 dataset tables

Table G.1 Quaternary catchment level, quantification of the resource GRA11 data

Quaternary catchment	Catchment area	Average groundwater resource potential		Average groundwater exploitation potential		Natural GW use	Harvest potential		Natural conditions	GRA 11		GRID		
		Normal	Dry	Normal	Dry				MAP	Recharge	Aquifer recharge	Recharge	Aquifer recharge	
	km^2	$10^6\ m^3/a$					mm/a	$10^6\ m^3/a$	mm/a	%	$10^6\ m^3/a$	%	mm/a	$10^6\ m^3/a$
A41A	692	165	159	62	60	1	13	9	625	4	19	1	9	6
A41B	357	98	96	37	36	0	12	4	587	4	9	2	12	4
A41C	1 111	247	242	89	87	0	9	10	512	3	16	0	2	2
A41D	1 911	281	274	94	91	2	8	15	492	2	20	0	2	4
A41E	1 934	185	179	73	71	0	7	13	438	2	15	1	3	5
A42A	573	110	105	41	39	5	15	9	640	4	16	12	74	42
A42B	522	136	131	46	45	4	13	7	660	5	17	8	54	28
A42C	698	175	169	66	63	6	13	9	656	5	22	9	60	42
A42D	497	139	134	52	50	3	12	6	667	6	19	10	68	34
A42E	1 007	274	266	103	100	8	13	13	605	5	30	4	24	25
A42F	1 022	282	276	104	102	3	12	13	577	4	22	6	34	35
A42G	1 206	331	324	111	109	0	10	12	551	4	25	2	10	12
A42H	1 057	272	267	90	89	0	10	10	518	3	16	1	6	7
A42J	1 811	192	188	68	66	0	8	14	428	2	13	1	2	4
A50A	298	82	79	31	30	3	13	4	654	6	11	12	77	23
A50B	406	111	107	42	40	1	13	5	599	5	12	10	61	25

Quaternary catchment	Catchment area	Average groundwater resource potential		Average groundwater exploitation potential		Natural GW use	Harvest potential		Natural conditions	GRA 11		GRID		
A50C	362	99	96	37	36	1	13	5	593	5	10	8	46	17
A50D	637	174	170	65	64	0	13	8	558	4	13	2	8	5
A50E	629	135	132	50	49	0	12	8	517	3	11	1	3	2
A50F	372	74	73	25	24	0	11	4	496	3	5	1	4	1
A50G	821	32	29	11	10	0	7	6	435	3	9	1	3	2
A50H	1 943	58	52	21	19	0	7	13	407	2	15	1	5	9
A50J	1 254	34	31	12	11	1	9	11	391	2	9	1	4	5
A61A	381	105	102	40	38	2	13	5	629	5	12	9	58	22
A61B	362	75	72	28	27	0	17	6	618	5	11	3	21	8
A61C	587	54	49	20	18	2	18	10	608	5	16	2	9	5
A61D	456	15	12	6	5	3	22	10	612	5	12	6	35	16
A61E	547	20	17	8	7	8	19	10	593	3	11	10	62	34
A61F	789	36	30	18	15	12	14	11	597	5	22	5	32	25
A61G	927	41	35	19	17	2	12	11	585	4	21	1	8	8
A61H	585	104	99	39	37	6	20	12	636	5	19	11	69	40
A61J	818	150	144	56	53	8	13	10	631	5	23	8	51	41
A62A	428	112	109	42	41	3	13	5	610	4	11	8	47	20
A62B	710	143	138	53	52	0	13	9	529	4	14	2	10	7

Quaternary catchment	Catchment area	Average groundwater resource potential		Average groundwater exploitation potential		Natural GW use	Harvest potential		Natural conditions	GRA 11		GRID		
A62C	385	100	98	37	37	0	12	5	478	4	6	3	13	5
A62D	603	162	159	61	60	0	14	8	489	3	10	2	12	7
A62E	621	33	30	15	14	1	12	7	460	3	9	1	6	4
A62F	620	34	31	15	13	0	11	7	478	3	9	1	3	2
A62G	627	144	142	50	49	0	9	5	437	3	8	1	3	2
A62H	871	84	81	35	34	0	11	10	439	3	11	1	4	4
A62J	930	161	157	54	53	0	7	6	450	3	12	1	6	6
A63A	1 928	69	63	24	22	1	4	8	433	2	18	1	4	8
A63B	1 505	64	61	22	21	1	10	15	394	2	11	1	4	6
A63C	1 319	50	46	15	14	0	11	15	378	2	8	1	4	6
A63D	1 319	74	69	27	25	1	11	14	412	3	14	2	6	8
A63E	1 989	33	28	11	9	21	6	12	358	2	14	1	3	6
A71A	1 144	53	47	28	25	27	11	12	468	3	16	3	16	18
A71B	882	37	34	17	16	3	10	9	450	2	9	2	8	7
A71C	1 331	55	52	26	25	6	10	13	418	2	10	1	5	6
A71D	892	26	26	14	13	0	8	7	390	1	2	1	2	2
A71E	893	34	32	20	18	10	11	10	421	2	6	2	6	6
A71F	683	24	22	13	12	8	9	6	400	2	4	2	8	5

Quaternary catchment	Catchment area	Average groundwater resource potential		Average groundwater exploitation potential		Natural GW use	Harvest potential		Natural conditions	GRA 11		GRID		
A71G	875	31	29	18	17	10	11	9	427	1	4	1	3	3
A71H	1 012	68	63	35	32	5	10	10	491	3	14	3	12	13
A71J	1 162	43	39	16	15	2	7	8	396	3	12	2	7	8
A71K	1 669	29	25	8	7	1	3	5	305	2	9	1	3	4
A71L	1 761	28	24	9	8	0	3	5	288	2	10	1	3	5
A72A	1 908	143	136	69	66	8	11	21	465	2	19	2	7	14
A72B	1 554	33	30	12	11	1	6	9	344	2	9	1	3	4
A80A	287	39	33	15	13	2	8	2	938	10	27	6	54	16
A80B	251	23	20	8	7	1	8	2	659	7	12	2	11	3
A80C	294	26	22	8	7	0	8	2	576	7	11	7	38	11
A80D	128	10	9	4	3	0	8	1	622	6	5	1	6	1
A80E	247	20	18	8	7	0	8	2	622	6	10	2	11	3
A80F	630	35	32	12	11	0	8	5	388	3	8	1	5	3
A80G	1 228	31	26	10	9	0	4	5	333	3	10	2	6	8
A80H	265	22	19	6	5	0	7	2	621	6	10	4	25	7
A80J	867	18	17	6	6	0	4	3	292	2	4	1	4	3

Table G.2 Water schemes, basic site information

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Aganang East GWS	CAGE/NC3	Capricorn	Aganang	Chloe A, Chloe B, Damplats, Eerste Geluk, Ga-Ngwetsana, Ga-Ramoshwane, Kgabo Park, Preezburg, Ramatlwane, Rampuru, Rapitsi, Ga-Mmabasotho, Ga-Modikana, Ga-Phago, Ga-Piet, Ga-Rankhuwe, Kalkspruit 1, Lehlohlong, Vischkuil, Wachtkraal and Ga-Nonyane	A62E A62H A71E A71F	521.81	7.47	4.95
Aganang LM Farms supply	AgaFS	Capricorn	Aganang	Farms Aganang LM	A62F	0.12	0.00	0.00
Aganang North GWS	CAGN/NC12	Capricorn	Aganang	Ga-Maboth, Ga-Mantlhodi, Ga-Mosehlong, Ga-Motlakgomo, Kanana, Mohlajeng, Ga-Kolopo, Ga-Maribana, Ga-Phagodi, Marowe, Modderput, Sekuruwe 2, Ga-Moropa, Ga-Mankgodi, Ga-Keetse, Ga-Dikgale, Uitkyk and Terbrugge	A62H A71E A72A	360.12	5.09	3.38
Alexandra Scheme	NN1	Vhembe	Makhado	Alexandra	A71H A80D	4.24	0.05	0.04
Alldays BS	CBALL	Capricorn	Blouberg	Alldays	A63D A63E	29.36	0.39	0.25
Archibald GWS	CBARCH/NC12	Capricorn	Blouberg	Archibald, Genua, Letswatla, Borwalathoto, Thorp	A63A A63B	179.43	2.10	0.69
Avon GWS	CBAV	Capricorn	Blouberg	Avon, Bul Bul, Dantzig 2, Ga-Kibi, Indermark, Innnes, Puraspan, Sewale North and The Glade	A63D A72A	209.46	3.00	1.95
Badimong RWS	CPBAD	Capricorn	Polokwane	Badimong, Bergvley, Ga-kole, Ga-Mailula, Ga-Makgoba, Ga-Mamphaka, Ga-Moropo, Ga-Silwane, Katzenstren, Kgatla, Kgwara, Komaneg, Lebowa, Leswane, Masealama, Melkboom, Mongwaneng, Moshate, Thema, Thune, Tsware	A71B	100.61	1.44	0.84
Bakenberg RWS	NW2	Waterberg	Mogalakwena	Bakenberg Basogadi, Bakenberg Kwanaite, Bakenberg Matlaba, Bakenberg Mautjana, Bakenberg Mmotong, Bakenberg Mothwathwase, Basterspad, Bohwidi, Buffelhoek, Claremont, Dikgokgopeng, Diphichi, Galakwenastroom, Ga-Masipa, Good Hope, Harmansdal, Jakkalskuil, Kabeane, Kaditshwene, Kgopeng, Kromkloof, Lesodi, Leyden, Lusaka Ngoru, Mabuladihlare 1,Makekeng, Malapila, Mamatlakala, Marulaneng, Matebeleng, Mphelelo, Nelly, Paulos, Pudiyakgopa, Raadslid, Ramosesane, Rantlakane, Sepharane, Skilpadskraal,Skrikfontein A, Skrikfontein B, Taolome, Van Wykspan, Vlakfontein, Vlakfontein 2, Wydhoek and Good Hope East	A61G A61J A62A A62B A62C A62F	953.50	10.11	9.95

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Bakone GWS	CAGBAK/NC3	Capricorn	Aganang	Bakone, Boratapelo, Dibeng, Ga-Ramakara, Madietane, Manamela 2, Mpone Ntlolane 1, Mpone Ntlolane 3, Nokayamatlala, Ntlolane 2, Phetole, Phofu, Ramalapa 1, Semaneng and Taung.	A62E A62F	370.64	4.63	3.58
Baltimore Supply	CBB0/1	Waterberg	Lephalale	Baltimore	A63A	19.00	0.22	0.07
Bandelierkop Supply	NN0/1	Vhembe	Makhado	Bandelierkop	A71D	4.32	0.06	0.03
Biesjeskraal WS	MOG01	Waterberg	Mogalakwena	Moepelfarm	A62D	6.83	0.07	0.07
Blouberg LM Farms Supply	BlbFS	Capricorn	Blouberg	Farms Blouberg LM	A62J	0.05	0.00	0.00
Blouberg RWS	CBB/NC11	Capricorn	Blouberg	Blouberg, Dantzig 1, Ditatsu, Ga-Mamohwibidu, Ga-Mamolele, Ga-Mmatemana, Ga-Motshemi, Ga-Rammutla 1, Ga-Rammutla 2, Ga-Tefu, Ga-Tshabalala, Matshira, Mophamamana, Pickum 1, Pickum 2, Schroelen, Schroelen 2, Sewale South, Tswatsane	A72A	208.24	3.01	1.94
Botlokwa GWS	CMBOT	Capricorn	Molemole	Ga-Phasha, Makgato, Mangata, Matseke, Mphakane, Ramatjowe, Sekakene, St Brendans Mission School	A71C	210.25	2.90	1.75
Buysdorp Scheme	NN3	Vhembe	Makhado	Buysdorp and Thalani	A71G A72A	85.60	1.33	0.75
Daggakraal WS	MOG02	Waterberg	Mogalakwena	Daggakraal	A50D A62B	3.25	0.03	0.03
Dalmeny Local WS	CBDAL	Capricorn	Blouberg	Dalmeny	A72A	5.63	0.08	0.05
Ga Mokobodi GWS	CAGM/NC3	Capricorn	Aganang	Ga-Lepadima, Ga-Mokobodi, Ga-Phaka, Ga-Ramakadi-Kadi, Goedgevonden, Hwibi, Juno, Moetagare, Schoongelegen, Tibana, Ga-Mabitsela, Ga-Ramotlokana, Leokaneng, Mamehlabe, Pinkie, Rozenkranz and Ngwanallela	A62E A62F A62G A62H	454.61	5.91	4.41
Ga Rawesi GWS	CBGR/NC12	Capricorn	Blouberg	Uitkyk 2, Mesehleng 1, Mesehleng 2, Mokudung, Kgokonyane, Nonono, Setlaole, Ga-Masekwa, Rotlokwa, Ga-Rawesi, Murasie, Ga-Letswalo, Lekiting, Aurora, Ga-Ngwepe and Schoongezicht	A62E A62G A62H A72A	349.00	4.54	3.19

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Ga-Phahladira Cluster	NW5	Waterberg	Mogalakwena	Ga-Phahladira Settlement	A50G	4.45	0.07	0.03
Ga-Seleka RWS	NW115	Waterberg	Lephalale	Botshabelo, Ga – Seleka, Kauletsi, Lebu, Madibaneng, Moong, Monwe, Mothlasedi, Sefithlogo, Tom Burke, and Tshelamfake	A50H	283.88	3.64	1.51
Glen Alpine GWS	CBGA/NC12	Waterberg	Mogalakwena	Mattanau, Breda, Duren, Galakwena, Ga-Tlhako, Khala, Lennes, Monte Christo, Polen, Preezburg, Rebone, Setuphulane, Sodoma, Taueatswala, Thabaleshoba, Tipeng, Uitzicht, Sterkwater	A62D A62G A62H A62J	520.75	4.86	3.79
Gorkum GWS	CBGor/NC11/NC12	Capricorn	Blouberg	Berg-en-Dal, Ga-Mamoleka, Gorkum, Varedig, Sekhung and Morotsi	A63A A63B A72A	313.16	3.67	1.22
Houtrivier RWS	CPH/NP44	Capricorn	Aganang / Polokwane	Koloti, Kamape 1, Komape 2, Komape 3, Mabukelele, Madikote, Mamadila, Moshate, Ramagaphota, Cristiana, Ga-Kgoroshi, Ga-Setshaba, Helena, Kalkspruit, Magongoa, Vlaklaagte and Waschbank	A62E A62H A71E A71F	295.62	4.39	2.83
Laaste Hoop RWS	CPLH	Capricorn	Polokwane	Laaste Hoop Ward 7, Maboi, Manthorwane, Mogoloe, Tsatsaneng	A71B	52.04	0.74	0.43
Lephalale LM Farms Supply	LepFS	Waterberg	Lephalale	Farms Lephalale LM	A62J	0.01	0.00	0.00
Lephalale Urban RWS	LEP01	Waterberg	Lephalale	Lephalale, Marapong, Marapong Squatter	A42F A42G A42H A42J	460.09	4.20	3.81
Luphephe / Nwandedzi North	NN6B	Vhembe	Musina / Mutale	Bale, Bale North, Malale, Mapakoni, Masea, Matshakatini, Matshena, Tshamutumbu Police Station and Tshiungani.	A80J	233.05	2.83	0.76
Luphephe / Nwanedzi Main RWS	NN6A	Vhembe	Musina / Mutale	Folovhodwe, Gumela, Musunda, Muswodi Dipeni, Muswodi Tshisimani, Nwanedzi Nature Resort, Tshikotoni and Tshitanzhe.	A80H A80J	158.25	1.53	0.71
Maasstroom Supply	CBB0/2	Capricorn	Lephalale	Maasstroom	A63C	23.06	0.31	0.22
Mabaleng RWS	MOD03	Waterberg	Modimolle	Mabaleng (Alma) & Mabaleng Squatter Settlements	A42A A42B A42C	82.13	1.02	1.00

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Mabatlane RWS	MOD02	Waterberg	Modimolle	Mabatlane (Vaalwater) & Mabatlane Squatter Settlement	A42C A42E	78.47	0.88	0.88
Makapans Valley Supply	NW0/1	Capricorn	Mogalakwena	Makapans Valley, Makapans Valley Scattered	A61F	13.09	0.17	0.15
Makgalong A & B GWS	CMMAKG	Capricorn	Molemole	Makgalong A and Makgalong B	A71E	18.30	0.30	0.18
Makhado Air Force Base Supply	NN0/2	Vhembe	Makhado	Makhado Air Force Base	A71D A71H	50.09	0.61	0.42
Makhado LM Farms Supply	MkdFS	Vhembe	Makhado	Farms Makhado LM	A63E	0.03	0.00	0.00
Makhado RWSS	NN5	Vhembe	Makhado	Tshikota, Louis Trichardt, Tshikota Squatter	A71H	61.42	0.72	0.53
Mankweng RWSS	CPMAN	Capricorn	Polokwane	Ga-Magowa, Ma-Makanye, Ga-Ramogale, Ga-Thoka, Makgwareng, Mankweng A, Mankweng B, Mankweng C, Mankweng D, Mankweng unit E, Mankweng unit F, Mankweng unit G, Moshate, Tsatsaneng, University of the North	A71B	74.99	1.07	0.62
Mapela RWS	NW3	Waterberg	Mogalakwena	Danisane, Ditlotswane, Ga-Chokoe, Ga-Magongoa, Ga-Mokaba, Ga-Molekana, Ga-Pila Sterkwater, Ga-Tshaba, Hans, Kgobudi, Kwakwalata, Lelaka, Maala Parekisi, Mabuela, Mabusela, Mabusela Sandsloot, Machikiri, Magope, Malokongskop, Masahleng, Masenya, Masoge, Matlou, Matopa, Mesopotania,, Millenium Park, Mmahlogo, Mmalepeteke, Phafola, Ramorulane, Rooiwal, Seema, Sekgoboko Sekuruwe, Skimming, Tshamahansi, Witrivier, Fothane, Mohlotlo Ga-Malebana, Mohlotlo Ga-Puka	A61F A61G A62B A62F A71B	715.98	8.27	7.42
Marken Supply	NW0/2	Capricorn	Mogalakwena	Marken	A62D	18.42	0.19	0.18
Marnitz Supply	LEP0/1	Waterberg	Lephalale	Marnitz	A50H	11.81	0.15	0.06
Matshavhawe / Kunda RWS	NN10	Vhembe	Makhado	Khunda, Matshavhawe, Manyuwa, Piesanghoek	A80A A80B	46.31	0.33	0.33

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Mmaletswai RWS	NW100	Waterberg	Lephalale	Dipompopong, Ditaung, Ga-Maeteletsa, Ga-Mocheko, Hlagalakwena, Keletse le Mma, Kiti, Mmaletswai, Mokuruanyane Abbottspoort, Mokuruanyane Martinique, Mokuruanyane Neckar, Motsweding, Reabetswe	A50G A50H	249.56	3.72	1.41
Modimolle LM Farms Supply	MdmFS	Waterberg	Modimolle	Farms Modimolle LM	A50B	0.03	0.00	0.00
Modimolle Urban RWS	Mod01	Waterberg	Modimolle	Modimolle (previously called Nylstroom), the outlying informal settlement area of Phagameng, the rural areas of Diflymachineng, Kokanja Retirement Village and Resort	A61A A61B	257.45	2.88	2.88
Mogalakwena LM Farms Supply	MogFS	Capricorn	Mogalakwena	Farms Mogalakwena LM	A61E	0.03	0.00	0.00
Mogwadi Wurthsdorp GWS	CMMW01	Capricorn	Molemole	Fatima, Ga-Madikana, Koniggratz, Mogwadi, Mohodi, Wurthsdorp	A61E A71E A71G A72A	180.05	2.77	1.61
Mokopane RWS	NW4	Waterberg	Mogalakwena	Madiba, Madiba East, Mzumbana North, Mzumbana South, Maribashoop/Oorlogsfontein plots, Masodi,	A61E A61F A61G A61H A61J	404.73	5.32	4.78
				Mahwelereng, Maruteng, Masehlaneng, Masodi, Mokopane, Moshate, Mountain View			0.00	0.00
				and Sekgakgapeng			0.00	0.00
Molemole LM Farms Supply	MolFS	Capricorn	Molemole	Molemole farms	A71D	0.03	0.00	0.00
Molemole West Individual GWS	CMMW02	Capricorn	Molemole	Ga-Mollele, Schellenburg A, Schellenburg B, Ga-Broekmane, Ga-Mokwele, Brilliant, Koekoek, Ga-Poopedi, Bouwlust, Brussels, Ga-Mokgehle, Schoonveld 1, Schoonveld 2, Reinland, Ga-Kgare, Ga-Sako, Sakoleng, Overdijk West, Ga-Madikana, Wurthsdorp, Mogwadi, Fatima, Mohodi and Koniggratz	A71G A72A	249.36	3.60	2.32
Moletje East Regional Groundwater SS	CPME/NP110	Capricorn	Polokwane	Chokoe, Ga-Mabotsa, Hlahla, Kobo, Mabitsela, Mabotsa 1, Mabotsa 2, Makibelo, Mashita, Masobohleng, Matikireng, Ramongwane 1, Ramongwane 2, Semenya, Setati	A71A A71E A71F	206.37	3.06	1.67
Moletje North Groundwater SS	CPMN/NPO44	Capricorn	Polokwane	Ditengteng, Kgoroshi (Mphela), Kgoroshi (Thansa), and Mahwibitswane, Manamela	A71E A71F	88.59	1.44	0.85

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Moletje South GWS	CPMS/NC8	Capricorn	Aganang	Boetse, Diana, Ga-Kgasha, Ga-Madiba, Ga-Mangou, Ga-Matlapa, Glen Roy, Jupiter, Mandela Park, Manyapye, Mapateng, Matlaleng, Maune, Mohlonong, Montwane 1, Montwane 2, Moshate, Naledi, Ngopane, Sebora, Sefahlane, Segoahleng, Sepanapudi, Utjane, Chebeng, Doornspruit, Ga-Mapangula, Makweya, Newlands, Pax College, Sengatane, Setotolwane College, Vaalkop 1 and Vaalkop 3 Venus and Waterplaats	A61F A61G A62E A62F A71E A71F	483.19	6.65	4.75
Mookgophong RWS	MOOK01	Waterberg	Mookgopong	Mookgopong (Naboomspruit), Mookgopong Phomolong, Phomolong Squatter Settlement and Rietbokvalley	A61C A61D	114.01	2.56	2.05
Mopane Supply	NN0/3	Vhembe	Musina	Mopane	A71K	7.05	0.09	0.02
Mothapo RWSS	CPMOT	Capricorn	Polokwane	Cottage, Ga-Mothiba, Makotopong 1, Makotopong 2, Nobody-Mothapo, Nobody-Mothiba and Ntshichane	A71B	195.45	2.80	1.63
Musina LM Farms Supply	MusFS	Vhembe	Musina	Farms Musina LM	A71J	0.02	0.00	0.00
Musina RWS	NN2	Vhembe	Musina	Musina (Messina), Harper, Harper Industrial, Lost City (Cambell), Musina Military Base, Nancefield	A71K A71L A80G	129.39	1.75	0.34
Mutale Main RWS	NN12A	Vhembe	Mutale	Dzamba Tshiwisa, Dzata Ruins, Dzumbama, Fefe, Gogogo, Goma, Gundani, Gwagwathini, Ha-Mabila, Helala, Khakhu Thondoni, Luheni, Madatshitshi, Madzororo, Mafhohoni, Mafhohoni, Mafhohoni South, Maname, Mavhode, Mavhuwa, Mazwimba, Mphagane, Mufongodi, Mufulwi, Ngalavhani, Mufulwi, Ngalavhani, Sheshe, Thonoda Lusidzana, Thononda, Tsaanda, Tsaanda 2 Tshiedeulu Thembaluvhilo, Tshiendeulu, Tshilimbane, Tshilovi, Tshitandani, ZTshixwandza and Tshumulungwi.	A80A A80B A80C A80G A80H	377.21	2.82	2.33
Nthabiseng RWS	CMN	Capricorn	Molemole	Capricorn Park, LCHMorebeng, Nthabiseng	A71C	35.79	0.49	0.30
Nzhelele North RWS	NN13	Vhembe	Makhado	Afton, Dolidoli, Garasite, Khomela, Maangani, Makushu, Mangwele, Maranikhwe, Mudimeli, Musekwa, Musekwa Korporasi, Natalie, Ndouvhada, Ngonavhanyai, Pfumembe, Pfumembe Tsha Fhasi, Phembani, Sane, Straighthardt, Tshitwi	A80B A80C A80E A80F A80G A80H A80J	555.14	4.99	3.28

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Nzhelele RWS	NN14	Vhembe	Makhado	Divhani, Domboni, Dopeni, Dzanani, Fondwe, Ha Matsa, Ha-Funyufunyu, Ha-Makatu, Ha-Mandiwana Dzanani, Ha-Manngo, Ha-Maphaha, Ha-Mapila, Ha-Matidza, Ha-Matshareni, Ha-Mphaila, Ha-Rabali, Khalavha, Lutomboni, Luvhalani, Magoloni, Makanga, Makhavhani, Makungwi, Malamba, Mamuhohi, Mamuhoyi, Mamvuka, Maname Paradise, Mandala A, Mandala B, Mandala Tshantha, Manyii, Manyuwa, Mapakophele, Matanda Zone 2, Matsa, Matsa A, Matsa B, Matserere, Mauluma, Mavhunga, Mbadoni, Mudunungu, Musanda Thondoni, Mutavhani, Posaito, Raliphaswa, Ramavhoya, Shanzha, Siloam, Siyawoadza, Thembaluvhilo, Thondoni, Tshatharu, Tshavhalovhedzi, Tshiheni, Tshikhalani, Tshikhalani East, Tshikhudo, Tshikuwi, Tshirolwe Ext 2, Tshirolwe Ext1, Tshisinisa, Tshiswenda, Tshitasini, Tshithuni Tshafhasi, Tshithuthuni, Tshituni, Tshituni B, Tshituni Tshantha, Tshivhambe, Tshivhilidulu, Vhutuwangazebu	A80A A80B A80E A80F	453.03	3.25	3.22
Olifants-Sand RWSS	CPOS	Capricorn	Polokwane	Bloedrivier, Bergnek Greenside, Kgohlwane, Mabotsa, Makgove, Mokgokong, Pietersburg, Seshego, Sepanapudi, Toska, Mashinini, Seshego, Toska Mashinini, Zone 6, Perskebult Ext 1&2, Polokwane, Montinti Park, Dalmada S/H, Doornbult S/H, Elmadal S/H, Geluk S/H, Ivydale, Mooifontein S/H, Myngenoeg S/H, Palmietfontein S/H A, B &C, Tweefontein S/H, Roodepoort S/H, Polokwane SDA3	A71A A71B A71F	756.15	11.13	6.65
Ramakgopa GWS	CMR	Capricorn	Molemole	Eisleben, Mokganya, Ramakgopa	A71C	155.85	2.15	1.30
Rebone RWS	NW1	Waterberg	Mogalakwena	Bavaria, Breda, Blinkwater, Chipana, Dipere, Duren, Ga-Chere, Galakwena, Galelia, Ga-Monare, Ga-Mushi, Ga-	A62C A62D A62F A62E A62G A62H	740.69	7.91	6.83
				Nong, Ga – Tlkako, Grasvlei, Ham 1, Hlogoyanku, Khala, Lekhureng, Lennes, Makobe, Mathekga, Matjitjileng, Mattanau, Monte Christo, Polen, Preezburg, Moshuka,			0.00	0.00
				Nkidikitlana, Rebone, Rapadi, Segole 1, Segole 2, Seirappes, Senita, Setophulane, Sodoma, Sterkwater, Taueatswala, Tennerif, Thabaleshoba, Tiberius, Tipeng, Uitzicht,			0.00	0.00
				Vergenoeg and Vianna			0.00	0.00

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Rietbokvalley Supply	MOOK0/4	Waterberg	Mookgopong	Rietbokvalley	A50A A50B	16.10	0.17	0.17
Rietgat GWS	CMRIET	Capricorn	Molemole	Rietgat (ZZ2)	A71C	6.79	0.09	0.06
Sebayeng-Dikgale RWSS	CPS/D	Capricorn	Polokwane	Dibibe, Dikgale 1, Dikgale 2, Dikgale 3, Ga-Kololo, Ga-Maphoto, Ga-Mawashasha, Ga-Mokgopo, Ga-Moswedi, Ga-Motholo, Kgokong, Kgwareng, Lenyenye, Madiga, Makengkeng, Makgoba 1, Makgoba 2, Makgwareng, Mamotintane, Mantheding, Masekho, Masekoleng, Masekwatse, Maelaphaleng, Mehlakong, Mnashemong, Moduwane, Mphalong, Sebayeng A, Sebayeng B, Sentserere, Toronto Zondo		288.77	4.09	2.40
Segwasi RWSS	CPSEG	Capricorn	Polokwane	Jack and Mohlakeng	A71B	10.59	0.15	0.09
Sentrum RWS	THB0/8	Waterberg	Thabazimbi	Sentrum	A41D	28.52	0.27	0.19
Senwabarwana GWS	CBS/NC11	Capricorn	Blouberg	Bochem, Bochem North, Bochum, Borkum, Cumbrae (Senwabarwana), Ga-Mashalane and Witten	A72A	75.06	1.08	0.70
Setuteng RWS	NW116	Waterberg	Lephalale	Bangalong, Ga-Monyeki, Matladi, Setateng, Steve Bhiko	A50G	67.99	1.14	0.41
Silwermyn / Kirstenspruit GWS	CBS/K/NC12	Capricorn	Blouberg	Driekoppies, Silwermyn, De Villiersdale 1, De Villiersdale 2, Swarts, Non-Parella, Mons, De Villiersdale, Thabanantlhana, De La Roche, Kirstenspruit, Grootdraai, Vergelegen, Ga-Mankgodi, Papegaai, Sebotlana, Madibeng, Ga-Ntshireletsa and Nieuwe Jerusalem	A62H A62J A63A A72A	624.97	6.26	3.94
Sinthumule/Kutama RWSS	NN16	Vhembe	Makhado	Diiteleni, Midorini, Tshikhodobo, Dzumbathoho, Zamenkom, Tshikwarani B, Makhita, Tshikwarane, Raphalu, Ha-Manavhela, Muduluni, Muraleni Block B, Muraleni Block C, Ha-Madonga, Ravele, Ha Mamburu, Gogobole, Tshiozwi, Ha-Ramahantsha, Ramakhuba, Madombidzha Zone 1, Madombidzha Zone 2, Madombidzha Zone 3, Rathidili, Ha-Magau, Mutavhani, Raliphaswa, Siyawoodza, Moebani and Mutayhani	A71D A71G A71H	323.83	3.83	2.78

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Taaiboschgroet	CBT/NN17	Capricorn	Blouberg	Simpson, Grootpan, Sais, Slaaphoek, Donkerhoek, Voorhout, Royston, Juniorsloop, Berseba, Wegdraai, Ga-Raphokola, Gideon, Thlonasedimong, Eldorado, Fonteine Du Champ, Esaurinca, Louisenthaal, The Grange, Longden, Taaiboschgroet, De Vrede, Kromhoek, Pax, Johannesburg, Lovely, Burgerregt, Edwinsdale, The Glen and Glenferness	A63A A63B A63D A72A	1035.33	13.83	9.19
Thalahane GWS	CBTHA/NC11	Capricorn	Blouberg	Kgatalala, Buffelshoek and Thalahane	A63A A63B A63D A72A	91.27	1.28	0.83
Tom Burke Supply	LEP0/2	Waterberg	Lephalale	Tom Burke	A50H	16.43	0.21	0.09
Tshifire Murunwa RWS	NN18	Vhembe	Makhado	Dzumbathoho, Phadzima, Mazhazhani, Mazuwa, Gudumabama, Maelula, Vuvha, Matakani, Mazhazhani, Mazuwa, Murunwa, Tshedza Tshihalwe, Tshifudi B, Tshifudi A, Tshidzini Tshifudi, Tshidzini, Phaswana, Mutshetshe, Mushiru, Mushiro Mahagala, Musenga, Mubvumoni South, Mubvomoni North, Masiwane, Manzemba, Lukalo, Ha-Lambani Tshantha, Tshitavha, Begwa, Buluni, Dimani	A80A	86.32	0.62	0.62
Tshipise Resort Supply	NN0/7	Vhembe	Musina	Tshipise Reserve	A80G	9.23	0.11	0.03
Uitspan Supply	NWO/3	Waterberg	Mogalakwena	Uitspan	A62D	8.05	0.09	0.08
Vivo Supply	CAGV	Capricorn	Makhado	Vivo	A72A	15.58	0.23	0.15
Waterpoort Supply	NN0/6	Vhembe	Mokado	Waterpoort	A71H A71J	6.63	0.08	0.04
Weenen Supply	NWO/4	Waterberg	Mogalakwena	Weenen	A61F	4.26	0.05	0.05
Witpoort RWS	NW114	Waterberg	Lephalale	Botsalanong, Kgobagodimo, Kopanong, Lerupurupurung, Letlora, Mongalo, Segale, Senoela, Thabo Mbeki, Tlapa le Borethe and the Witpoort CBD	A50H	205.69	2.63	1.09
Zwartwater Supply	CBB0/3	Waterberg	Lephalale	Zwartwater	A50J	19.46	0.26	0.17

Scheme name	Number	District	Local municipality	Villages	Quaternary catchment	Area	Harvest potential	Exploit-ability
						(km²)	(10^6 m^3/a)	
Ga-Hlako RWS	CBGH/NC12	Capricorn	Blouberg	Bodie, Brodie Hill, Dithabaneng, Ga-Hlako, Ga-Mabeba, Ga-Maboth, Gamakgwata, Ga-Malokela, Ga-Mampote, Ga-Maselela, Ga-Mokopane, Kobe, Kutumpa, Kwaring, Manye, Manye extension, Miltonduff 1, Mokumuru, Mongalo, Sesalong, Udney 1, Werden	A72A A63A	316.14	4.56	2.94

Appendix H

Recharge, harvest potential and exploitation potential maps

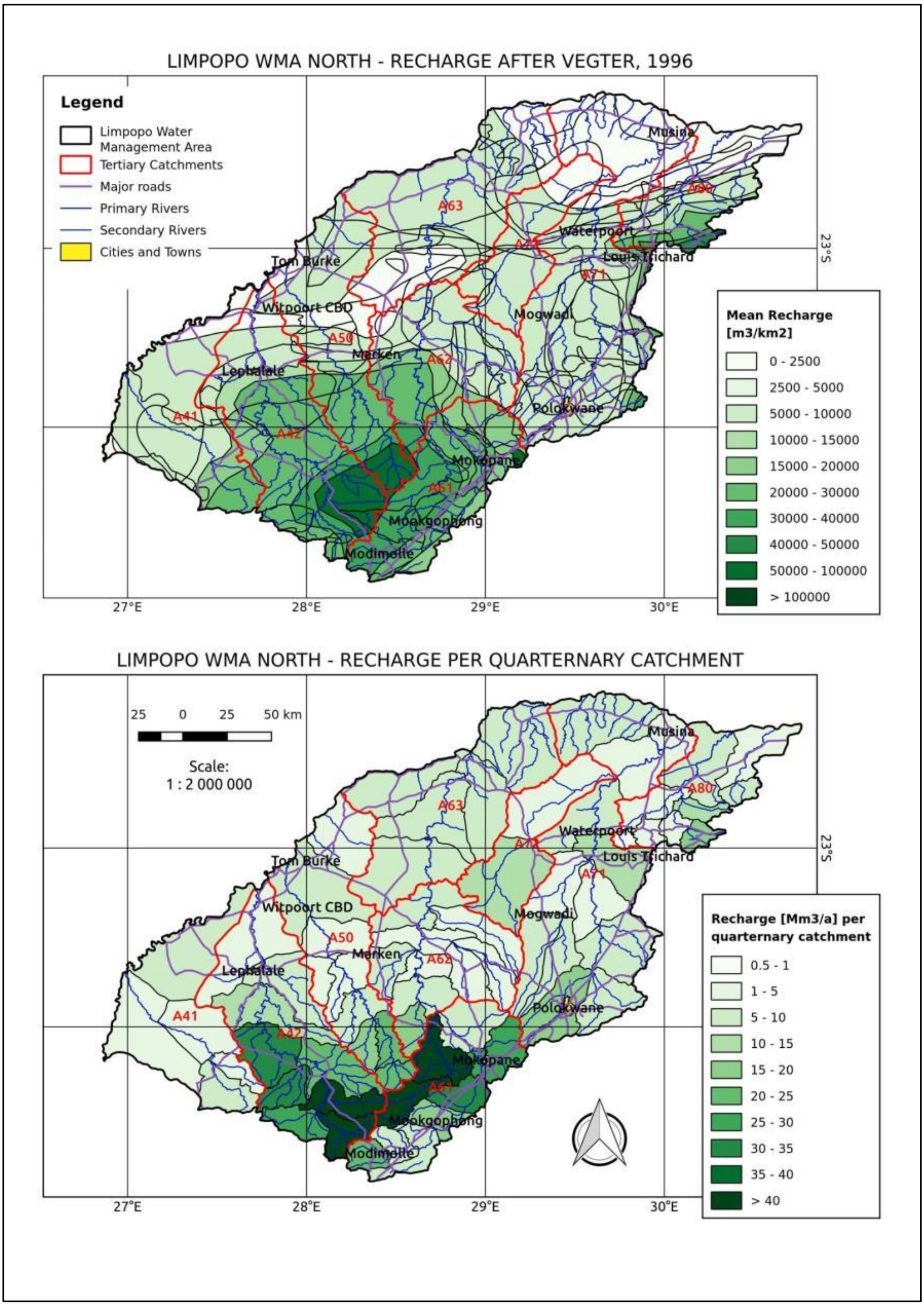


Figure H.1 Recharge after Vegter 1996 m³/km²/a and recharge volume/quaternary catchment

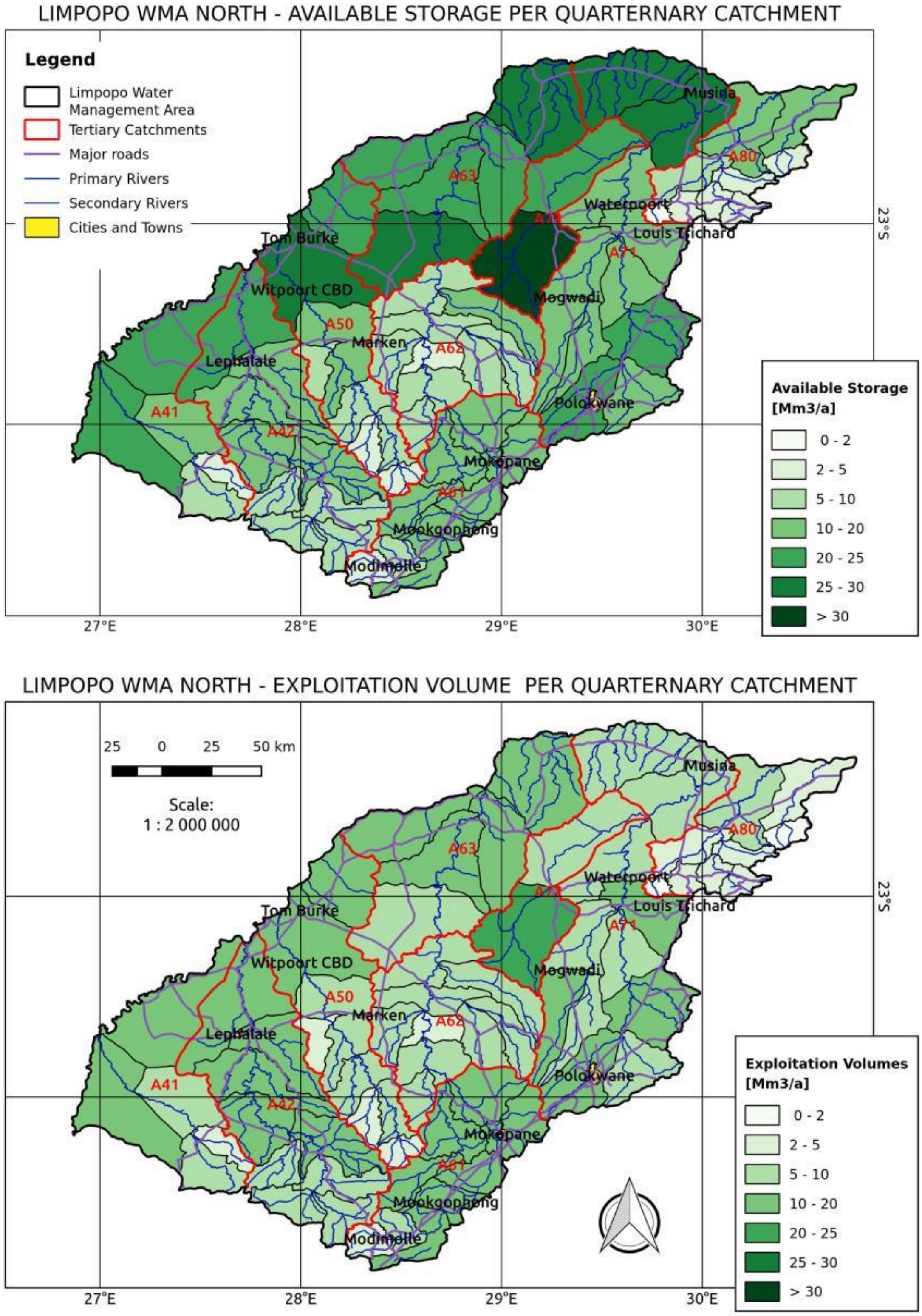


Figure H.2 Available storage and exploitation volume per quaternary catchmen

Appendix I

Intervention potential and cost estimates

Table I.1 Evaluation per scheme, maximum development potential and current developed volume, proposed intervention

Domestic water schemes	Area (km²)	Exploitation potential for 2010 population (ℓ/c/d)	Exploitation potential for 2040 population (ℓ/c/d)	Current equipped sources 70% effective & surface sources (ℓ/c/d) 2010 population	Not equipped but tested (>50 m³/d) 70% effective (ℓ/c/d) 2010 population	Total tested volume (ℓ/c/d) 2010 population	Current equipped sources 70% effective & surface sources (ℓ/c/d) 2040 population	Not equipped but tested (>50 m³/d) 70% effective (ℓ/c/d) 2040 population	Total tested volume (ℓ/c/d) 2040 population	Estimated sources (ℓ/c/d)	Water source	Total tested count all borehole	Total pumped volume (m³/day) bh less than 25m³/d	Not equipped not tested	To be tested already motorized	Intervention, comments
Aganang East GWS	521.81	392	327	65	96	162	54	81	135		GW	55	66.96	71	8	Test, equip, maintain, develop
Aganang LM Farms supply	0.116	5	10	?	?	?	?	?	?	100	GW					Farms
Aganang North GWS	360.123	418	564	108	70	178	146	94	240		GW	38	23.76	33	10	Test, equip, maintain, develop
Alexandra Scheme	4.244	485	480	?	?	?	?	?	?	100	GW					No information
Allays BS	29.363	180	102	37	80	117	21	46	66		GW	7	0	3	2	Test, equip, maintain, develop
Archibald GWS	179.431	280	147	370	153	523	194	80	274		GW	15	43.2	17	1	Over developed, maintain
Avon GWS	209.46	171	165	51	68	119	49	66	115		GW	37	31.82	31	8	Test, equip, maintain, develop
Bakenberg RWS	953.495	427	432	22	44	65	22	44	66		GW	62	179.85	123	18	Test, equip, maintain, develop
Bakone GWS	370.644	287	330	57	60	117	65	69	135		GW	39	28.37	63	12	Test, equip, maintain, develop
Baltimore Supply	18.999	2985	3397	?	?	?	?	?	?	100	GW					No information
Bandelierkop Supply	4.321	1014	1068	?	?	?	?	?	?	100	GW	1	17.28	0	0	Low yielding bh's, develop
Biesjeskraal WS	6.827	755	604	?	?	?	?	?	?	80	GW	1	0	0	0	Low yielding bh's, develop
Blouberg LM Farms Supply	0.054	0	0	?	?	?	?	?	?	90	GW					Farms
Blouberg RWS	208.237	230	122	111	79	190	59	42	101		GW	43	29.38	94	4	Test, equip and maintain
Botlokwa GWS	210.251	106	106	24	78	102	24	79	103		GW	38	21.6	106	14	Test, equip and maintain
Buysdorp Scheme	85.596	1366	1429	?	?	?	?	?	?	80	GW	0	0	2	1	Test, equip and maintain
Daggakraal WS	3.245	1128	911	?	?	?	?	?	?	80	GW					No information
Dalmeny Local WS	5.633	3598	3912	?	?	?	?	?	?	100	GW					No information
Ga Mokobodi GWS	454.609	344	301	74	51	125	65	45	109		GW	42	76.46	53	25	Test, equip, maintain
Ga Rawesi GWS	349	889	1343	30	258	288	45	390	435		GW	35	3.46	30	2	Test, equip, maintain
Ga-Phahladira Cluster	4.45	44	43	?	?	?	?	?	?	50	GW	0	0	1	1	Test, maintain
Ga-Seleka RWS	283.88	211	15	137	54	191	10	4	14		GW	36	99.36	19		Test, equip, maintain, develop
Ga Hlako RWS	316.143	287	270	0	77.7	77.7	0	73.2	73.2		GW	37	0	111	5	Test, equip, maintain, develop
Glen Alpine GWS	520.747	394	289	48	54	102	35	40	75		GW	41	130.03	43	15	Test, equip, maintain, develop
Gorkum GWS	313.164	309	209	44	340	385	30	230	260		GW	34	54.43	48	1	Test, equip and maintain

Domestic water schemes	Area (km²)	Exploitation potential for 2010 population (ℓ/c/d)	Exploitation potential for 2040 population (ℓ/c/d)	Current equipped sources 70% effective & surface sources (ℓ/c/d) 2010 population	Not equipped but tested (>50 m³/d) 70% effective (ℓ/c/d) 2010 population	Total tested volume (ℓ/c/d) 2010 population	Current equipped sources 70% effective & surface sources (ℓ/c/d) 2040 population	Not equipped but tested (>50 m³/d) 70% effective (ℓ/c/d) 2040 population	Total tested volume (ℓ/c/d) 2040 population	Estimated sources (ℓ/c/d)	Water source	Total tested count all borehole	Total pumped volume (m³/day) bh less than 25m³/d	Not equipped not tested	To be tested already motorized	Intervention, comments
Lephalale LM Farms Supply	0.014	0	0	?	?	?	?	?	?	100	GW					Farms
Luphephe / Nwandedzi North	233.047	165	259	32	93	125	50	147	197		GW	27	0	11	1	Test, equip, maintain, develop
Luphephe / Nwanedzi Main RWS	158.253	177	185	60	53	112	62	55	117		GW	11	8.64	5	0	Test, equip, maintain, develop
Maasstroom Supply	23.056	13045	12976	?	?	?	?	?	?	100	GW					No information
Mabaleng RWS	82.127	1090	1748	?	117	117	0	187	187		GW	6	0	6	0	Test, equip, maintain, develop
Mabatlane RWS	78.465	146	81	18	45	62	10	25	35		GW	12	19.73	0	0	Test, equip, maintain, develop
Makapans Valley Supply	13.094	740	615	bulk							GW	2	0	2	1	Bulk supply monitor
Makgalong A & B GWS	18.304	950	1031	439	130	569	476	142	618		GW	3	0	5	0	Test, equip, maintain, develop
Makhado Air Force Base Supply	50.094	983	1029	?	?	?	?	?	?	100	GW					Air force base
Makhado LM Farms Supply	0.026	0	0	?	?	?	?	?	?	100	GW					Farms
Mapela RWS	715.983	228	175	58	47	106	45	36	81		GW	99	123.41	82	29	Test, equip, maintain, develop
Marken Supply	18.416	1608	1288	?	?	?	?	?	?	80	GW	0	0	2	0	Test, equip, maintain, develop
Marnitz Supply	11.812	929	834	?	?	?	?	?	?	100	GW					No information
Matshavhawe / Kunda RWS	46.31	372	377	27	45	72	28	45	73		GW	2	21.6	0	0	Test, equip, maintain, develop
Mmaletswai RWS	249.56	250	217	178	75	253	154	65	219		GW	40	39.6	38	16	Test, equip, maintain,
Modimolle LM Farms Supply	0.026	0	0	?	?	?	?	?	?	100	GW					Farms
Mogalakwena LM Farms Supply	0.027	0	0	?	?	?	?	?	?	100	GW					Farms
Mogwadi Wurthsdorp GWS	180.047	155	157	160.3	54	214.2	162.3	54.6	217		GW	58	37.15	41	6	Over developed, maintain
Molemolle LM Farms Supply	0.025	0	0	?	?	?	?	?	?	100	GW					Farms
Molemolle West Individual GWS	249.364	646	156	430	664	1094	104	160	264		GW	50	1.44	55	5	Over developed, maintain
Moletje East Regional GW SS	206.367	110	138	30	73	103	38	92	129		GW	27	53.65	47	6	Test, equip and maintain
Moletje North Individual GW SS	88.585	300	183	92	48	140	57	29	86		GW	12	17.28	21	1	Test, equip, maintain, develop
Moletje South GWS	483.187	246	293	38	89	127	45	105	151		GW	65	107.57	110	17	Test, equip, maintain, develop
Mopane Supply	7.049	247	224	?	?	?	?	?	?	80	GW	0	0	1	2	Test, equip, maintain, develop
Musina LM Farms Supply	0.024	0	0	?	?	?	?	?	?	100	GW					Farms
Mutale Main RWS	377.209	349	367	64	14	78	67	14	81		GW	15	18.14	24	5	Test, equip, maintain, develop

Domestic water schemes	Area (km^2)	Exploitation potential for 2010 population (ℓ/c/d)	Exploitation potential for 2040 population (ℓ/c/d)	Current equipped sources 70% effective & surface sources (ℓ/c/d) 2010 population	Not equipped but tested (>50 m^3/d) 70% effective (ℓ/c/d) 2010 population	Total tested volume (ℓ/c/d) 2010 population	Current equipped sources 70% effective & surface sources (ℓ/c/d) 2040 population	Not equipped but tested (>50 m^3/d) 70% effective (ℓ/c/d) 2040 population	Total tested volume (ℓ/c/d) 2040 population	Estimated sources (ℓ/c/d)	Water source	Total tested count all borehole	Total pumped volume (m^3/day) bh less than 25m^3/d	Not equipped not tested	To be tested already motorized	Intervention, comments
Nthabiseng RWS	35.79	126	139	122	154	277	134	169	304		GW	16	17.28	10	8	Test, equip and maintain
Ramakgopa GWS	155.845	133	139	0	71	71	0	74	74	80	GW	22	52.7	15	5	Test, equip, maintain, develop
Rebone RWS	740.686	466	356	49	64	113	37	49	87		GW	54	168.41	52	13	Test, equip, maintain, develop
Rietbokvalley Supply	16.1	3039	2249	?	?	?	?	?	?	80	GW					No information
Rietgat GWS	6.791	564	618	?	?	?	?	?	?	80	GW					No information
Sentrum RWS	28.516	4861	4336	?	?	?	?	?	?	60	GW	0	0	0	1	Obtain info, test
Senwabarwana GWS	75.056	92	63	105	91	196	71	62	133		GW	22	11.52	10	10	Test, equip and maintain, overdeveloped
Setuteng RWS	67.99	72	61	18	30	49	15	25	41		GW	10	89.85	28	20	Test, equip, maintain, develop
Silwermyn / Kirstenspruit GWS	624.966	685	558	23	51	74	19	41	60		GW	20	100.79	58	5	Test, equip, maintain, develop
Thalahane GWS	91.268	750	343	?	0	0	0	0	0	200	GW	1	1.4	10	0	Test, equip, maintain, develop
Tom Burke Supply	16.429	1055	953	?	0	0	0	0	0	100	GW	0	0	0	0	Test, equip, maintain, develop
Tshipise Resort Supply	9.234	2374	2259	?	?	?	?	?	?	100	GW	0	0	1	1	Resort
Uitspan Supply	8.053	232	175	?	?	?	?	?	?	100	GW	0	6.91	2	0	Farms
Vivo Supply	15.577	5617	6431	?	?	?	?	?	?	100	GW					No information
Waterpoort Supply	6.627	928	996	?	?	?	?	?	?	100	GW	1	25			Limited information
Weenen Supply	4.264	661	537	bulk						bulk	GW					Bulk supply monitor
Witpoort RWS	205.693	225	197	75	21	96	65	18	83		GW	18	139.1	36	17	Test, equip, maintain, develop
Zwartwater Supply	19.46	3081	3565	?	?	?	?	?	?	100	GW					No information
Houtrivier RWS	295.615	211	556	78	36	115	135	96	231		GW+SW	31	17.28	45	9	Test, equip, maintain, develop
Laaste Hoop RWS	52.041	163	146	31	0	31	30	0	30		GW+SW	1	0	15	2	Test, equip, maintain, develop
Lephalale Urban RWS	460.094	381	285	1721	113	1833	1721	84	1805		GW+SW	12	0	6	1	Test, equip, maintain, develop
Makhado RWSS	61.42	77	60	475	0	475	472	0	472		GW+SW	4	4.32	5	15	Test, equip and maintain
Mankweng RWSS	74.994	28	26	92	14	106	92	12	104		GW+SW	9	17.28	8	0	Test, equip and maintain
Modimolle Urban RWS	257.453	164	111	184	8	192	178	6	184		GW+SW	7	25.92	2	3	Test, equip and maintain
Mokopane RWS	404.732	106	73	133	12	146	122	9	131		GW+SW	56	37.15	41	6	Test, equip and maintain

Domestic water schemes	Area (km²)	Exploitation potential for 2010 population (ℓ/c/d)	Exploitation potential for 2040 population (ℓ/c/d)	Current equipped sources 70% effective & surface sources (ℓ/c/d) 2010 population	Not equipped but tested (>50 m³/d) 70% effective (ℓ/c/d) 2010 population	Total tested volume (ℓ/c/d) 2010 population	Current equipped sources 70% effective & surface sources (ℓ/c/d) 2040 population	Not equipped but tested (>50 m³/d) 70% effective (ℓ/c/d) 2040 population	Total tested volume (ℓ/c/d) 2040 population	Estimated sources (ℓ/c/d)	Water source	Total tested count all borehole	Total pumped volume (m³/day) bh less than 25m³/d	Not equipped not tested	To be tested already motorized	Intervention, comments
Mookgophong RWS	114.005	266	129	84	15	100	75	8	82		GW+SW	6	0	3	5	Test, equip, maintain, develop
Mothapo RWSS	195.446	154	127	176	166	343	168	138	306		GW+SW	37	25.92	51	2	Test, equip and maintain
Musina RWS	129.394	31	30	952	16	968	952	16	968		GW+SW	7	0	11	13	Test, equip and maintain
Nzhelele North RWS	555.14	614	632	56	52	108	58	53	111		GW+SW	29	21.6	22	16	Test, equip, maintain, develop
Nzhelele RWS	453.031	70	73	5	16	21	5	17	22		GW+SW	52	28.8	46	51	Test, equip, maintain, develop
Olifants-Sand RWSS	756.148	86	53	327	31	358	320	19	339		GW+SW	96	56.81	125	62	Bulk supply monitor
Sebayeng-Dikgale RWSS	288.766	112	101	162	35	197	158	32	190		GW+SW	49	86.4	71	10	Test, equip and maintain
Segwasi RWSS	10.594	63	60	40	0	40	39	0	39		GW+SW	2	0	0	0	Test, equip and maintain, develop
Sinthumule/Kutama RWSS	323.832	93	97	33	13	46	34	14	48		GW+SW	43	14.25	29	48	Test, equip, maintain, develop
Taaiboschgroet	1035.332	458	516	73	51	125	82	61	144		GW+SW	62	1513.95	82	23	Test, equip, maintain, develop
Tshifire Murunwa RWS	86.318	31	33	28	0	28	28	0	28		GW+SW	3	25.92	1	1	Test, equip and maintain

Table I.2 Water schemes, maintenance and equipping cost for existing boreholes [(1)]

Scheme name	Total equipped and tested	Current pumped volume (10^6 m³/a)	Current equiped production boreholes O&M cost @R122K[(2)]	Cost R/m³/a existing production boreholes (O&M)	Tested, not motorised (h,n,w count) (25 to 50 m³/d)	Available volume not in use Mm³/a (25 to 50 m³/d)	Tested sources 25 to 50m³/d, cost to equip R300k/source and one year O&M @122K[(2)]	Cost/m³/a first year 25-50m³/d	Total tested, not motorised (h,n,w count) (>50 m³/d)	Available volume not in use Mm³/a (>50 m³/d)	Tested sources >50 m³/d, cost estimate for equipping at R300k/source and one year O&M @R122k[(2)]	Cost/m³/a first year 25-50 m³/d[(2)]	Total motorised-equipped	Total pumped volume (10^6 m³/a)	Operation cost estimate per annum @R72k/a/BH[(2)]	Cost/m³/a existing production boreholes (O&M)[(2)]
Capricorn District Municipality Aganang Local Municipality																
Moletje South GWS	33	1	4 026 000	3.82	5	0	2 110 000	45	27	2	11 394 000	5	8	0	576 000	15
Ga Mokobodi GWS	18	1	2 196 000	1.62	3	0	1 266 000	35	21	1	8 862 000	9	6	0	432 000	15
Aganang East GWS	22	1	2 684 000	2.29	10	0	4 220 000	33	22	2	9 284 000	5	6	0	432 000	18
Bakone GWS	16	1	1 952 000	1.92	4	0	1 688 000	33	19	1	8 018 000	7	3	0	216 000	21
Aganang North GWS	20	1	2 440 000	1.95	4	0	1 688 000	43	15	1	6 330 000	8	3	0	216 000	25
Aganang LM Farms supply	no info				no info				no info				no info			
	109	6	13 298 000	2.27	26	0	10 972 000	36	104	7	43 888 000	6	26	0	1 872 000	17
Capricorn District Municipality Aganang/Polokwane Local Municipality																
Houtrivier RWS	13	1	1 586 000	2	6	0	2 532 000	37	11	1	4 642 000	7	1	0	72 000	4 167
Capricorn District Municipality Blouberg Local Municipality																
Taaiboschgroet	33	2	4 026 000	2	12	0	5 064 000	36	17	1	7 174 000	5	51	1	3 672 000	7
Archibald GWS	7	1	854 000	1	2	0	844 000	42	6	1	2 532 000	5	3	0	216 000	14
Gorkum GWS	9	0	1 098 000	4	7	0	2 954 000	33	18	2	7 596 000	4	4	0	288 000	15
Silwermyn / Kirstenspruit GWS	6	0	732 000	4	1	0	422 000	45	13	0	5 486 000	13	9	0	648 000	18
Avon GWS	16	1	1 952 000	2	4	0	1 688 000	28	17	1	7 174 000	7	3	0	216 000	19
Blouberg RWS	20	1	2 440 000	2	6	0	2 532 000	31	17	1	7 174 000	8	3	0	216 000	20
Senwabarwana GWS	12	1	1 464 000	1	1	0	422 000	27	9	1	3 798 000	4	2	0	144 000	34
Ga Rawesi GWS	5	0	610 000	4	9	0	3 798 000	40	21	1	8 862 000	7	1	0	72 000	57
Thalahane GWS	no info				1	0	422 000	27	no info				3	0	216 000	423
Alldays BS	4	0	488 000	7	1	0	422 000	33	2	0	844 000	5	no info			
Blouberg LM Farms Supply	no info				no info				no info				no info			
Dalmeny Local WS	no info				no info				no info				no info			
Ga-Hlako RWS	no info				no info				no info				no info			
	112	7	13 664 000	2	44	1	18 568 000	34	120	9	50 640 000	6	79	1	5 688 000	9

Scheme name	Total equipped and tested	Current pumped volume (10^6 m^3/a)	Current equiped production boreholes O&M cost @R122K(2)	Cost R/m^3/a existing production boreholes (O&M)	Tested, not motorised (h,n,w count) (25 to 50 m^3/d)	Available volume not in use Mm^3/a (25 to 50 m^3/d)	Tested sources 25 to 50m^3/d, cost to equip R300k/source and one year O&M @122K(2)	Cost/m^3/a first year 25-50m^3/d	Total tested, not motorised (h,n,w count) (>50 m^3/d)	Available volume not in use Mm^3/a (>50 m^3/d)	Tested sources >50 m^3/d, cost estimate for equipping at R300k/source and one year O&M @R122k(2)	Cost/m^3/a first year 25-50 m^3/d(2)	Total motorised-equipped	Total pumped volume (10^6 m^3/a)	Operation cost estimate per annum @R72k/a/BH(2)	Cost/m^3/a existing production boreholes (O&M)(2)
Capricorn District Municipality Molemole Local Municipality																
Nthabiseng RWS	7	0	854 000	2	2	0	844 000	36	7	1	2 954 000	6	1	0	72 000	11
Botlokwa GWS	13	1	1 586 000	3	5	0	2 110 000	34	20	2	8 440 000	5	3	0	216 000	27
Molemole West Individual GWS	20	2	2 440 000	1	4	0	1 688 000	38	26	3	10 972 000	3	2	0	144 000	274
Makgalong A & B GWS	2	0	244 000	2	no info				1	0	422 000	12	no info			
Mogwadi Wurthsdorp GWS	42	2	5 124 000	2	4	0	1 688 000	34	14	1	5 908 000	7	3	0	216 000	365
Molemole LM Farms Supply	no info				no info				no info				no info			
Ramakgopa GWS	no info				no info				no info				no info			
Rietgat GWS	no info				no info				no info				no info			
	84	6	10 248 000	2	15	0	6 330 000	36	68	7	28 696 000	4	9	0	648 000	26
Capricorn District Municipality Polokwane Local Municipality																
Mankweng RWSS	2	0	244 000	5	2	0	844 000	32	5	0	2 110 000	5	1	0	72 000	11
Moletje North Individual Groundwater SS	5	0	610 000	2	1	0	422 000	27	6	0	2 532 000	13	1	0	72 000	11
Mothapo RWSS	13	1	1 586 000	2	1	0	422 000	33	24	3	10 128 000	4	2	0	144 000	15
Sebayeng-Dikgale RWSS	23	1	2 806 000	2	9	0	3 798 000	33	17	1	7 174 000	7	8	0	576 000	18
Badimong RWS	1	0	122 000	5	2	0	844 000	33	4	0	1 688 000	9	3	0	216 000	19
Moletje East Regional Groundwater SS	10	1	1 220 000	2	2	0	844 000	38	15	2	6 330 000	4	6	0	432 000	22
Olifants-Sand RWSS	30	2	3 660 000	2	13	0	5 486 000	35	50	3	21 100 000	6	9	0	648 000	31
Segwasi RWSS	1	0	122 000	4	no info				no info				no info			
Laaste Hoop RWS	1	0	122 000	4	no info				no info				no info			
	86	5	10 492 000	2	30	0	12 660 000	34	121	9	51 062 000	5	30	0	2 160 000	21
Vhembe District Municipality Makado Local Municipality																
Vivo Supply	no info				no info				no info				no info			
Matshavhawe / Kunda RWS	1	0	122 000	4	no info				1	0	422 000	7	1	0	72 000	9
Bandelierkop Supply	no info				1	0	422 000	27	no info				1	0	72 000	11

Scheme name	Total equipped and tested	Current pumped volume (10^6 m^3/a)	Current equiped production boreholes O&M cost @R122K(2)	Cost R/m³/a existing production boreholes (O&M)	Tested, not motorised (h,n,w count) (25 to 50 m^3/d)	Available volume not in use Mm³/a (25 to 50 m^3/d)	Tested sources 25 to 50m³/d, cost to equip R300k/source and one year O&M @122K(2)	Cost/m³/a first year 25-50m³/d	Total tested, not motorised (h,n,w count) (>50 m^3/d)	Available volume not in use Mm³/a (>50 m^3/d)	Tested sources >50 m³/d, cost estimate for equipping at R300k/source and one year O&M @R122k(2)	Cost/m³/a first year 25-50 m³/d(2)	Total motorised-equipped	Total pumped volume (10^6 m^3/a)	Operation cost estimate per annum @R72k/a/BH(2)	Cost/m³/a existing production boreholes (O&M)(2)
Tshifire Murunwa RWS	2	0	244 000	3	1	0	422 000	27	no info				2	0	144 000	15
Nzhelele North RWS	18	0	2 196 000	5	3	0	1 266 000	45	8	0	3 376 000	9	2	0	144 000	18
Nzhelele RWS	9	0	1 098 000	4	20	0	8 440 000	36	22	1	9 284 000	9	4	0	288 000	27
Makhado RWSS	4	0	488 000	4	no info				no info				1	0	72 000	46
Sinthumule/Kutama RWSS	24	1	2 928 000	2	8	0	3 376 000	33	11	1	4 642 000	8	8	0	576 000	111
Alexandra Scheme	no info				1	0	422 000	46	no info				no info			
Buysdorp Scheme	no info				no info				no info				no info			
Makhado Air Force Base Supply	no info				no info				no info				no info			
Makhado LM Farms Supply	no info				no info				no info				no info			
Waterpoort Supply	no info				1	0	422 000	45	no info				no info			
	58	2	7 076 000	3	35	0	14 770 000	35	42	2	17 724 000	9	19	0	1 368 000	28
Vhembe District Municipality Musina and Mutale Local Municipality																
Musina RWS	2	0	244 000	4	1	0	422 000	33	4	0	1 688 000	7	no info			
Mopane Supply	no info				no info				no info				no info			
Musina LM Farms Supply	no info				no info				no info				no info			
Tshipise Resort Supply	no info				no info				no info				no info			
Luphephe / Nwanedzi Main RWS	4	0	488 000	1	4	0	1 688 000	38	2	0	844 000	3	1	0	72 000	23
Luphephe / Nwandedzi North	8	0	976 000	5	5	0	2 110 000	35	13	1	5 486 000	9	no info			
Mutale Main RWS	12	1	1 464 000	2	no info				3	0	1 266 000	10	3	0	216 000	33
	26	1	3 172 000	3	10	0	4 220 000	36	22	1	9 284 000	7	4	0	288 000	29
Waterberg District Municipality Lephalale Local Municipality																
Setuteng RWS	3	0	366 000	2	4	0	1 688 000	32	3	0	1 266 000	5	5	0	360 000	11
Witpoort RWS	15	1	1 830 000	4	1	0	422 000	36	2	0	844 000	6	9	0	648 000	13
Mmaletswai RWS	21	1	2 562 000	2	7	0	2 954 000	37	12	1	5 064 000	8	3	0	216 000	15
Ga-Seleka RWS	24	1	2 928 000	2	1	0	422 000	36	11	1	4 642 000	8	9	0	648 000	18

Scheme name	Total equipped and tested	Current pumped volume (10^6 m^3/a)	Current equiped production boreholes O&M cost @R122K(2)	Cost R/m^3/a existing production boreholes (O&M)	Tested, not motorised (h,n,w count) (25 to 50 m^3/d)	Available volume not in use Mm^3/a (25 to 50 m^3/d)	Tested sources 25 to 50m^3/d, cost to equip R300k/source and one year O&M @122K(2)	Cost/m^3/a first year 25-50m^3/d	Total tested, not motorised (h,n,w count) (>50 m^3/d)	Available volume not in use Mm^3/a (>50 m^3/d)	Tested sources >50 m^3/d, cost estimate for equipping at R300k/source and one year O&M @R122k(2)	Cost/m^3/a first year 25-50 m^3/d(2)	Total motorised-equipped	Total pumped volume (10^6 m^3/a)	Operation cost estimate per annum @R72k/a/BH(2)	Cost/m^3/a existing production boreholes (O&M)(2)
Lephalale Urban RWS	no info				1	0	422 000	45	11	2	4 642 000	3	no info			
Baltimore Supply	no info				no info				no info				no info			
Lephalale LM Farms Supply	no info				no info				no info				no info			
Maasstroom Supply	no info				no info				no info				no info			
Marnitz Supply	no info				no info				no info				no info			
Tom Burke Supply	no info				no info				no info				no info			
Zwartwater Supply	no info				no info				no info				no info			
	63	4	7 686 000	2	14	0	5 908 000	36	39	3	16 458 000	5	26	0	1 872 000	14
Waterberg District Municipality Modimole and Mookgopong Local Municipality																
Modimolle Urban RWS	3	0	366 000	1	no info				4	0	1 688 000	8	2	0	144 000	15
Mabatlane RWS	3	0	366 000	2	1	0	422 000	33	8	0	3 376 000	9	2	0	144 000	20
Mabaleng RWS	no info				2	0	844 000	30	4	0	1 688 000	11	no info			
Modimolle LM Farms Supply	no info				no info				no info				no info			
Mookgophong RWS	4	0	488 000	2	no info				2	0	844 000	5	no info			
Rietbokvalley Supply	no info				no info				no info				no info			
Sentrum RWS	no info				no info				no info				no info			
	10	1	1 220 000	2	3	0	1 266 000	31	18	1	7 596 000	8	4	0	288 000	17
Waterberg District Municipality Mogalakwena Local Municipality																
Marken Supply	no info				no info				no info				no info			
Mogalakwena LM Farms Supply	no info				no info				no info				no info			
Rebone RWS	25	1	3 050 000	3	13	0	5 486 000	34	16	1	6 752 000	5	12	0	864 000	14
Mapela RWS	50	3	6 100 000	2	9	0	3 798 000	37	40	2	16 880 000	8	9	0	648 000	14
Mokopane RWS	38	2	4 636 000	2	4	0	1 688 000	34	14	1	5 908 000	7	3	0	216 000	16
Bakenberg RWS	31	1	3 782 000	5	9	0	3 798 000	37	24	1	10 128 000	7	17	0	1 224 000	19
Glen Alpine GWS	15	1	1 830 000	3	11	0	4 642 000	31	16	1	6 752 000	9	13	0	936 000	20
Uitspan Supply	no info				no info				no info				1	0	72 000	29

Scheme name	Total equipped and tested	Current pumped volume (10^6 m^3/a)	Current equiped production boreholes O&M cost @R122K[(2)]	Cost R/m^3/a existing production boreholes (O&M)	Tested, not motorised (h,n,w count) (25 to 50 m^3/d)	Available volume not in use Mm^3/a (25 to 50 m^3/d)	Tested sources 25 to 50m^3/d, cost to equip R300k/source and one year O&M @122K[(2)]	Cost/m^3/a first year 25-50m^3/d	Total tested, not motorised (h,n,w count) (>50 m^3/d)	Available volume not in use Mm^3/a (>50 m^3/d)	Tested sources >50 m^3/d, cost estimate for equipping at R300k/source and one year O&M @R122k[(2)]	Cost/m^3/a first year 25-50 m^3/d[(2)]	Total motorised-equipped	Total pumped volume (10^6 m^3/a)	Operation cost estimate per annum @R72k/a/BH[(2)]	Cost/m^3/a existing production boreholes (O&M)[(2)]
Biesjeskraal WS	no info				1	0	422 000	45	no info				no info			
Daggakraal WS	no info				no info				no info				no info			
Ga-Phahladira Cluster	no info				no info				no info				no info			
Makapans Valley Supply	no info				no info				no info				no info			
Weenen Supply	no info				no info				no info				no info			
	159	7	19 398 000	3	47	1	19 834 000	34	110	7	46 420 000	7	55	0	3 960 000	17
	720	40	87 840 000	2	230	3	97 060 000	35	655	47	276 410 000	6	253	1	18 216 000	14

Note: (1) *All the data is based on tested boreholes with yields >25 m^3/d.*

(2) *Cost price in Rands.*

Appendix J

Water balances tables

Table J.1 Quaternary catchments, groundwater balance

Quaternary Catchment	Calculated Exploitation Potential from (Baron, Seward & Seymour, 1998) 10^6 m^3/a	Estimated current and future groundwater use						Groundwater balance					
		2015	2020	2025	2030	2035	2040	Mean annual Groundwater Exploitation Potential-Total Groundwater use					
		Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	2015 10^6 m^3/a	2020 10^6 m^3/a	2025 10^6 m^3/a	2030 10^6 m^3/a	2035 10^6 m^3/a	2040 10^6 m^3/a
A41A	8.804	0.450	0.468	0.488	0.510	0.534	0.561	8.354	8.336	8.316	8.294	8.270	8.244
A41B	4.474	0.109	0.116	0.123	0.131	0.140	0.149	4.365	4.358	4.351	4.343	4.334	4.325
A41C	9.775	0.320	0.340	0.362	0.386	0.412	0.441	9.455	9.435	9.414	9.389	9.363	9.334
A41D	15.090	2.585	2.639	2.699	2.764	2.836	2.915	12.505	12.451	12.392	12.326	12.254	12.175
A41E	12.561	1.430	1.478	1.530	1.588	1.651	1.721	11.131	11.084	11.031	10.974	10.910	10.841
A42A	9.567	1.494	1.571	1.656	1.749	1.852	1.965	8.074	7.997	7.912	7.818	7.715	7.602
A42B	5.860	0.748	0.784	0.823	0.866	0.913	0.965	5.112	5.076	5.037	4.994	4.947	4.895
A42C	9.843	2.667	2.832	3.013	3.212	3.431	3.672	7.175	7.011	6.830	6.631	6.411	6.171
A42D	6.302	0.155	0.165	0.176	0.188	0.202	0.217	6.147	6.137	6.126	6.113	6.100	6.085
A42E	12.907	1.441	1.501	1.566	1.639	1.718	1.806	11.466	11.406	11.340	11.268	11.188	11.101
A42F	12.783	1.088	1.120	1.157	1.196	1.240	1.288	11.696	11.663	11.627	11.587	11.543	11.495
A42G	12.449	0.602	0.648	0.699	0.755	0.816	0.883	11.847	11.801	11.750	11.695	11.634	11.566
A42H	10.477	2.232	2.446	2.680	2.937	3.219	3.529	8.245	8.031	7.797	7.541	7.258	6.948
A42J	13.552	4.497	4.941	5.431	5.954	6.530	7.163	9.056	8.612	8.122	7.598	7.023	6.389

Quaternary Catchment	Calculated Exploitation Potential from (Baron, Seward & Seymour, 1998) 10^6 m^3/a	Estimated current and future groundwater use						Groundwater balance					
		2015	2020	2025	2030	2035	2040	Mean annual Groundwater Exploitation Potential-Total Groundwater use					
		Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	2015 10^6 m^3/a	2020 10^6 m^3/a	2025 10^6 m^3/a	2030 10^6 m^3/a	2035 10^6 m^3/a	2040 10^6 m^3/a
A50A	3.816	0.148	0.159	0.170	0.183	0.198	0.214	3.668	3.657	3.645	3.632	3.618	3.602
A50B	5.206	0.186	0.199	0.214	0.230	0.248	0.268	5.020	5.007	4.992	4.976	4.958	4.938
A50C	4.641	0.179	0.193	0.209	0.226	0.245	0.266	4.462	4.448	4.432	4.415	4.396	4.375
A50D	8.166	0.289	0.303	0.318	0.335	0.353	0.374	7.877	7.863	7.848	7.831	7.813	7.792
A50E	8.767	0.240	0.255	0.271	0.289	0.308	0.329	8.526	8.512	8.496	8.478	8.459	8.437
A50F	4.195	0.100	0.106	0.112	0.119	0.126	0.135	4.094	4.089	4.083	4.076	4.068	4.060
A50G	5.873	2.898	3.120	3.365	3.633	3.929	4.254	2.975	2.753	2.508	2.240	1.944	1.619
A50H	12.268	3.459	3.786	4.146	4.542	4.978	5.457	8.809	8.482	8.122	7.726	7.290	6.811
A50J	13.034	0.966	1.009	1.057	1.109	1.166	1.230	12.068	12.025	11.977	11.925	11.867	11.804
A61A	4.886	2.533	2.650	2.778	2.918	3.073	3.244	2.353	2.237	2.109	1.968	1.813	1.643
A61B	6.234	0.607	0.644	0.685	0.730	0.779	0.833	5.627	5.590	5.549	5.504	5.455	5.400
A61C	10.347	3.153	3.219	3.292	3.373	3.461	3.558	7.194	7.127	7.054	6.974	6.886	6.788
A61D	10.010	3.597	3.705	3.824	3.955	4.099	4.257	6.413	6.305	6.186	6.055	5.911	5.753
A61E	10.439	9.352	9.401	9.454	9.513	9.578	9.649	1.086	1.038	0.984	0.925	0.860	0.789
A61F	10.980	4.773	5.082	5.423	5.798	6.211	6.664	6.207	5.897	5.556	5.181	4.769	4.315

Quaternary Catchment	Calculated Exploitation Potential from (Baron, Seward & Seymour, 1998) 10^6 m^3/a	Estimated current and future groundwater use						Groundwater balance					
		2015	2020	2025	2030	2035	2040	Mean annual Groundwater Exploitation Potential-Total Groundwater use					
		Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	2015 10^6 m^3/a	2020 10^6 m^3/a	2025 10^6 m^3/a	2030 10^6 m^3/a	2035 10^6 m^3/a	2040 10^6 m^3/a
A61G	11.555	4.294	7.827	10.597	12.459	12.866	13.527	7.262	3.728	0.959	-0.904	-1.311	-1.972
A61H	10.357	2.582	2.616	2.654	2.695	2.741	2.791	7.775	7.741	7.703	7.662	7.616	7.566
A61J	10.269	1.710	1.777	1.849	1.929	2.018	2.114	8.559	8.493	8.420	8.340	8.252	8.155
A62A	5.464	0.832	0.866	0.904	0.945	0.991	1.041	4.632	4.598	4.560	4.519	4.473	4.423
A62B	8.954	1.537	1.685	1.848	2.027	2.224	2.441	7.417	7.269	7.106	6.927	6.730	6.514
A62C	4.729	0.633	0.693	0.759	0.832	0.912	1.001	4.096	4.036	3.969	3.897	3.816	3.728
A62D	7.127	1.162	1.208	1.259	1.315	1.377	1.444	5.965	5.919	5.868	5.812	5.750	5.683
A62E	7.446	2.016	2.214	2.432	2.671	2.935	3.225	5.430	5.232	5.014	4.775	4.511	4.221
A62F	7.052	5.368	5.672	6.007	6.375	6.780	7.225	1.684	1.380	1.045	0.677	0.272	-0.173
A62G	5.431	1.094	1.199	1.315	1.442	1.582	1.735	4.337	4.232	4.116	3.989	3.849	3.695
A62H	9.701	2.682	2.941	3.226	3.539	3.884	4.263	7.019	6.760	6.475	6.162	5.817	5.438
A62J	6.168	0.996	1.057	1.123	1.197	1.277	1.366	5.172	5.112	5.045	4.972	4.891	4.802
A63A	8.028	20.596	20.900	21.234	21.602	22.006	22.451	-12.568	-12.872	-13.206	-13.574	-13.978	-14.423
A63B	15.624	2.688	2.793	2.909	3.037	3.177	3.331	12.936	12.831	12.715	12.588	12.448	12.293
A63C	14.797	0.469	0.502	0.539	0.580	0.624	0.674	14.328	14.295	14.258	14.217	14.172	14.123

Quaternary Catchment	Calculated Exploitation Potential from (Baron, Seward & Seymour, 1998) 10^6 m^3/a	Estimated current and future groundwater use						Groundwater balance					
		2015	2020	2025	2030	2035	2040	Mean annual Groundwater Exploitation Potential-Total Groundwater use					
		Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	2015 10^6 m^3/a	2020 10^6 m^3/a	2025 10^6 m^3/a	2030 10^6 m^3/a	2035 10^6 m^3/a	2040 10^6 m^3/a
A63D	14.055	4.752	4.925	5.116	5.325	5.556	5.810	9.303	9.130	8.939	8.730	8.499	8.245
A63E	11.690	4.897	4.931	4.969	5.010	5.055	5.105	6.793	6.759	6.722	6.681	6.635	6.586
A71A	12.371	45.947	47.470	49.164	51.049	52.919	54.976	-33.576	-35.098	-36.793	-38.678	-40.548	-42.605
A71B	8.825	12.484	13.217	14.046	14.766	15.558	16.429	-3.659	-4.392	-5.220	-5.940	-6.732	-7.604
A71C	13.239	25.103	25.263	25.412	25.576	25.757	25.956	-11.864	-12.024	-12.173	-12.338	-12.518	-12.717
A71D	7.557	5.958	6.000	6.045	6.095	6.150	6.210	1.598	1.557	1.512	1.462	1.407	1.346
A71E	10.302	8.380	8.723	9.106	9.531	10.003	10.529	1.922	1.578	1.196	0.771	0.298	-0.227
A71F	6.273	7.571	7.752	7.957	8.188	8.449	8.744	-1.298	-1.479	-1.684	-1.915	-2.176	-2.471
A71G	9.062	10.995	11.127	11.273	11.434	11.610	11.804	-1.933	-2.066	-2.211	-2.372	-2.549	-2.743
A71H	10.370	3.479	3.762	4.026	4.317	4.637	4.989	6.891	6.608	6.344	6.053	5.733	5.381
A71J	7.456	16.472	16.519	16.571	16.628	16.690	16.759	-9.017	-9.064	-9.115	-9.172	-9.235	-9.303
A71K	5.082	4.698	4.877	5.078	5.304	5.558	5.844	0.384	0.205	0.004	-0.222	-0.476	-0.763
A71L	5.302	0.550	0.589	0.632	0.680	0.732	0.790	4.752	4.713	4.669	4.622	4.569	4.511
A72A	21.151	23.207	24.017	24.908	25.887	26.965	28.150	-2.056	-2.866	-3.757	-4.736	-5.814	-7.000
A72B	9.294	3.594	3.622	3.653	3.688	3.725	3.767	5.700	5.672	5.641	5.606	5.569	5.527

Quaternary Catchment	Calculated Exploitation Potential from (Baron, Seward & Seymour, 1998) 10^6 m^3/a	Estimated current and future groundwater use						Groundwater balance					
		2015	2020	2025	2030	2035	2040	Mean annual Groundwater Exploitation Potential-Total Groundwater use					
		Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	Total GW use 10^6 m^3/a	2015 10^6 m^3/a	2020 10^6 m^3/a	2025 10^6 m^3/a	2030 10^6 m^3/a	2035 10^6 m^3/a	2040 10^6 m^3/a
A80A	2.437	0.353	0.388	0.425	0.467	0.512	0.563	2.083	2.049	2.011	1.970	1.924	1.874
A80B	2.131	0.386	0.407	0.429	0.453	0.480	0.509	1.745	1.724	1.702	1.678	1.651	1.622
A80C	2.490	0.290	0.317	0.347	0.380	0.415	0.455	2.199	2.172	2.143	2.110	2.074	2.035
A80D	1.059	0.415	0.455	0.499	0.548	0.601	0.660	0.644	0.604	0.560	0.511	0.458	0.399
A80E	2.009	1.497	1.563	1.636	1.715	1.803	1.899	0.512	0.446	0.373	0.294	0.206	0.110
A80F	4.774	0.804	0.843	0.887	0.935	0.988	1.046	3.970	3.931	3.887	3.839	3.786	3.728
A80G	5.165	3.111	3.151	3.195	3.244	3.297	3.356	2.054	2.014	1.969	1.921	1.867	1.808
A80H	1.771	0.060	0.064	0.068	0.073	0.079	0.085	1.711	1.707	1.703	1.698	1.692	1.686
A80J	3.316	1.257	1.375	1.505	1.647	1.804	1.976	2.059	1.941	1.812	1.669	1.512	1.340
Mm^3/a	**573.2**	**287.2**	**300.2**	**313.3**	**326.4**	**339.0**	**353.0**						