Mopane Coal Project

Groundwater Flow
Impact Assessment Report

October 2013

WSM LESHIKA CONSULTING (PTY) LTD

CESA Consulting Engineers South Africa

SABI

Mopane Coal Project

Groundwater Flow Impact Assessment Report

REPORT: WH13076 8 November 2013 Ver Final

Job WH13076–Mopane Coal Project

COMPILED BY

WSM LESHIKA CONSULTING (PTY) LTD

Postnet Suite #8
Private Bag X9676
POLOKWANE
0700
TEL: (015) 296-1560

2 Rhodesdrift Street
Hampton Court
POLOKWANE
0699
FAX: (015) 296-4158
ENQUIRIES: MR CJ Haupt, Pr.Sci.Nat.

LIST OF ACRONYMS

C	Celsius
CoAL	Coal of Africa Limited
DMR	Department of Mineral Resources
DWA	Department of Water Affairs
EIA	Environmental Impact Assessment
GRA II	Groundwater Resources Assessment Study II
GRIP	Groundwater Resources Information Project
GSP	Greater Soutpansberg Projects
Ha	Hectare or 10 000 m^2
LMB	Limpopo Mobile Belt
Ma	Million years ago
Mbgl	metres below ground level
mamsl	metres above mean sea level
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MIA	Mining infrastructure area
MODFLOW	Numerical groundwater modeling programme
MPRDA	Mineral and Petroleum Resources Development Act (Act 28 of 2002)
MRA	Mining right application
Mtpa	Million tonnes per annum
NGDB	National Groundwater Data Base
NOMR	New Order Mining Right
RLT	Railway Load-out Terminal
RoM	Run of Mine
RMF	Regional Maximum Flood
RoM	Run of Mine
WR2005	Water Resources 2005 study
WQT	Water Quality Threshold

UNITS OF MEASUREMENT

1 Ml = 1 000 Kl = 1 000 m^3 = 1 000 000 l

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

An application for a New Order Mining Right (NOMR) in terms of Section 22 of the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA) for the Mopane Project has been lodged by Coal of Africa Limited (CoAL) to the Department of Mineral Resources (DMR). The Mopane Project forms part of an asset of proposed mining projects collectively known as the Greater Soutpansberg Project (GSP) situated to the north of the Soutpansberg in the Limpopo Province. Similar applications for NOMR's have already been submitted by CoAL and/or subsidiary companies held by them in the Greater Soutpansberg area. The locality of the project relative to some of the main towns in the Limpopo Province is indicated in Figure 1.

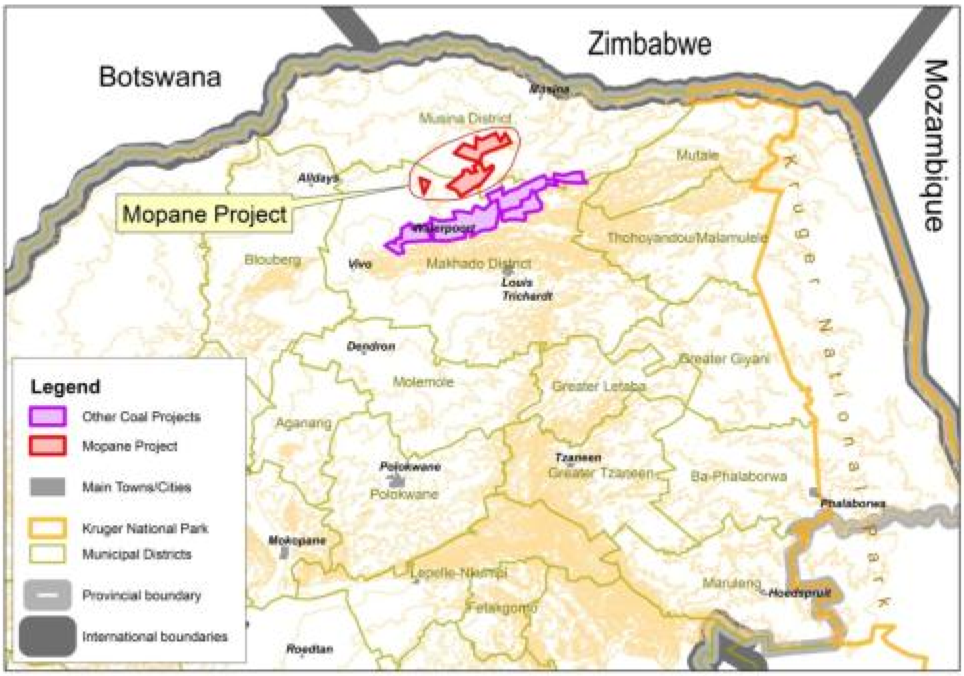


FIGURE 1: COAL GREATER SOUTPANSBERG PROJECTS IN THE LIMPOPO PROVINCE

As evident from the locality map, the various projects are close to each other, permitting rationalisation of infrastructure. The objective is to have a consolidated project with economically minable blocks which are contiguous.

WSM Leshika Consulting was appointed to conduct the groundwater flow study for the Environmental Impact Assessment (EIA) for the proposed Mopane Colliery Project. See Appendix A for WSM Leshika's statement of independency, the details of the project team and their curriculum vitae

The EIA report describes the current groundwater status and the potential impact on the groundwater flow, of the Mopane Colliery Project. The other surrounding CoAL Projects were taken into account and cumulative impacts evaluated.

2. PROJECT DESCRIPTION

The Mopane Project footprint covers an area of 1 572 hectares (ha) for mining and a further 1 964 ha for infrastructure development. The Voorburg mining pits cover approximately 905 ha and the elongated Jutland mining pit of about 12 kilometres (km) long, a further 667 ha. The mine footprint of the Voorburg mining pit is restricted by the Sand River running along the northern side of the mining pit.

The mining and infrastructure layouts are shown in Figure 2. This figure demonstrates the total extent of mining and is not a moment in time. The pits will be backfilled concurrent to mining and it is anticipated that no more than 600 ha will be open at any one time.

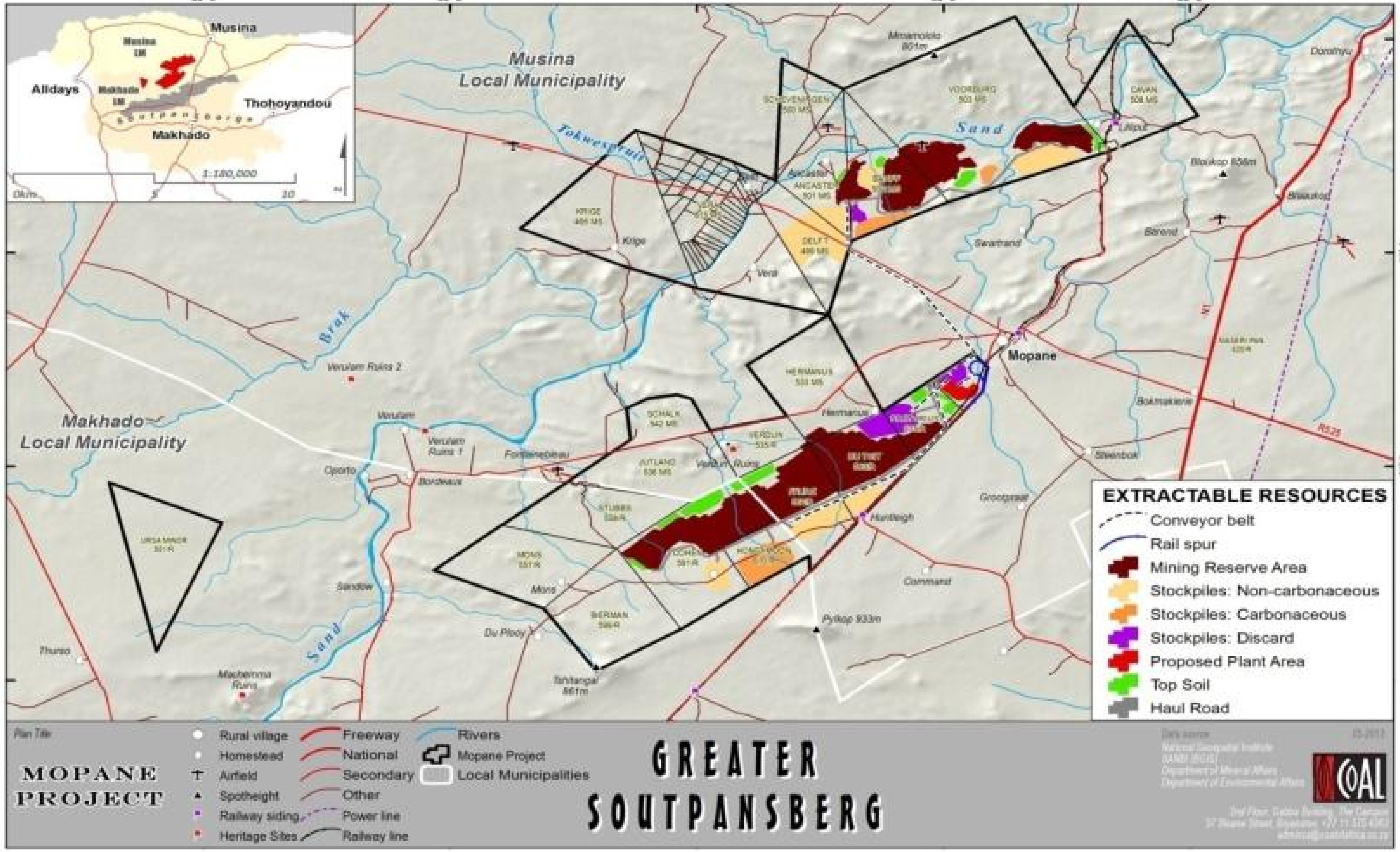


FIGURE 2: PROPOSED MINING LAYOUT WITH PITS AND DUMP MATERIAL

The Mopane Project has the potential to produce good quality semi soft coking coal and a domestic thermal coal product. Measured and indicated resources are approximately 633.48 million tons mineable in situ.

The resource outcrops and dips predominantly to the north. It is estimated that in most instances it is mineable to a depth of 200 metres (m) through open cast methods. Due to the flat dipping nature of the coal resource a normal strip open cast mining method is likely to prove the most cost effective.

The current planning is that construction and mining will commence at the Voorburg Section first, followed by the Jutland Section as capacity in infrastructure is developed. The Voorburg Section will be mined at 2.5 million tonnes per annum (Mtpa) product for a period of 33 years followed by the Jutland Section mined at 2.5 Mtpa of product for a period of 28 years.

From the date of granting of the mining right (anticipated to be in 2015) further exploration, feasibility studies and final design studies will be undertaken. Construction is anticipated only to commence in 2018. Production at the Voorburg Section will commence in late 2019 and build up to 4 Mtpa Run-of-Mine (RoM) (2.5 Mtpa product) by 2020. RoM will be crushed and screened and the product will be transported by conveyor to the beneficiation plant next to the railway loop on Jutland. Due to rail logistics constraints, mining at the Voorburg Section continues for about 33 years to exhaustion of the resource. The total life of the Mopane Project is in excess of 50 years.

It is expected that additional rail capacity will become available after 2030, allowing for an increase in coal production. Mine development at the Jutland Section will therefore commence in 2030 with first production in 2032. To cater for the additional production from 2033 onward, a further coal beneficiation plant will be required at the Jutland Section and a new Rapid Load-out Terminal (RLT) will be built at the rail loop.

Infrastructure to support the mining activities has been laid out and engineered to best suit the topography and mining pit layouts, but can be influenced by the environmental impact assessments and stakeholder engagement process.

Although the mining operation will start at the Voorburg Section, the centre of gravity for the infrastructure layouts will be on the farm Pretorius 531 MS next to Mopane Railway Station. The Voorburg Section will however be provided with a workshop and other necessary infrastructure required for the mining operation.

The centrally located Infrastructure Hub (at the Mopane Railway Station) will comprise the coal beneficiation plant, personnel support structures, vehicle support structures, water management structures and management and monitoring systems.

Other mine infrastructure includes:

- Access and on-site haul roads
- Topsoil stockpiles and berms
- Overburden (carbonaceous and non-carbonaceous) stockpiles for initial placement, thereafter to be disposed in-pit
- RoM coal storage area
- RoM coal processing plant (primary, secondary and tertiary crusher)
- Associated conveyors from the processing plant to the product storage areas
- Product stockpile areas
- Carbonaceous discards stockpile
- Storm water management infrastructure (i.e. clean & dirty water run-off canals and dams)
- On-site water management and reticulation systems
- Change houses and offices

- Wastewater (sewage) treatment plant
- Bulk electricity supply infrastructure
- Bulk water supply infrastructure
- Railway Siding and rail loop
- Rapid Load-out Terminal (RLT)

3. GENERAL DESCRIPTION OF THE STUDY AREA

3.1 LOCALITY

The Mopane Project is situated in the magisterial district of Vhembe, in the Limpopo Province, approximately 40 km (direct) and 63 km (via road) north of the town of Makhado and 7 km west of Mopane in the Musina and Makhado Local Municipal areas. The nearest town is Musina, situated approximately 30 km to the north (Figure 3).

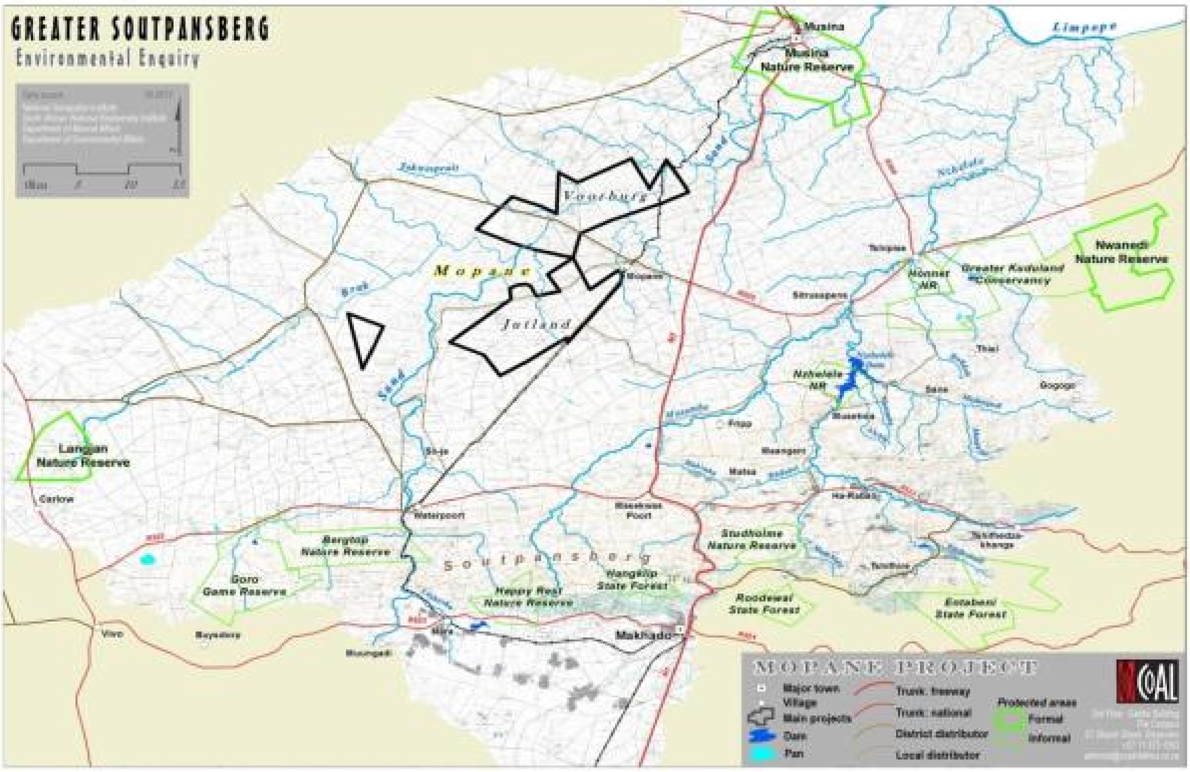


FIGURE 3: MOPANE PROJECT LOCALITY

The Mopane Project, consisting of the Voorburg and Jutland Sections, is well situated with respect to major infrastructure, including rail, road and power. The Mopane Railway Station is situated between the Voorburg and Jutland Sections to the east and is linked to the N1 with a surfaced road of 7 km length. The Jutland Section is traversed by the R525 road between Mopane and Alldays. Additional roads to connect mine infrastructure will need to be established.

3.2 CLIMATE

3.2.1 REGIONAL CLIMATE

The Mopane Project area is situated in a semi-arid zone to the north of the Soutpansberg. The regional climate is strongly influenced by the east-west orientated mountain range which represents an effective barrier between the south-easterly maritime climate influences from the Indian Ocean and the continental climate influences (predominantly the Inter-Tropical Convergence Zone and the Congo Air Mass) coming from the north.

The Mopane Project falls within the hot-arid zone to the north of the Soutpansberg with a Mean Annual Precipitation (MAP) in the low 300 millimetre (mm) range. Rainfall in this area occurs in summer (October to March), with cool, dry winters (May to August), with April and September being transition months. Temperature ranges from 0.9° Celsius (C) to 39.9°C and the area is generally frost free. The region is also within the impact zone of tropical cyclones occurring in the Indian Ocean which may cause high-intensity rainfalls and peak run-off events.

The mountains give rise to wind patterns that play an important role in determining local climates.

3.2.2 PRECIPITATION

The project spans across three quaternary catchments A71J, A71K and A72B (Figure 3), defined in the WR2005 Study (Middleton and Bailey, 2009).

All three quaternary catchments are located in Rainfall Zone A7C. The mean monthly precipitation values are given in Table 1 below. The maximum monthly rainfall of 20.49% occurs in January and the lowest of 0.31% in August.

Table 1: Mean monthly rainfall distribution of site rainfall (Zone A7C)

Rainfall Zone	Mean Monthly Precipitation (% Distribution)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
A7C	7.37	14.96	17.25	20.49	17.07	11.84	5.21	2.04	1.14	0.67	0.31	2.40

(Source: Middleton, B.J. and A.K. Bailey (2009). Water Resources of South Africa, 252005 Study. WRC Rep No TT381. Pretoria)

The absolute monthly rainfall (% distribution x MAP), for the 3 affected quaternary catchments is shown in Table 2 below. The average rainfall for the three catchments have been determined and the maximum rainfall of 71mm occurs in January and the lowest of 1mm in August. The data in the table is plotted as a bar chart below (Figure 4).

Table 2: Mean monthly quaternary rainfall (mm)

Quaternary	Mean Annual Rainfall (mm)	Rainfall Zone	Mean Monthly Precipitation (mm)											
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
A71J	396	A7C	29	59	68	81	68	47	21	8	5	3	1	10
A71K	305	A7C	22	46	53	63	52	36	16	6	3	2	1	7
A72B	344	A7C	25	51	59	70	59	41	18	7	4	2	1	8
Average	**348**		**26**	**52**	**60**	**71**	**59**	**41**	**18**	**7**	**4**	**2**	**1**	**8**

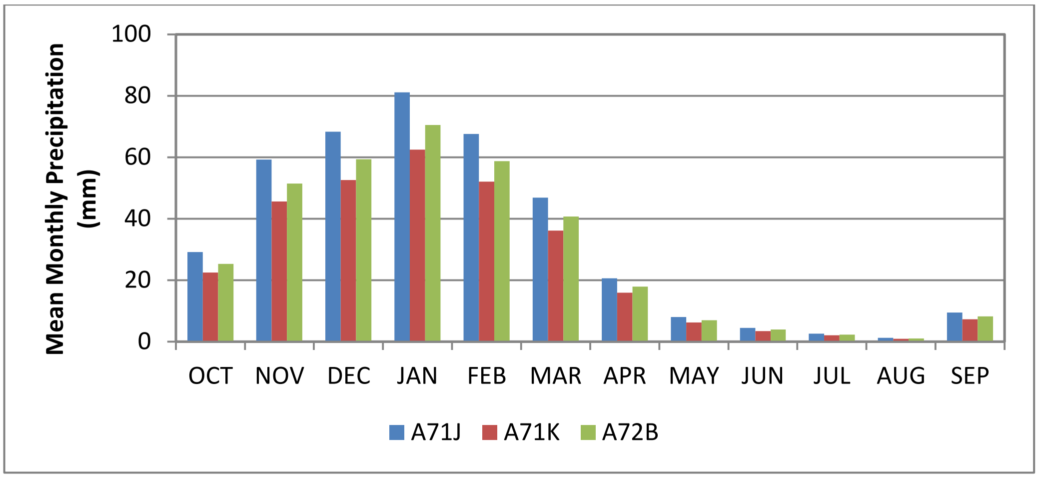


FIGURE 4: DISTRIBUTION OF MEAN MONTHLY PRECIPITATION IN MM

The rainfall data was taken from SA Weather Services' rain gauge 765007 at "Bandur", which is about 20 km west of the site. This station has a record length of 40 years and a MAP of 284 mm. Its mean maximum annual daily rainfall value (or 'M2') is 50 mm. The station MAP of 284 mm is 18% less than the average MAP of catchments A71J, A71K and A72B shown in Table 2 above. This illustrates the variability in rain gauge data which can sometimes not be explained by physical features such as a higher location. In this instance the lower value probably reflects the lower rainfall generally experienced towards the west.

3.2.3 TEMPERATURE

Average monthly minimum and maximum temperatures for the Tshipise weather station (No. 0766277 1) some 32 km south-east of the Mopane Project area is shown in Table 3 below. Note that this station is the closest station with long term available climate data. Average daily maximum and minimum summer temperatures (November to February) at the weather station range between ~33°C and ~20°C, while winter temperatures (May to August) range between ~28°C and ~7°C respectively. The high average temperatures are reflected by the fact that the minimum average daily summer temperature is a high 20°C and the minimum average daily winter temperature does not dip below 7°C.

Table 3: Temperature data for Tshipise for the period from 1994 to 2006

Month	Temperature (° C)			
	Highest Recorded	**Average Daily Maximum**	**Average Daily Minimum**	**Lowest Recorded**
January	42.2	32.8	21.5	12.6
February	41.4	32.3	21.5	14.9
March	42.9	31.5	20.1	13.0
April	40.9	30.1	16.3	5.7
May	42.3	27.9	11.2	1.7
June	34.3	25.6	8.2	-0.4
July	34.1	25.0	7.3	-1.2
August	37.4	27.8	10.3	1.7
September	41.2	27.7	12.9	3.6
October	41.4	29.1	16.5	8.0
November	42.5	32.2	20.1	11.1
December	43.4	33.1	21.0	13.8
Year	43.4	29.6	15.6	-1.2

Source: Weather SA (Station No 0766277 1)

The two figures below, Figure **5** and Figure **6,** indicate the maximum and minimum annual temperature distribution for the region.

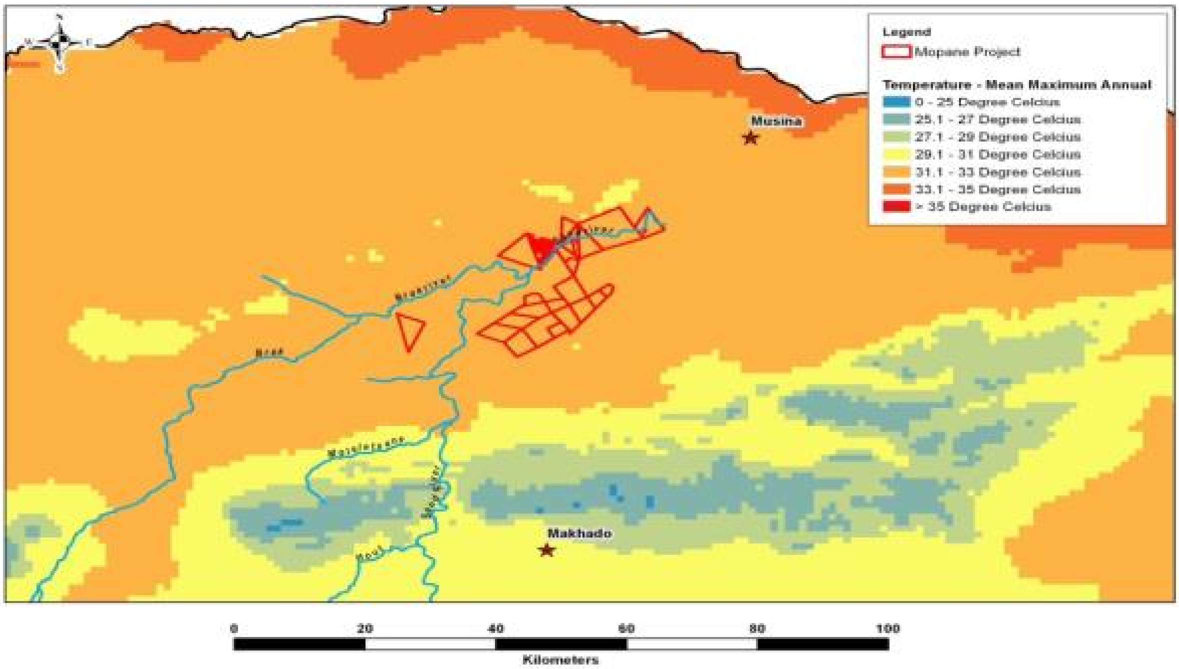


FIGURE 5: MEAN ANNUAL MAXIMUM TEMPERATURE

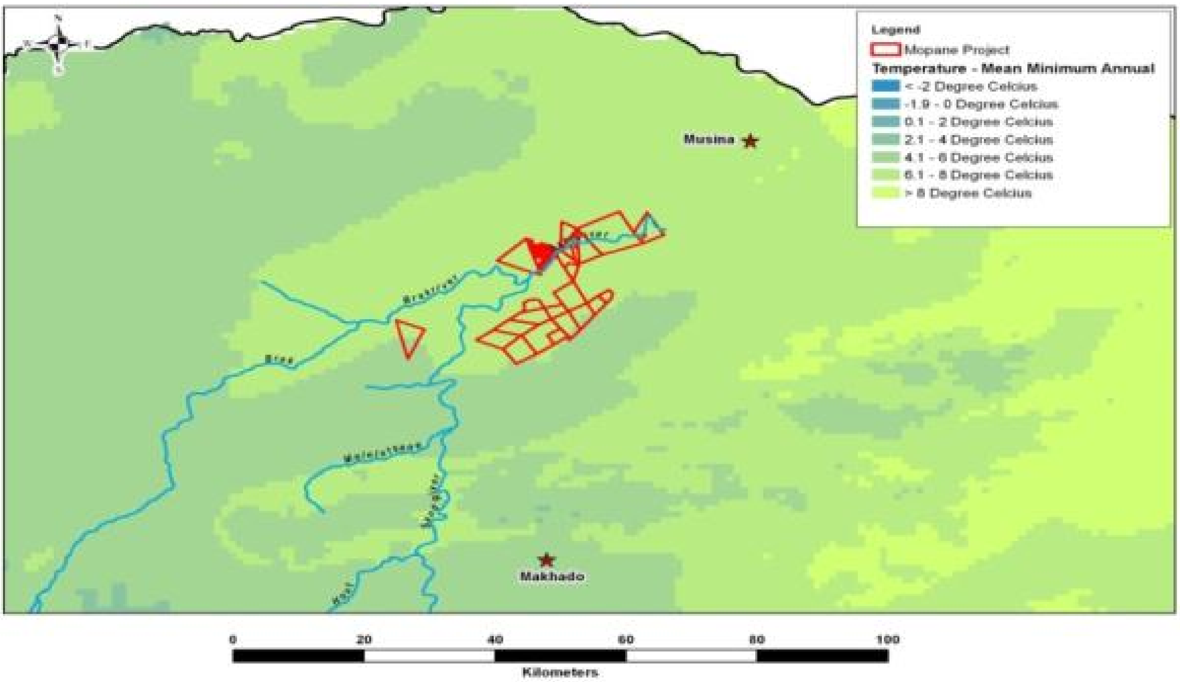


FIGURE 6: MEAN ANNUAL MINIMUM TEMPERATURE

3.3.4 EVAPORATION

The mean annual evaporation data for the 3 quaternary catchments are summarized in the table below. Mean Annual Evaporation data is given in Table 4 and the monthly evaporation pattern (as percentages of the total) is given in Table 5 below.

Table 4: Evaporation data per quaternary (from WR2005)

Quaternary catchment	Area (km2)	Mean Annual Evaporation (MAE) (mm)
A71J	905	1800
A71K	1668	2000
A72B	1269	1950

Table 5: Monthly evaporation distribution

(Source: WR90 Study, Evaporation zone 1B)

Month	Evaporation (%)
October	10.46
November	10.03
December	10.68
January	10.43
February	8.49
March	8.49
April	6.94
May	6.55
June	5.40
July	6.08
August	7.42
September	9.03

3.3 TOPOGRAPHY

Topography is formed as a consequence of the landscaping effect of erosional forces (wind and water) on rocks of variable susceptibility to weathering. The topography is described in the Terrain Morphological Map of Southern Africa as "irregular plains with moderate relief (almost hilly)".

Weather resistant rocks such as sandstones form flat topped "kopjes" or topographic highs surrounded by plains consisting of shale and basalt. Conical and rounded boulder "kopjes" are formed on the gneissic basement by quartz vein and pegmatite intruded shear zones and the younger granite intrusives.

3.4 CATCHMENTS AND DRAINAGES

The Mopane Project is situated within the Sand River Basin, which is a tributary of the Limpopo River. The Sand River originates south of Polokwane in a cold semi-arid zone, summer rainfall area of 500 to 600 mm precipitation. High precipitation also occurs on the Soutpansberg which creates high local run-off. The study area extends across three of the lower quaternary catchments i.e. A71J, A71K and A72B which form part of the Sand River basin (Figure 7).

The main drainages flowing through the study area are the Sand River (A71J, A71K) and the Brak Rivier (A72B). The Sand River has well developed alluvium in places that hosts abstractable interstitial water utilized for the irrigation of cash crops.

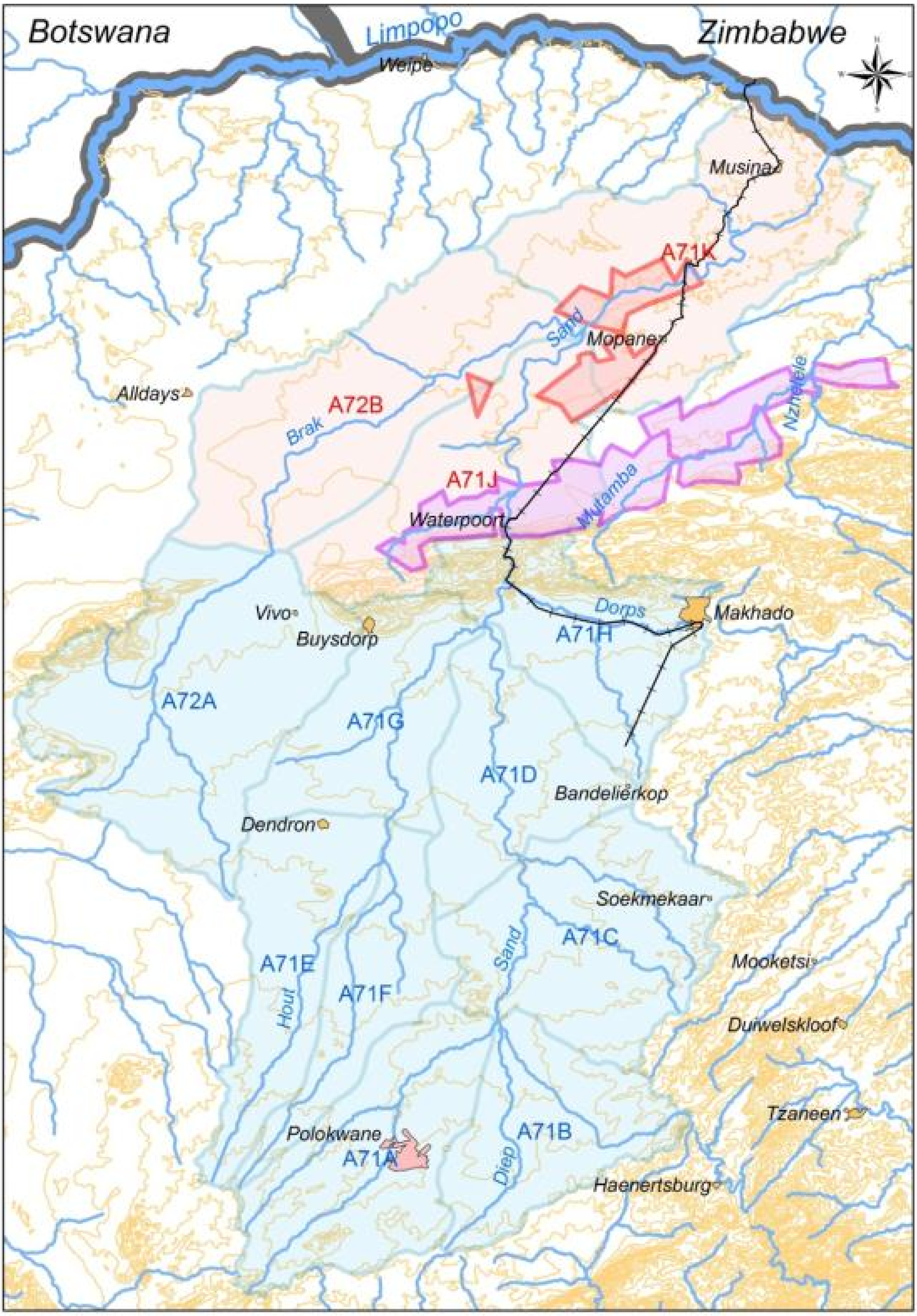


FIGURE 7: SAND RIVER BASIN AND QUATERNARY CATCHMENT AREAS

3.5 GEOLOGY

3.5.1 REGIONAL GEOLOGY

The regional geology consists of 2 main lithological groups i.e. the Limpopo Mobile Belt, and the Karoo Sequence rocks:

i) The Limpopo Mobile Belt (LMB); forms the gneissic basement on which the overlying strata (Soutpansberg Group and the Karoo Sequence) was deposited. The LMB rocks are the metamorphic expression of the collision and welding together of the Kaapvaal craton and the Zimbabwe craton. The LMB has a long and complex history of deformation occurring from 3200 Ma (million years ago) to 2000 Ma. The LMB gneisses are made up of inter-cratonic sediments and volcanics, deformed and metamorphosed to granulite facies and intruded by granite bodies which have themselves been metamorphosed to varying degrees. The rift fault systems controlling the various basins, in which the Soutpansberg and Karoo strata have been preserved, are major zones of crustal weakness preferentially re-activated during periods of tectonic instability over time.

ii) The Karoo Sequence strata were deposited on LMB basement between 300 – 180 Ma. Karoo deposits are preserved in rift basins and are often terminated against major east-west trending faults on their northern margins. The dips are between 3° and 20° to the north with coal located at the base of the sequence. The nature of the coal deposits changes from a multi-seam coal-mudstone association (7 seams) approximately 40m thick in the west (Mopane Coalfield), to two thick seams in the east (Pafuri Coalfield in the Tshikondeni area).

3.5.2 COAL DISTRIBUTION OF THE SOUTPANSBERG COALFIELD

The Mopane Colliery Project lies within the Soutpansberg Coalfield which stretches for ± 190km from Waterpoort in the west to the Kruger National Park in the east.

The Soutpansberg Coalfield has been divided into 3 separate coal fields i.e. the Mopane Coalfield, the Tshipise Coalfield and the Pafuri Coalfield.

The Pafuri Coalfield terminates at the northern limit of the Kruger National Park in the east and is not part of this study.

The Mopane and Tshipise Coal fields are host to several CoAL mining projects at an advanced stage of development (Figure 8).

- The Mopane Coalfield, lies between the towns of Mopane and Waterpoort in the west and is the target of 2 mining projects;
  i) The Chapudi Project
  ii) The Mopane Project

- The Tshipise Coalfield, stretching east of the town of Mopane to Tshipise and is the target of 2 mining projects;
  i) The Makhado Project
  ii) The Generaal Project

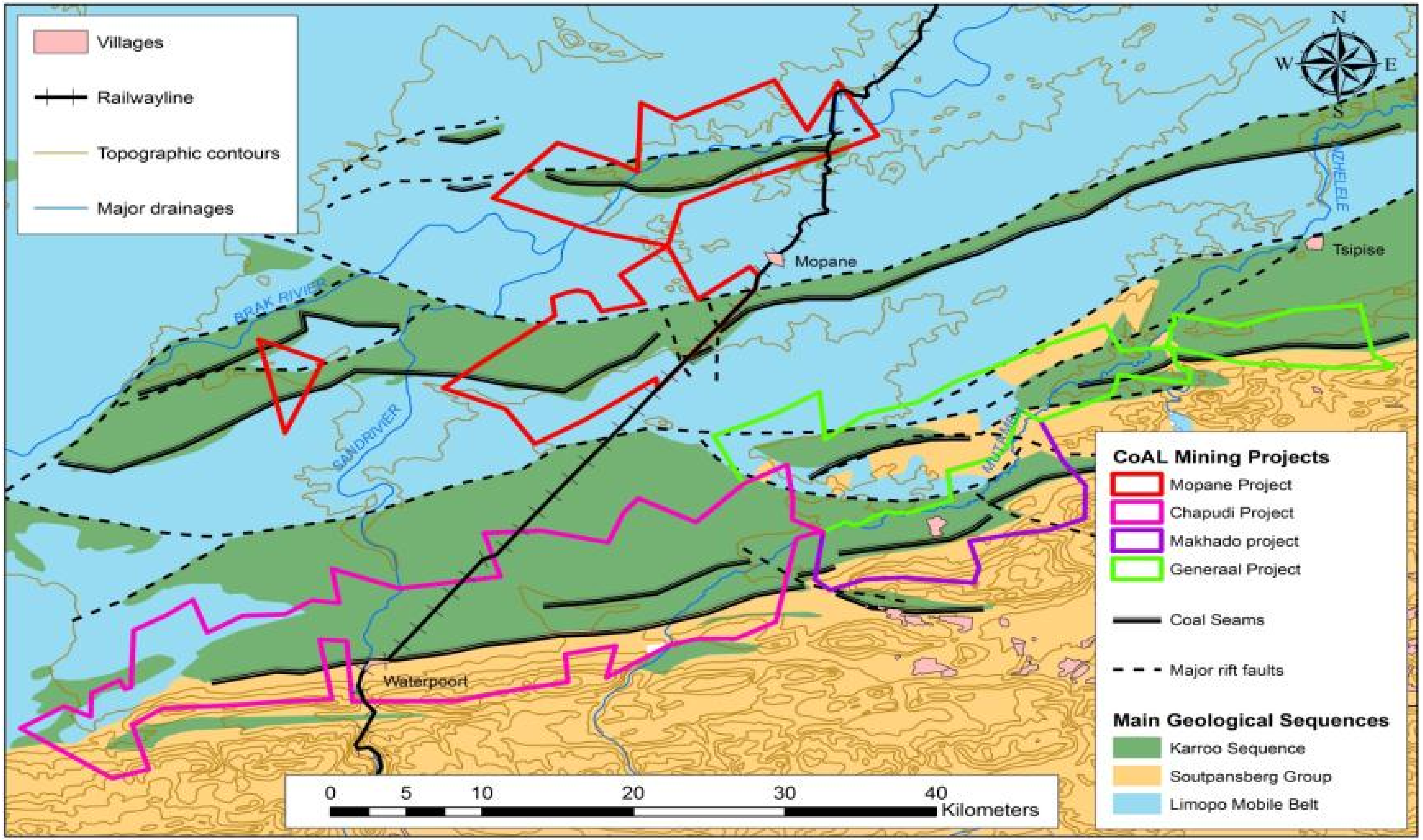


FIGURE 8: REGIONAL GEOLOGY OF COAL MINING PROJECTS WITHIN THE SOUTPANSBERG COALFIELD

3.5.3 MOPANE PROJECT GEOLOGY

The Mopane Project consists of the Voorburg Section and the Jutland Section where Karoo sediments have been deposited directly onto gneissic basement and preserved in two separate fault bounded basins. For purposes of representation the Karoo Sequence is divided into Lower Karoo, Middle Karoo (includes the fluvial Cave Member, of the Clarens Formation) the upper Karoo (Aeolian member of the Clarens Formation) and the Letaba basalts. See Figure 9 for the detailed geological map and Figure 10 for a geological cross-section.

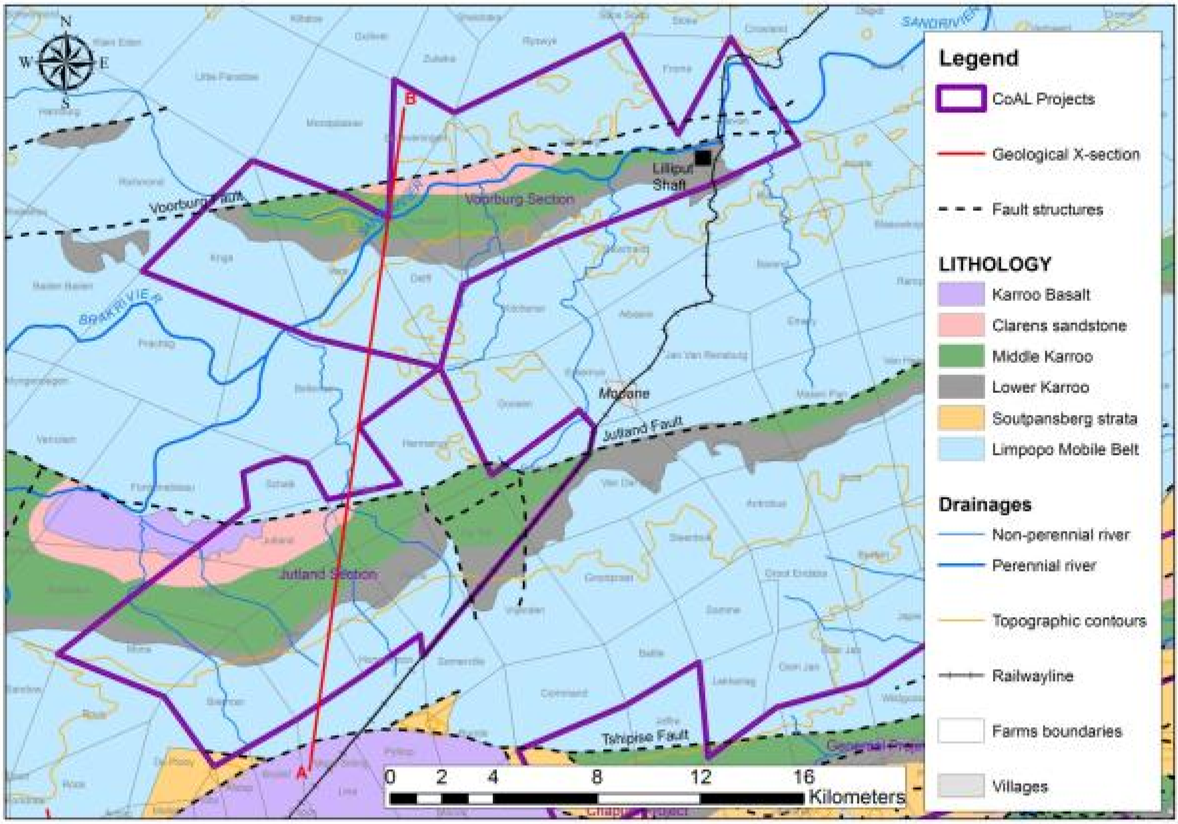


FIGURE 9: MOPANE MINING PROJECT GEOLOGY.

FIGURE 10: MOPANE MINING PROJECT GEOLOGICAL CROSS-SECTION

The Lower Karoo consists of a basal glacial deposit overlain by carbonaceous and coaliferous mudstones. From oldest to youngest the stratigraphy is as follows;

(i) *Tshidzi Formation* is a 10m thick basal conglomerate/diamictite and can be correlated to glacial Dwyka Tillite in the main Karoo basin.

(ii) *The Madzoringwe Formation* is a succession of alternating black shale, micaceous sandstone, siltstones and inter-bedded coal seams attaining a thickness of 190m. The coals seams are of economic potential.

(iii) *The Mikambeni Formation* overlying the above consists of dark grey mudstone and shale with subordinate sandstone attaining an approximate thickness of 140m. The Madzoringwe and Mikambeni Formations can be correlated with the Ecca Group of the main Karoo basin.

The Middle Karoo consists of overlying fluvial deposits made up of sandstones and grey, purple and red mudstones. The stratigraphy is as follows:

i) *The Fripp Sandstone Formation* consists (10 – 20 m) of coarse feldspathic sandstone or “grit” and often forms a ridge on outcrop and marks a change from a mature meandering river depositional environment to a braided stream environment.

ii) *The Solitude Formation* is 110m thick inter-layered grey and purple shale with minor sandstone and grit intercalations.

iii) *The Klopperfontein Formation* (10 – 20 m) resembles the Fripp Sandstone Formation and is a coarse, feldspathic “gritty” sandstone.

iv) The overlying *Bosbokpoort Formation* consists of red very fine sandstone and dark red silty mudstone.

v) The fluviatile *Red Rocks Member* (150 m) of the overlying Clarens Formation is also placed in the Middle Karoo strata.

The upper Karoo comprises the *Tshipise Member* (150 m) of the Clarens Formation which caps the underlying fluvial sediments with aeolian sands and is the terminal phase of Karoo sedimentary deposition in an ever increasing arid environment.

The Letaba basalt ends Karoo Sequence deposition with widespread outpouring of continental lavas, heralding a period of tectonic instability and the start of the break-up of Gondwanaland. Dolerite sills and dykes served as feeders to the basalt lava and are the hyperbyssal component of this event.

The Jutland Section.

The complete package of Karoo sequence strata from the basalts to the basal tillite is preserved in this half graben. Clarens sandstone forms prominent hills, surrounded by flat plains consisting of basalt to the north and mudstone to the south. The general dip is 10º - 12º to the north, terminating against a regional rift fault (Jutland or Bosbokpoort Fault) along the northern margin.

The Voorburg Section.

The complete Karoo sedimentary package (no basalt) is preserved in this half graben basin. The Fripp Formation forms a small flat topped ridge into which the Lilliput Shaft was excavated (Figure 9).

The sediments are again truncated along its’ northern margin by a WSW trending rift fault (Voorburg fault) with a down-throw of approximately 1,000m to the south.

The strata on average dip at 5°N. Of all the exploration holes drilled in the past to present, only one hole intersected dolerite.

3.5.4 IMPACT ON HYDROGEOLOGY

Groundwater flow for most of the study area is in a northward direction to the Sand River which abuts against the Voorburg fault and then flows eastwards. Groundwater is on average high in salt content indicating the arid climate and which may increase when in contact with upper Karoo strata. The study area can be regarded as having a low groundwater potential for the following reasons;

i) low rainfall and therefore poor recharge,

ii) Shallow weathering of the LMB gneisses. The LMB is exposed on the up-thrown block of a horst/graben set resulting in the removal of unconsolidated or weathered material from the elevated block.

iii) relatively undisturbed / un-fractured Karoo strata away from the major faults

Higher yielding boreholes are found along the faults and in the alluvial deposits. The Primary Alluvial Aquifer is utilized on a commercial basis by irrigation farmers along the Sand River where the alluvium is deep enough to store abstractable quantities. Good alluvial deposits often coincide with Karoo strata where the terrain is flatter and more conducive to alluvial deposition. The Karoo shale also produces a loamy to clayey soil more suitable for crops.

4. DATA COLLECTION

4.1 HYDROCENSUS

A borehole census was conducted on the mining right application area and adjacent farms. The farms include; Ancaster, Banff, Delft, Voorburg, Zwartrand, Ryswyk, Erasmus, Du Toit, Erasmus, Faure, Verdun, Hermanus, Goosen, Pretorius, Vera, Jutland, Sonskyn, Cohen, Honeymoon, Valharden and Vrienden. Where possible water levels were measured and abstraction information obtained. Water samples were taken for macro and micro chemical analysis. The borehole localities are indicated on Figure 11. The hydrocensus borehole data are summarized in Table 6.

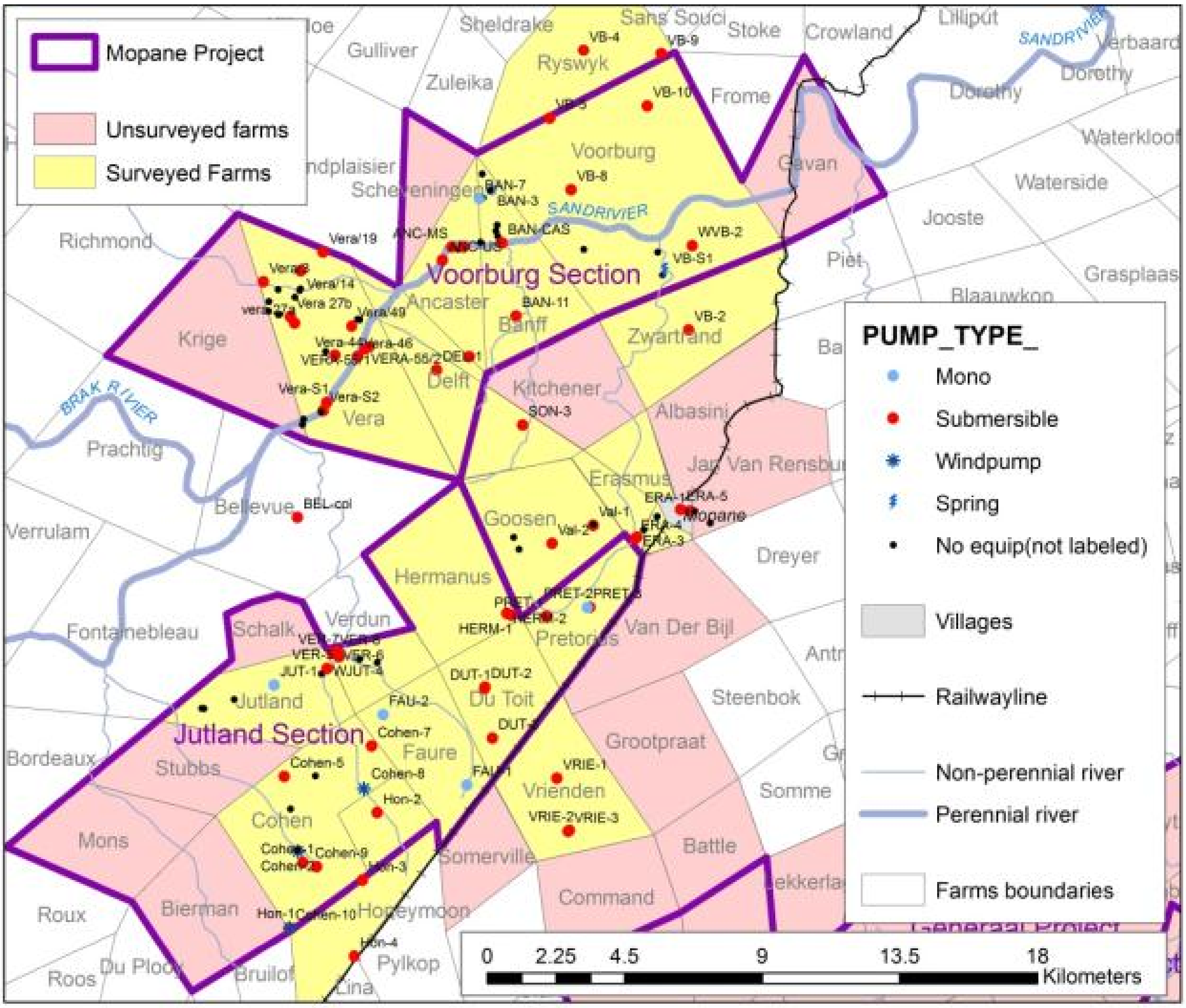


FIGURE 11: MOPANE PROJECT HYDROCENSUS BOREHOLE LOCALITIES

Table 6: Hydrocensus borehole data

	*	E-Electric/D-Diesel/W-Wind/N-None												
	**	S-Submersible/M-Mono/W-Windpump/F-Spring/N-None												

Farm	Borehole Number	Latitude	Longitude	Elevation	Date	DEPTH (m)	SWL (mbgl)	Est. Yield (l/s)	Pump Cycle	Method	Kl/day	EQUIPMENT Power Type*	EQUIPMENT Pump Type**	COMMENTS
Ancaster	ANC-1	-22.54415	29.79417	582	29/5/13		6.3			sensus	-	N	N	old borehole on the river bank
	ANC-2	-22.57338	29.79758	635	29/5/13		>27			sensus	-	E	S	small pump too weak to lift SWL >27m
	ANC-DS	-22.54358	29.79587	578	29/5/13	7	0.3	11.0	8.0	sensus	316.8	E	S	Sandpoint for irrigation(down stream)
	ANC-MS	-22.54358	29.79247	582	29/5/13	7	0.3	11.0	8.0	sensus	316.8	E	S	Sandpoint for irrigation(mid stream)
	ANC-US	-22.54715	29.78967	582	29/5/13	7	0.3	11.0	8.0	sensus	316.8	E	S	Sandpoint for irrigation(up stream)
Banf	BAN-1	-22.54068	29.80588	585	29/5/13		12.9	6.0		sensus		N	N	Open hole at house
	BAN-10	-22.53767	29.80572	586	29/5/13		12.8			sensus		N	N	Open hole
	BAN-11	-22.56225	29.81130	605	29/5/13		28.1	6.0		sensus		E	S	Irrigation
	BAN-2	-22.52368	29.80133	608	29/5/13		7.0			sensus		N	N	Dry borehole - SWL from seepage
	BAN-3	-22.52802	29.80405	598	29/5/13		-	3.0	8.0	sensus	86.4	M	D	Refurbishment of old hole -redrilled
	BAN-4	-22.52818	29.80372	599	29/5/13		12.9			sensus		N	N	Open. Pump removed
	BAN-5	-22.53020	29.80160	597	29/5/13		-			sensus		N	N	Pumphouse. Pump engine removed. Borehole collapsed
	BAN-6	-22.52978	29.80075	596	29/5/13		6.2	6.0		sensus		N	N	Pump, engine removed
	BAN-7	-22.53045	29.80045	595	29/5/13		6.8	8.0	8.0	sensus	230.4	D	M	Newly equipped borehole.
	BAN-8	-22.54232	29.80080	580	29/5/13		-	8.0		sensus		N	N	Alluvial water borehole
	BAN-9	-22.53925	29.80535	585	29/5/13		12.9			sensus		N	N	Open hole
	BAN-CAS	-22.54248	29.80720	578	29/5/13		3.2	20.0	8.0	sensus	576.0	E	Sx5	Well field of 5 of cassion pits in alluvium
Du Toit	DUT-1	-22.66345	29.80207	691	30/5/13		37.3	1.3	3.0	sensus	13.5	E	S	Cattle watering/vegetable garden
	DUT-2	-22.66302	29.80220	691	30/5/13		35.6	1.6	3.0	sensus	17.3	E	S	Cattle watering
	DUT-3	-22.67683	29.80435	706	30/5/13		-	1.6	2.0	sensus	11.5	E	S	Domestic supply
Erasmus	ERA-1	-22.61530	29.86245	673	30/5/13		32.8			sensus		E	S	Working order - poor quality. Sampled
	ERA-2	-22.61680	29.85275	662	30/5/13		14.3			sensus		N	N	Not working - salty
	ERA-3	-22.62233	29.84695	658	30/5/13		-	3.0	6.0	sensus	64.8	E	S	School supply(H18-0580)
	ERA-4	-22.62280	29.84637	659	30/5/13		-			sensus		E	S	School supply
	ERA-5	-22.61487	29.85967	672	30/5/13		25.2	0.5	4.0	sensus	7.2	E	S	Station supply
	ERA-6	-22.61533	29.86378	675	30/5/13		-			sensus		N	N	DWAF Monitor hole green(H18-0647)
	ERA-7	-22.61857	29.86832	686	30/5/13		-			sensus		N	N	DWAF hole yellow(H18-0646)
	ERA-8	-22.62038	29.84880	659	30/5/13		13.9			sensus		N	N	Not in use
Faure	FAU-1	-22.68958	29.79685	720	30/5/13		-	2.0	1.0	sensus	7.2	E	M	Working order - domestic supply
	FAU-2	-22.67053	29.77227	676	30/5/13		2.3			sensus		D	M	Unused
Verdun	VER-1	-22.65270	29.75895	660	30/5/13		3.6	0.5		sensus		N	N	open hole
	VER-10	-22.65642	29.77045	667	30/5/13		7.8			sensus		N	N	open
	VER-2	-22.65328	29.75865	660	30/5/13		3.1	2.2	3.0	sensus	23.8	E	S	Irrigation
	VER-3	-22.65405	29.75893	661	30/5/13		4.8	2.2	3.0	sensus	23.8	E	S	Irrigation
	VER-4	-22.65432	29.75908	662	30/5/13		5.8			sensus		N	N	Unused
	VER-5	-22.65487	29.75923	664	30/5/13		3.5	5.5	3.0	sensus	59.4	E	S	Irrigation
	VER-6	-22.65412	29.75865	660	30/5/13		2.5	2.2	3.0	sensus	23.8	E	S	Irrigation
	VER-7	-22.65367	29.75732	661	30/5/13		-	2.2	3.0	sensus	23.8	E	S	pumping at the time-irrigation
	VER-8	-22.65388	29.75767	660	30/5/13		8.2	2.2	3.0	sensus	23.8	E	S	pumped water level-irrigation
	VER-9	-22.65558	29.76525	664	30/5/13		1.5			sensus		N	N	
Pretorius	PRET-1	-22.64380	29.82018	676	31/5/13		?			sensus	30.0	E	S	game,pumps to goosen,sampled
	PRET-2	-22.64133	29.83293	673	31/5/13		-			sensus	15	E	S	cattle,game,domestic
	PRET-3	-22.64143	29.83219	673	31/5/13		?			sensus		D	M	Old Bh, not working
Hermanus	SON-1	-22.59163	29.81358	652	31/5/13		39.6			sensus		N	N	open hole
	SON-2	-22.59152	29.81322	653	31/5/13		39.8			sensus		N	N	open hole
	SON-3	-22.59187	29.81322	654	31/5/13		39.8	0.2	6.0	sensus	4.3	E	S	domestic supply
	HERM-1	-22.64348	29.80988	683	31/5/13		?	1.9	8.0	sensus	56.0	E	S	7000l, domestic, irrigation, sampled
	HERM-2	-22.64300	29.80861	684	31/5/13					sensus		E	S	Not working properly, game, sampled
Jutland	JUT-1	-22.66247	29.74020	689	15/05/12		40.0	0.3	8.0	Coal exp	8.6	D	M	Domestic supply. Over pumped
	WJUT-1	-22.66886	29.71952	657	15/05/12	120	16.0	0.2		Coal exp		N	N	Drilled for CoAL exploration water supply
	WJUT-2	-22.66880	29.71888	656	16/05/12	120	22.0	0.3		Coal exp		N	N	Drilled for CoAL exploration water supply
	WJUT-3	-22.65946	29.75400	665	20/05/12	90	-			Coal exp		N	N	Drilled for CoAL exploration water supply
	WJUT-4	-22.65802	29.75570	663	21/05/12	40	1.5	2.0	4.0	Coal exp	28.8	E	S	Drilled for CoAL exploration water supply
	WJUT-5	-22.66643	29.72838	673	22/05/12	120	22.0	0.2		Coal exp		N	N	Drilled for CoAL exploration water supply
Voorburg	VB-1	-22.54502	29.85293	574	27/03/12		10.2	0.2		sensus		N	N	Capped, not in use
	VB-2	-22.56602	29.86204	600	28/03/12		12.1	4.0	6.0	sensus	86.4	E	S	Supply to home/Voorburg camp/game watering points
	VB-3	-22.54423	29.83106	582	29/03/12		3.0			sensus		N	N	Exploration borehole
	VB-4	-22.49012	29.83106	627	29/03/12		-	0.1	10.0	sensus	3.6	E	S	Solar power
	VB-5	-22.50853	29.82117	622	11/09/13		1.6	0.1	10.0	sensus	3.6	E	S	Solar power/Game/sampled
	VB-6	-22.55109	29.85436	582	9/11/09	31	3.8	0.2		sensus		N	N	Access to borehole not permitted by owner.
	VB-8	-22.52793	29.82741	592	11/09/13		5.1	0.1	10.0	sensus	3.6	E	S	Game
	VB-9	-22.49102	29.85407	600	11/09/13		8.0	0.1	10.0	sensus	3.6	E	S	Game/sampled
	VB-10	-22.50523	29.84992	619	11/09/13			0.1	10.0	sensus	3.6	E	S	Game
	VB-S1	-22.55007	29.85493	580	27/03/12					sensus	86.0	N	N	Perrenial Spring
	WVB-1	-22.54319	29.86309	579	26/03/12	122	1.0	-		sensus		N	N	Borehole adjacent to spring
	WVB-2	-22.54319	29.86309	579	27/03/12	122	16.0	2.2	1.0	sensus	7.9	E	S	CoAL Exploration water supply now used for game.
Cohen	Cohen-1	-22.71066	29.74867	729	17/7/13		38.4	0.2	7.0	sensus	5.0	E	S	domestic, game
	Cohen-2	-22.70761	29.74719	717	17/7/13		19.8	0.1	8.0	sensus	2.9	W		game, wind pump
	Cohen-3	-22.70744	29.74694	716	17/7/13		19.7			sensus		N	N	domestic back up hole
	Cohen-4	-22.69615	29.74495	695	17/7/13		5.5	0.2	5.0	sensus	3.6	Solar	N	used only in dry seasons
	Cohen-5	-22.68723	29.74317	687	17/7/13		15.4	0.2	5.0	sensus	3.6	E	S	used only in dry seasons when dam level is low
	Cohen-6	-22.68707	29.75222	698	17/7/13		?			sensus		W	N	windpump,not in use, too salty, corrodes pipes
	Cohen-7	-22.67900	29.76892	687	17/7/13		37.5			sensus		E	S	Game, not in use, used when dam level is low
	Cohen-8	-22.69052	29.76662	703	17/7/13		23.9	0.1	8.0	sensus	2.5	W	W	windpump,game,low yielding, 2500l
	Cohen-9	-22.71175	29.75271	732	17/7/13		36.6			sensus		E	S	Back up domestic hole
	Cohen-10	-22.72840	29.74467	762	17/7/13		48.0			sensus	0.5	E	S	game, 500l, low yielding
Goosen	Goos-1	-22.62566	29.81210	684	17/7/13		?			sensus		N	N	Not in use, blocked
	Goos-2	-22.62241	29.81053	677	17/7/13		?			sensus		N	N	pump removed. Low yielding
Honeymoon	Hon-1	-22.72840	29.74467	762	17/7/13		?	0.1	8.0	sensus	2.0	W	W	Windpump,game
	Hon-2	-22.69715	29.77057	712	17/7/13		21.3			sensus	2.0	Solar	S	game
	Hon-3	-22.71541	29.76622	739	17/7/13		33.6			sensus	2.0	Solar	S	game,sampled
	Hon-4	-22.73607	29.76374	751	17/7/13		?			sensus	2.5	E	S	domestic, sampled
Vrienden	VRIE-1	-22.68774	29.82327	715	11/9/13		25.1	0.1	2.0	sensus	1.0	E	S	Game/domestic.
	VRIE-2	-22.70195	29.82698	731	11/9/13		33.2	0.1	2.0	sensus	1.0	E	S	Game
	VRIE-3	-22.70222	29.82652	730	11/9/13			0.1	2.0	sensus	1.0	E	S	Game
Bellevue	BEL-col	-22.61700	29.74700	637	12/06/13					Naledi sensus	5.0	E	S	Game watering
Delft	DEL-col	-22.57700	29.78800	627	12/06/13		2.0			Naledi sensus	548	E	S	Vegetables and Tobacco

Table 6: cont.……

Farm	Borehole Number	Latitude	Longitude	Elevation	Date	DEPTH (m)	SWL (mbgl)	Est. Yield (l/s)	Pump Cycle	Method	Kl/day	EQUIPMENT Power Type*	Pump Type**	COMMENTS
Vera/Johnson	VERA-55/1	-22.57063	29.76815	597	31/5/13		15.5	2.0	8.0	sensus	57.6	E	S	+/- irrigation
	VERA-55/2	-22.57128	29.76697	595	31/5/13		14.2	2.0	8.0	sensus	57.6	E	S	+/- irrigation
Vera/Maanda	Vera-51	-22.56332	29.76536	595	17/7/13		6.4			sensus		N	N	Not equipped, sampled
	Vera-51a	-22.56314	29.76472	596	17/7/13		11.4			sensus		N	N	Not equipped
Vera/Du Toit	Vera-44	-22.57300	29.758	606	17/7/13			3.0	8.0	sensus	86.4	E	S	point in sand river, domestic, sampled
	Vera-44a	-22.57198	29.75522	604	17/7/13		?			sensus		N	N	sealed, not in use
	Vera-46	-22.57334	29.76484	589	17/7/13			3.0	8.0	sensus	86.4	E	S	point in sand river, 8000l, irrigation, sampled
Vera/Maree	Vera/3	-22.55300	29.73700	617						Naledi sensus	20	E	S	Livestock/game
Vera/Steyn	Vera/14	-22.55000	29.74800	614						Naledi sensus	90	E	S	Household/irrigation
Vera/Marais	Vera/19	-22.54600	29.75500	618						Naledi sensus	70	E	S	Irrigation/sandpoints
Vera/Botha	Vera/49	-22.56500	29.76300	600						Naledi sensus	10	E	S	Household
Vera/Singh	Vera-S1	-22.58578	29.75562	596	17/7/13		3.3	0.2	8.0	sensus	6	E	S	Domestic, garden watering, sampled
	Vera-S2	-22.58796	29.75462	595	17/7/13			2.0	8.0	sensus	60	E	S	Point in sand river, pumps to neighbouring farm
	Vera-S3	-22.58842	29.75388	597	17/7/13		?			sensus		N	N	Not in use
Vera/ Hannekom	vera-5	-22.56185	29.74166	617	17/7/13		-			sensus		N	N	Blocked
	vera-5a	-22.56193	29.74138	616	17/7/13		-			sensus		N	N	Blocked
	vera-5b	-22.56095	29.73849	620	17/7/13		-			sensus		N	N	Blocked
	vera-4	-22.55836	29.73863	623	17/7/13		-			sensus		N	N	Blocked
	vera-4a	-22.55511	29.74130	614	17/7/13		-			sensus		N	N	Blocked
	vera-7	-22.55719	29.74619	615	17/7/13		-			sensus		N	N	Blocked
	vera-16	-22.55529	29.74762	610	17/7/13		-			sensus		N	N	Not in use
	vera-16a	-22.55494	29.74785	609	17/7/13		-			sensus		N	N	Blocked
	Vera 27b	-22.56249	29.74494	614	17/7/13		18.6			sensus	28	E	S	Irrigation, domestic (pumping in progress)
	vera 27a	-22.56417	29.74619	613	17/7/13		16.0			sensus	28	E	S	Irrigation, domestic (pumping in progress)
	vera-35	-22.59029	29.74876	599	17/7/13		5.8			sensus		N	N	Not in use
	vera-35a	-22.59185	29.74846	597	17/7/13		-			sensus		N	N	point in sand river, filled with sand
	vera-35b	-22.59029	29.74877	598	17/7/13		5.6			sensus		N	N	sampled, not in use
Valharden	Val-1	-22.61919	29.83389	626	17/7/13		?	0.2	3.0	sensus	2.2	E	S	domestic, game
	Val-2	-22.62410	29.82186	670	17/7/13		?			sensus		D	S	game
	Val-3	-22.61894	29.83392	656	17/7/13		?			sensus		W	N	old blocked hole, windpump

4.2 PIEZOMETRY AND GROUNDWATER FLOW

If the water table is undisturbed, the groundwater surface tends to mimic a subdued form of the topography. Water levels measured during the hydrocensus exhibited water levels ranging from 0-40 meters below ground level (mbgl). The water level data was colour coded according to set piezometric height ranges from which a piezometric contour map was drawn (see Figure 12).

Water levels are shallowest in the Sand River bed and tributaries with water tables lying just below the sand after the recent good rains in January 2013. Ancaster and Banff have well developed sand deposits (7m thick) and substantial abstraction for irrigation occurs from this section of the river. Water levels in the sands are lowered by 2 – 3m into the dry period but generally recover annually by the summer wet season.

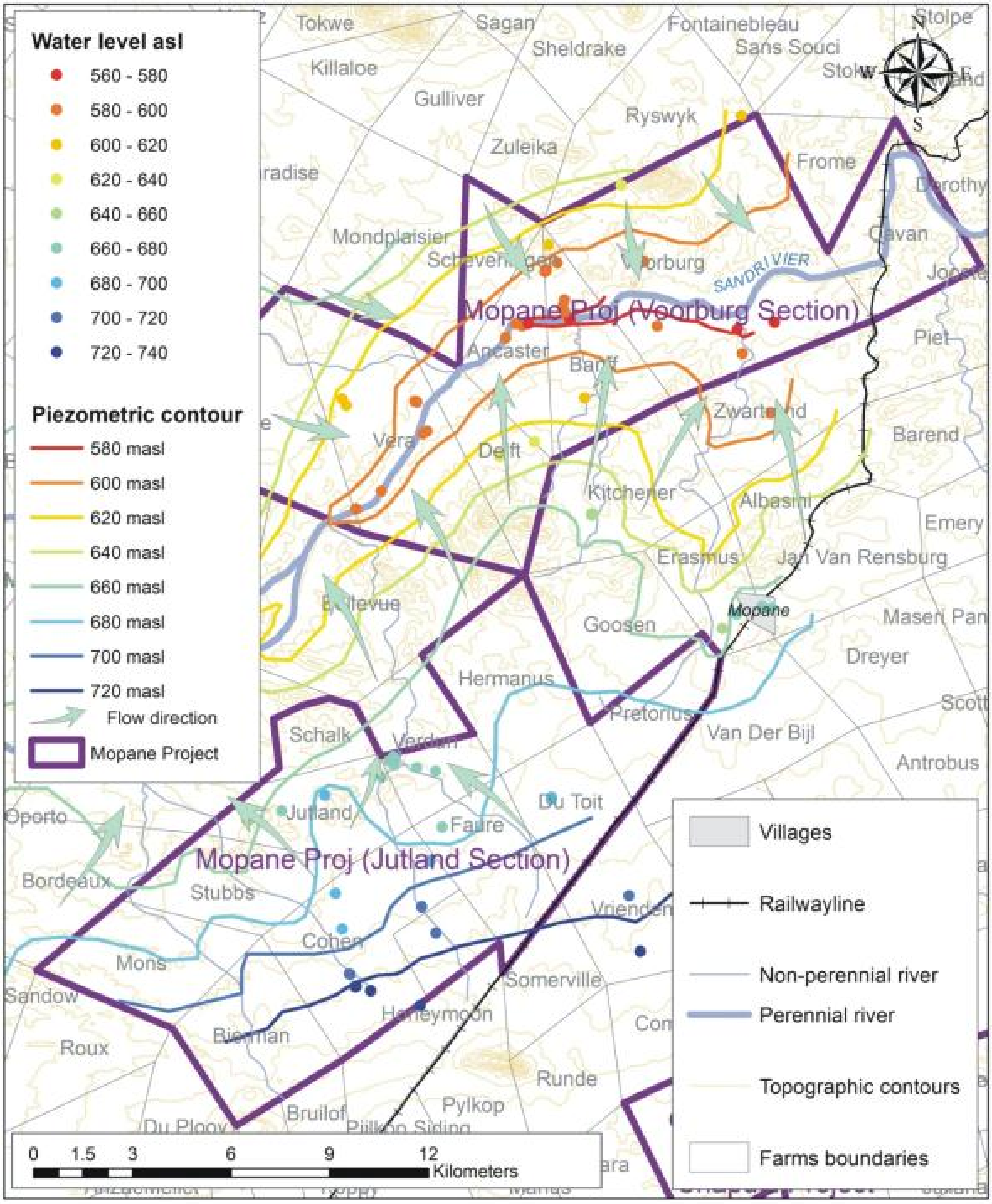


FIGURE 12: PIEZOMETRIC CONTOUR MAP SHOWING GENERAL GROUNDWATER FLOW DIRECTION

The water table as observed from water level data appears to be in an equilibrium state, under the current levels of abstraction. This is to be expected as the bulk of the abstraction is taken from the alluvial aquifer which is replenished each year by surface run off. The fractured aquifer is utilized mostly as a supplementary source of water for irrigation or for game and domestic supply requirements

Springs occur where the water table intersects the surface, usually along some structure. There is one known spring on Voorburg (Figure 11) with a yield of about 1 l/s.

4.3 GROUNDWATER QUALITY

Groundwater quality is dependent on the concentrations of soluble salts and the residence time of water within the host rock. Most of the water derived from secondary aquifers reflects the aridity of the study area with elevated salt content.

The data is presented with reference to the Water Quality Threshold (WQT) according to the Department of Water Affairs Water Quality Guidelines for Rivers and Streams as summarized in the table below, for the following water uses;

i Drinking water

ii Agriculture-irrigation

iii Agriculture-livestock

Macro chemistry

Table 7: DWAF Water Quality Threshold Classification – Macro chemistry

Species	pH	E.C	TDS	NO_3	F	SO4	Cl	Ca	Mg	Na
Unit		mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Drinking	6.0 - 9.0	150	1000	6	1	400	200	150	100	200
Agriculture (irrigation)	6.5 - 8.4	40	260	5	2		100			70
Agriculture (livestock)			1000	100	2	1000	1500	1000	500	2000

A total of 43 hydro-census samples were analysed for pH and major and micro elements. The chemistry results are listed in the table below. Concentrations exceeding the WQT for any of the above uses are marked in red.

Table 8: Macro chemistry results

BH No	Date	pH	E.C	TDS	NO_3	F	SO4	Cl	Ca	Mg	Na
ANC-US	29/05/13	7.4	183	1188	<1.4	0.2	153	331	97	64	181
ANC-DC	29/05/13	7.4	192	1249	2.9	0.3	160	365	119	75	167
ANC-MS	29/05/13	7.2	412	2678	31.2	0.2	362	895	267	167	342
BAN-1	28/05/13	7.1	809	5259	<1.4	0.2	444	2309	153	348	949
BAN-7	28/05/13	7.0	254	1651	12.5	1.4	134	356	92	137	256
BAN-CAS	11/12/12	7.6	944	6722	0.4	0.4	1516	2333	294	344	1270
BAN-CASX5	28/05/13	7.4	275	1788	3.6	0.3	325	534	79	89	387
BANF-11	19/11/12	7.1	683	4694	0.2	1.9	712	2048	395	48	1096
BANF-3	11/12/12	8	287	1816	18.0	1.2	173	480	84	132	337
BAN-MG	28/05/13	7.3	325	2113	<1.4	0.2	389	679	132	114	407
BAN-N	28/05/13	7.2	711	4622	<1.4	1.9	649	2017	468	47	1009
Cohen - 1	19/07/13	7.8	123	796	2.0	1.6	19	71	63	65	128
Cohen-8	19/07/13	7.1	359	2336	7.8	1.3	196	728	119	202	334
DOT-3	30/05/13	6.8	268	1742	6.2	0.8	174	456	128	115	244
DUT-2	30/05/13	6.8	234	1521	1.6	1.7	325	277	76	89	248
ERA-1	29/05/13	7.1	218	1417	33.9	0.5	109	192	101	148	133
ERA-2	29/05/13	6.9	445	2893	44.1	0.9	380	875	227	280	275
FAU-1	19/11/12	8.1	95	650	4.7	2.4	20	43	43	40	116
FAU-1	29/05/13	7.5	103	668	4.0	2.1	20	38	47	49	128
Herm-1	16/07/13	7.3	358	2324	4.0	1.1	482	644	156	178	349
Herm-2	15/07/13	7.2	367	2383	5.1	1.3	462	668	154	181	373
Hon-3	18/07/13	7.2	299	1941	3.6	2.0	127	388	65	119	443
Hon-4	18/07/13	7.0	171	1114	8.8	0.5	57	237	85	80	156
PRET-1	29/05/13	7.1	293	1905	32.4	2.2	134	376	74	181	287
PRET-2	29/05/13	6.8	297	1931	24.2	1.3	152	397	105	130	333
SON-3	30/05/13	7.0	119	770	23.8	0.4	26	58	78	80	68
Val-1	16/07/13	7.7	138	897	49.7	0.7	58	122	85	67	91
VB-1	3/04/12	7.7	402	2530	62.0	1.2	261	753	132	201	374
VB-2	3/04/12	7.5	298	1760	0.9	2.6	345	624	165	21	328
VB-5	11/09/13	8.5	166	1076					64	113	133
VB-7	18/11/11	7.24	1694	10223	3.7	0.7	742	3175	314	751	1451
VB-9	11/09/13	7.2	188	1221					103	83	196
VB-10	11/09/13	7.0	277	1803					124	176	233
WVB-2	3/04/12	7.5	389	2534	0.9	2.4	399	806	349	15	403
Vera - 44	17/07/13	7.7	326	2116	4.3	0.3	233	770	173	151	259
Vera - Singh	17/07/13	7.3	358	2327	4.0	1.2	504	634	161	183	359
Vera 35b	17/07/13	7.9	473	3076	<1.4	0.2	465	1136	43	297	533
Vera 51	16/07/13	7.0	75	485	<1.4	0.2	4	82	19	14	120
Vera-27a	16/07/13	7.6	378	2459	10.2	1.5	337	916	144	136	419
Vera-27b	17/07/13	7.6	332	2155	2.5	1.6	325	828	146	72	412
Vera-46	16/07/13	7.4	634	4121	2.4	0.6	377	1719	254	305	595
VER-5	28/05/13	7.8	116	755	3.0	1.4	58	99	21	44	168
VER-8	28/05/13	7.5	124	808	2.0	2.2	52	83	40	46	188
VERA-1	28/05/13	6.8	486	3159	36.0	0.9	547	915	177	335	331

The study area is characterized by predominantly poor groundwater quality typical of arid environments. Salt is also an inherent component of the Karoo strata with associated elevated TDS concentrations. A histogram showing the frequency distribution of TDS content for the three main geological units is provided below.

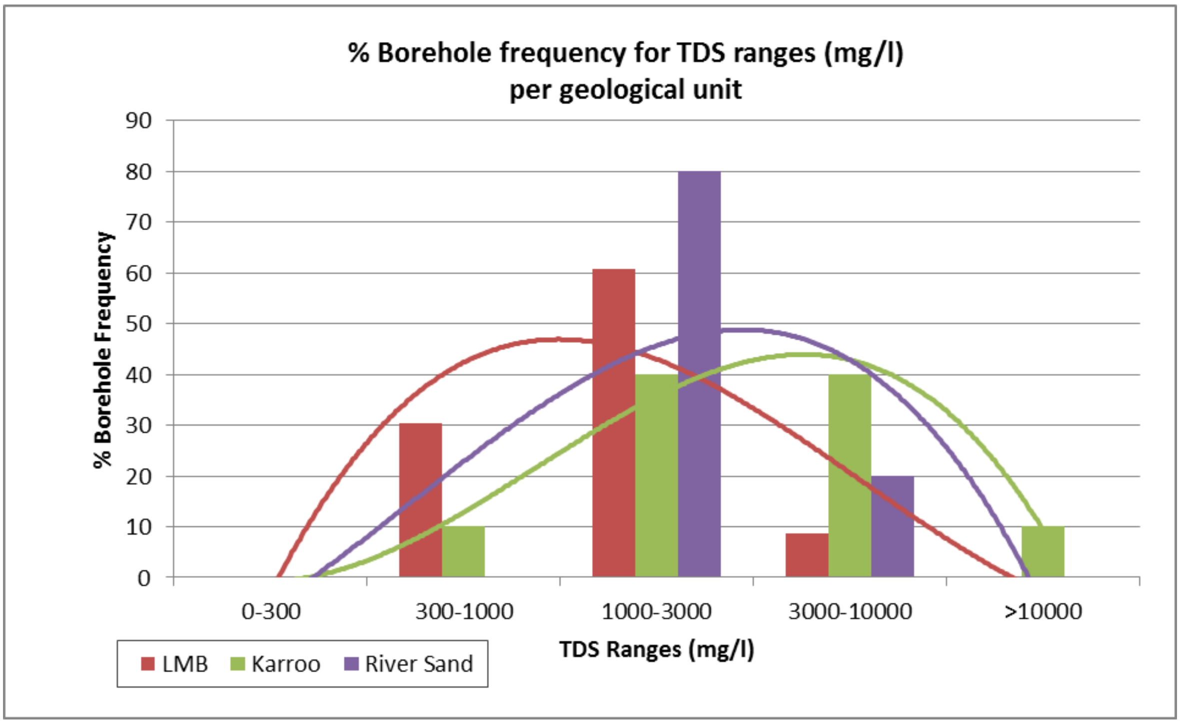


FIGURE 13: % FREQUENCY DISTRIBUTION OF TDS FOR THE 3 MAJOR ROCK TYPES.

Groundwater in the LMB gneisses have TDS concentrations that range between 300 to 3000 mg/l with a median of 1534 mg/l for the samples analysed. The Karoo strata exhibits higher TDS concentrations from 1000 to 10 000mg/l with a median of 2805 mg/l. Water quality in the river sand appears to mimic the Karoo water quality with a median TDS of 2185 mg/l. This supports the idea that groundwater and/or irrigation return water is recharging the river system. All the sand points and irrigated land in the data set is underlain by Karoo strata and is reflected in the river water chemistry. The TDS in the river sand varies according to the season with salt build up into the winter season and dilution from surface water after a flow event in summer. The samples taken at BAN-CAS exhibits this trend i.e. alluvial water taken from a caisson in the Sand River in 2012 with a TDS of 6722 mg/l showing a marked reduction in salinity levels (BAN-CASx5 at 1788 mg/l) since the recent floods in January 2013. Despite the recent floods the TDS content is still over a 1000 mg/l and is not ideal irrigation quality.

In an attempt to classify the groundwater of the study area the ratios of the macro elements were plotted on a Durov Diagram (Figure 14).

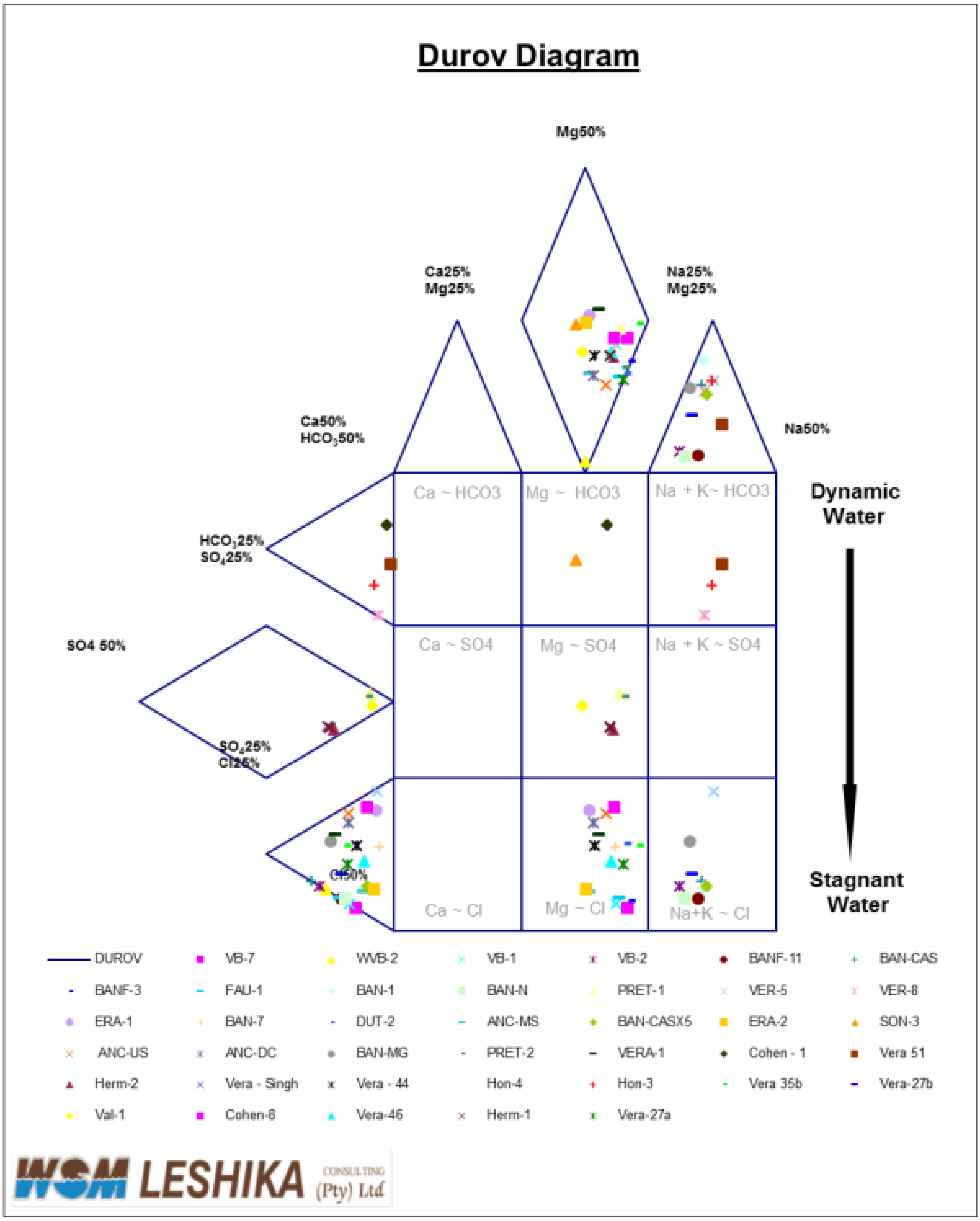


FIGURE 14: DUROV CLASSIFICATION OF WATER

The diagram indicates that most of the water sampled falls within the lower stagnant water or chloride-type block. The data was classified in terms of the expanded Durov diagram and plotted on the geology map.

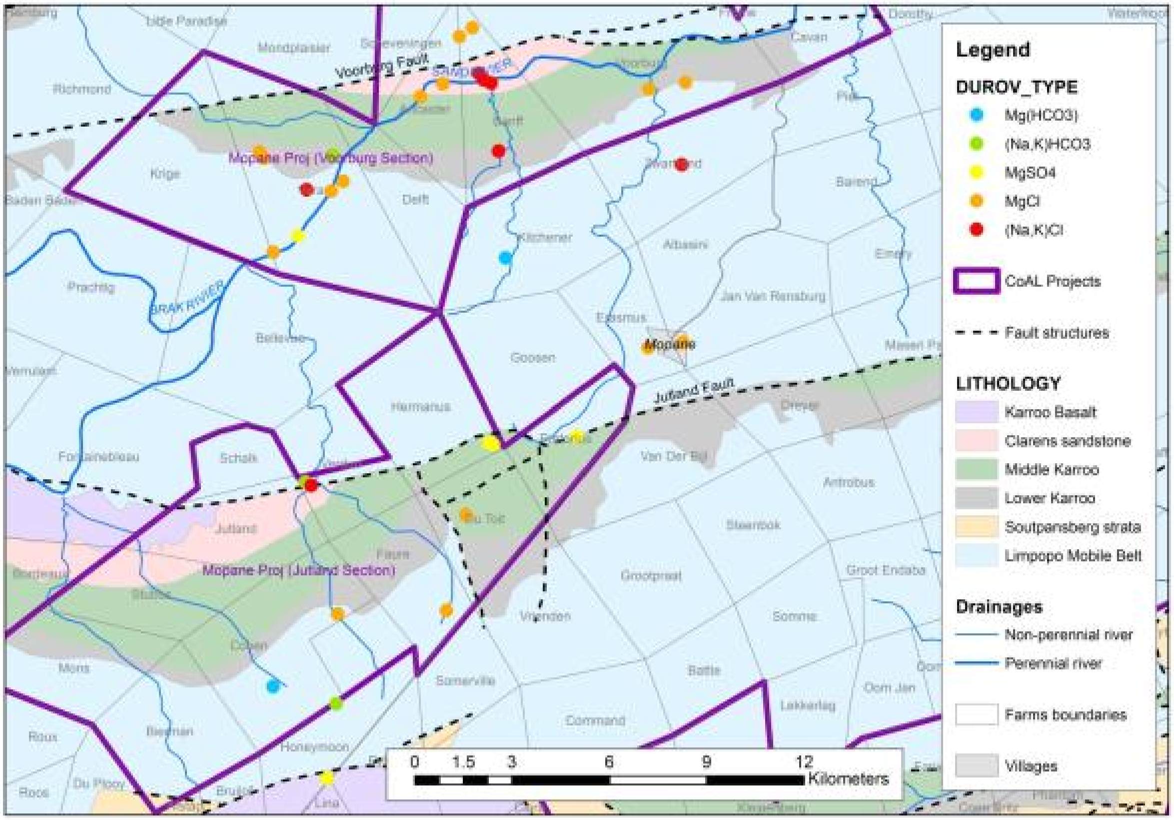


FIGURE 15: DUROV WATER TYPES PLOTTED ON THE GEOLOGY.

Although no direct correlation is apparent between the water types and the rocks, some observations can be made.

i) The water type in the alluvium is the same as that of the groundwater indicating that groundwater feeds the river system.

ii) HCO_3 and SO_4 type water is found along the major faults indicating higher flow rates and a more recent recharge component to the water.

iii) Away from the major structures the water is pervasively of the chloride type except for isolated pockets of bicarbonate water usually near the top of a sub-catchment or on catchment divides.

Microchemistry

Table 9: Micro-chemistry with DWAF-WQT Classification.

Specie	Al	As	B	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Se	V	Zn
Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Drinking	0.5	0.05		0.005		0.05	1,3	0.001	0.4			0.01	0.05	0.1	5
Agriculture (irrigation)	5	0.1	0.5	0.01	0.05	0.1	0.2		0.02	0.01	0.2	0.2	0.02	0.1	1
Agriculture (livestock)	5	1	5	0.01	1	1	0.5	0.001	10	0.01	1	0.1	0.05	1	20

Concentrations exceeding the WQT for any of the above uses are marked in red. It must be noted that concentrations exceeding the WQT are often below the detection limit for some elements.

Table 10: Micro-chemistry with DWAF-WQT Classification.

Specie	Al	As	B	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Se	V	Zn
Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
ANC-DC	0.01	<0.03	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.01	0.03
ANC-MS	<0.01	<0.03	0.16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	0.02	0.01	<0.01
ANC-US	<0.01	<0.03	0.18	<0.01	<0.01	<0.01	<0.01	<0.01	0.45	<0.05	<0.01	<0.09	<0.02	0.01	0.01
BAN-1	<0.01	<0.03	0.62	<0.01	<0.01	<0.01	<0.01	<0.01	0.37	<0.05	<0.01	<0.09	<0.01	<0.01	0.03
BAN-7	<0.01	<0.03	0.70	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	0.01	<0.09	<0.02	0.07	2.89
BAN-CAS	0.19	<0.010	0.93	0.20	<0.025	<0.025	<0.025	-	1.36	<0.025	<0.025	<0.020	0.04	<0.025	0.03
BAN-CASX5	<0.01	<0.03	0.44	<0.01	<0.01	<0.01	<0.01	<0.01	0.44	<0.05	<0.01	<0.09	0.03	0.01	0.01
BANF-11	0.16	<0.010	0.83	<0.005	<0.025	<0.025	<0.025	-	0.31	<0.025	<0.025	<0.020	<0.020	<0.025	0.14
BANF-3	0.13	<0.010	0.92	<0.005	<0.025	<0.025	0.04	-	<0.025	<0.025	<0.025	<0.020	0.02	0.05	<0.025
BANF-MC	<0.01	<0.03	0.33	<0.01	<0.01	<0.01	<0.01	<0.01	0.25	<0.05	<0.01	<0.09	<0.02	0.02	0.01
BANF-N	<0.01	<0.03	0.67	<0.01	<0.01	<0.01	0.06	<0.01	0.34	<0.05	<0.01	<0.09	<0.02	<0.01	0.21
Cohen - 1	<0.01	<0.03	0.24	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.02	0.01
Cohen-8	<0.01	<0.03	0.64	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.05	<0.01	<0.09	0.02	<0.01	0.08
DUT-2	<0.01	<0.03	0.55	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.05	0.01	<0.09	0.02	<0.01	0.01
ERA-1	<0.01	<0.03	0.50	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.04	0.02
ERA-2	0.01	<0.03	0.82	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	0.02	0.06	2.95
FAU-1	<0.01	<0.03	0.22	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.05	0.03
Herm-1	<0.01	<0.03	0.79	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	0.04	0.01	0.06
Herm-2	<0.01	<0.03	0.91	<0.01	<0.01	<0.01	0.10	<0.01	0.01	<0.05	0.02	<0.09	0.03	0.01	0.44
Hon-3	<0.01	<0.03	1.08	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.03	0.04
Hon-4	<0.01	<0.03	0.33	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	0.03	0.07	0.01
PRET-1	<0.01	<0.03	0.91	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.08	<0.01
PRET-2	0.01	<0.03	0.75	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.01	<0.01
SON-3	0.01	<0.03	0.15	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.04	<0.01
Val-1	<0.01	<0.03	0.18	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	0.02	0.05	0.01
VB-1	0.41	0.05	1.18	<0.005	<0.025	<0.025	<0.025	-	0.16	<0.025	<0.025	NA	0.03	<0.025	0.48
VB-2	0.49	0.05	0.68	<0.005	<0.025	<0.025	<0.025	-	0.14	<0.025	<0.025	NA	0.02	<0.025	1.36
VB-5	<0.01	<0.03	0.22	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02		
VB-9	<0.01	<0.03	0.32	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02		
VB-10	<0.01	<0.03	0.72	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02		
WVB-2	0.21	0.05	0.71	<0.005	<0.025	<0.025	<0.025	-	0.26	<0.025	<0.025	NA	0.02	<0.025	0.36
VER-5	<0.01	<0.03	0.30	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.09	0.05
VER-8	<0.01	<0.03	0.47	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.11	<0.01
Vera - 44	<0.01	<0.03	0.21	<0.01	<0.01	<0.01	<0.01	<0.01	0.30	<0.05	<0.01	<0.09	<0.02	0.02	0.01
Vera - Singh	0.02	<0.03	0.79	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.01	0.07
Vera 35b	<0.01	<0.03	0.84	<0.01	<0.01	<0.01	<0.01	<0.01	0.25	<0.05	<0.01	<0.09	<0.02	<0.01	<0.01
Vera 51	<0.01	<0.03	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	0.72	<0.05	<0.01	<0.09	0.02	<0.01	<0.01
VERA-1	<0.01	<0.03	1.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	0.02	0.08	<0.01
Vera-27a	<0.01	<0.03	0.67	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.03	0.01
Vera-27b	<0.01	<0.03	0.69	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.09	<0.02	0.01	0.01
Vera-46	0.01	<0.03	0.43	<0.01	<0.01	<0.01	<0.01	<0.01	0.08	<0.05	<0.01	<0.09	0.02	0.01	0.06

The microchemistry shows elevated boron in most samples analysed with significantly higher manganese associated with the alluvial water. High zinc concentrations occur in some boreholes located in the gneisses of the LMB.

4.4 GROUNDWATER USE

In the Mopane Mining Right Application area, irrigation is prevalent mostly along the Sand River where well developed alluvial sand deposits occur. The regional secondary aquifer is utilised mainly for household, stock and game watering.

For irrigation estimates where numbers were not provided by the farmers, the following assumptions were made;

- the irrigation requirement for cash crops in the area was taken as 7 880 m^3/ha/annum
- irrigation occurs throughout the year.
- that not all of the cleared land is under irrigation. The area of lands under irrigation is dependent on crop rotation and water availability and many lands lie fallow.

Abstraction quantities are regarded as conservative (i.e. an overestimation).

Voorburg Section

The groundwater abstraction within the Voorburg section is summarized in the table below.

Table 11: Voorburg Section: Groundwater use per farm

Project Section	Farm	Cleared land	Ha under irrigation	Water Use Kl/day	Water Use (Ml/ annum)	WARMS (Ml/ annum)	Assessment Method
Voorburg	Ancaster	84	35	755	276	276	sensus
	Banff	90	36	777	283	297	sensus
	Delft	77	40	863	315	99	sensus
	Vera	160	30	647	236	892	sensus
	Voorburg	-	-	76	28	80	sensus
	Krige	-	-	10	4	92	Inferred
	Cavan	-	-	5	2	-	Inferred
	Scheveningen	5	-	10	4	-	Inferred
	TOTAL	**416**	**141**	**3143**	**1147**	**1736**	

Ancaster; has approximately 84 ha of cleared land of which about 35 ha is irrigated for lucerne/grass for game. There was 8 abstraction points in the sand of which only three are working due to recent flood damage. Abstraction is quoted at 276 Ml/annum. There are no functional hard rock aquifer abstraction points (boreholes).

Banff; has approximately 90 ha of cleared land of which about 40 ha is currently under irrigation. Most of the water is derived from sand points and caissons in the Sand River bed although numerous fractured aquifer boreholes (some with good yields) have also been drilled which are being refurbished for future use. Abstraction currently is in the region 283 Ml/annum which will be steadily increased as the new owner re-develops the farm according to availability and water quality.

Delft: obtains its water from alluvial sands backed up behind a weir by means of a concrete well point at the base of the weir. The farm has 77 ha of cleared land of which about 40 ha is irrigated. The owner could not be contacted and an abstraction of 315 Ml/annum is estimated.

Vera; comprises numerous small plots with approximately 160 ha of cleared land of which about 30 ha was being irrigated at the time of the census. The crop consists mainly of annual cash crops. Based on the information provided by the 9 plot owners interviewed during the census, a total abstraction of 236 Ml per annum was determined.

Krige: has a registered use of 92 Ml/annum. No irrigation is apparent currently on the farm and therefore a 4 Ml/annum use is allocated.

Voorburg / Zwartrand / Ryswyk / Cavan: Data was collected during a baseline study on Voorburg in 2012. The farm has various low yielding, solar powered boreholes used as game watering points. There is a strong borehole (VB-2, tested at 7 l/s) on Zwartrand which provides water to the owner's farmhouse, to the Voorburg lodge and a few game watering points (43 Kl/day). The remaining 6 boreholes provide game water supply and are estimated to each abstract not more than Kl/day. Total groundwater abstraction for Voorburg / Ryswyk / Swartrand / Cavan farms is estimated at 28 Ml/annum.

Scheveningen; has 6 ha of cleared land lying fallow in the southern corner. Water usage is assumed to be 4 Ml/annum.

The total existing abstraction for the Voorburg section is thus estimated at a maximum of 1 147 Ml per annum most of which is abstracted from the alluvial deposits in the Sand River (1 110 Ml per annum).

Jutland Section

The groundwater abstraction within the Jutland Section Mine Application Area is summarized in the table below.

Table 12: Jutland Section; summary of groundwater use per farm

Project Section	Farm	Cleared land	Ha under irrigation	Water Use Kl/day	Water Use (Ml/ annum)	WARMS (Ml/ annum)	Assessment Method
Jutland	Bellevue	-	-	5	2	-	sensus
	Cohen	-	-	18	7	-	sensus
	Du Toit	-	-	42	15	-	sensus
	Erasmus	-	-	72	26	-	sensus
	Faure	-	-	2	1	-	sensus
	Hermanus	40	2	60	22	-	sensus
	Honeymoon	-	-	9	3	-	sensus
	Jutland	-	-	20	7		sensus
	Pretorius	-	-	45	16	-	sensus
	Verdun	6	6	178	65	4	sensus
	Vrienden	-	-	3	1	-	sensus
	Schalk	-	-	10	4	-	inferred
	Stubbs	-	-	10	4	-	inferred
	Mons	-	-	10	4	-	inferred
	Bierman	-	-	10	4	-	inferred
	TOTAL	**46**	**8**	**494**	**180**	**4**	

Bellevue; was evaluated in a preliminary census by Naledi. The farm has two functioning boreholes which provide water to the residents and to the game. An annual abstraction of 2 Ml/annum was estimated.

Cohen: A total of 10 boreholes were located on the farm of which 6 are in use. They supply water for household use and game and abstract approximately 7 Ml/annum.

Du Toit has 3 boreholes, two for cattle watering and a vegetable garden and 1 for domestic supply. An abstraction of 15 Ml/annum is estimated.

Erasmus/Jan van Rensburg: The town of Mopane straddles the boundary of Erasmus and Jan van Rensburg farms. One borehole (ERA-1) supplies the Boerevereniging clubhouse and auction venue. The water is of poor quality and is used for washing purposes only. An abstraction of not more than 1 Kl/day is inferred.

Borehole ERA-2 supplies water to the occupants of the railway houses at the Mopane station and to the limestone mine. The mine and the houses use about 3 – 5 Kl/day according to one of the station residents.

The Mopane Intermediate School is supplied by ERA-3 and 4 and has an approximate daily use of 50 Kl/day.

The total estimated use for the two farms is approximately 26 Ml/annum.

Faure: is a game farm with 1 functional borehole and an unequipped but strong hole at the northern end of the farm. The equipped hole provides household supply of about 2 Kl/day or 1 Ml/annum.

Hermanus: has about 42.5ha of cleared lands of which about 2.2ha is under citrus trees. The estimated water use is 22 Ml/annum.

Honeymoon; has 4 functional boreholes supplying domestic and game with water. The estimated water use is 3 Ml/annum.

Jutland; has two boreholes which supply to the owners residence. Estimated use is approximately 20 Kl/day or 7 Ml/annum.

Pretorius; has 2 functional boreholes. PRET-1 pumps 30 m^3/day to Goosen for game watering purposes. PRET-2 (15 Kl/day) is used for domestic and cattle watering. A total of 16 Ml/annum is abstracted.

Sonskyn; is a compilation of portions of Erasmus, Kitchner and Delft. There is only one functional borehole on the Kitchner portion, used for domestic supply (1.5 Kl/day) or 0.5 Ml /annum.

Verdun; has many boreholes all drilled along a major fault and abstracting from a fractured aquifer. 5 boreholes are equipped with submersible pumps which abstract about 1200 Kl/week or 65Ml/annum for irrigation of cash crops.

Vrienden; has 3 functioning borehole supplying water for domestic use and game and using about 1 Ml/annum.

Farms in the Jutland Section mine application area that were not surveyed for various reasons **(Schalk, Stubbs, Mons, Bierman)** have no cleared or cultivated lands and are therefore either game or cattle farms with low groundwater abstraction volumes. A conservative estimation of 4 Ml/annum abstraction per farm was allocated.

The total existing abstraction for the Jutland area is thus estimated at 180 Ml per annum abstracted from the secondary hard rock aquifers.

5. REGIONAL GROUNDWATER FLOW

To determine the orientation of groundwater flow on a regional scale, water levels were available from 965 boreholes. Historic data from 657 boreholes was obtained from the National Groundwater Database (NGDB), and the remainder were collected by hydrocensus during the study for Makhado mine and the present study. These data were converted to absolute water levels by determining borehole elevation from Google Earth. The MODFLOW model (section 6), was utilised to generate current water levels as a piezometric map (Figure 16). The Model was also utilised to generate a map of water level under virgin conditions (Figure 17).

Regional groundwater flow is oriented northeast towards the Limpopo River (Figure 17). Flow volumes are extremely low due to the low permeabilities and low recharge, especially in the northern half of the catchment underlain by the Limpopo Mobile Belt and overlain by alluvium.

In the south, where the catchment is underlain by Karoo and Soutpansberg rocks and where mining is proposed, a local northward hydraulic gradient is present due to high recharge in the Soutpansberg Mountains. A significant cone of depression exists around the Sand River directly north of the Soutpansberg Mountains due to the large scale irrigation from groundwater. Quantifying abstraction is problematic, since not all the lands are irrigated every year. Irrigation was estimated from lands identified as being irrigated on the most recent Google Earth images.

Under natural conditions, groundwater drains via localised springs, as baseflow to the perennial tributaries flowing from the Soutpansberg, and by evapotranspiration by riverine vegetation along the main river channels.

Groundwater is of good quality in the Soutpansberg rocks, which is the main recharge zone; however, increased salinity occurs northwards as groundwater flows through saline Karoo sediments, accumulating salts. Low recharge rates in the drier terrain north of the Soutpansberg also results in low recharge rates to dilute these salts. The movement of groundwater passing through saline deposits of the Karoo rocks, and subsequent evapotranspiration by riverine vegetation, causes a rapid salt accumulation northward, with a peak salt load along the fringes of the channels lying over Karoo rocks, like the Mutamba, the Brak and Sand Rivers, resulting in poor natural water quality.

The Mufungudi entering Nzhelele dam, the Kandanama River a tributary of the Mutamba River, entering the catchment in the south along the N1 highway, and the upper reaches of the Mutamba emerging from the Soutpansberg are perennial, but lose water to groundwater as they flow out of the Soutpansberg), becoming ephemeral. This water is abstracted by boreholes for irrigation on the farms Windhoek, Eckland and Overwinning along the Kandanama, and by irrigation boreholes along the Sand River on Sterkstroom, Sitapo, Sutherland and Waterpoort, or is utilized by riparian vegetation. Very little surface runoff is believed to recharge the regional aquifers north of the Soutpansberg, since high salinity levels in the Karoo aquifers suggest it is not recharged by fresh water from the river. In comparison, groundwater is of good quality in the Karoo aquifer along the southern tributaries such as the Kandanama River, where river losses take place. Isotope studies conducted during the Makhado investigation confirm this.

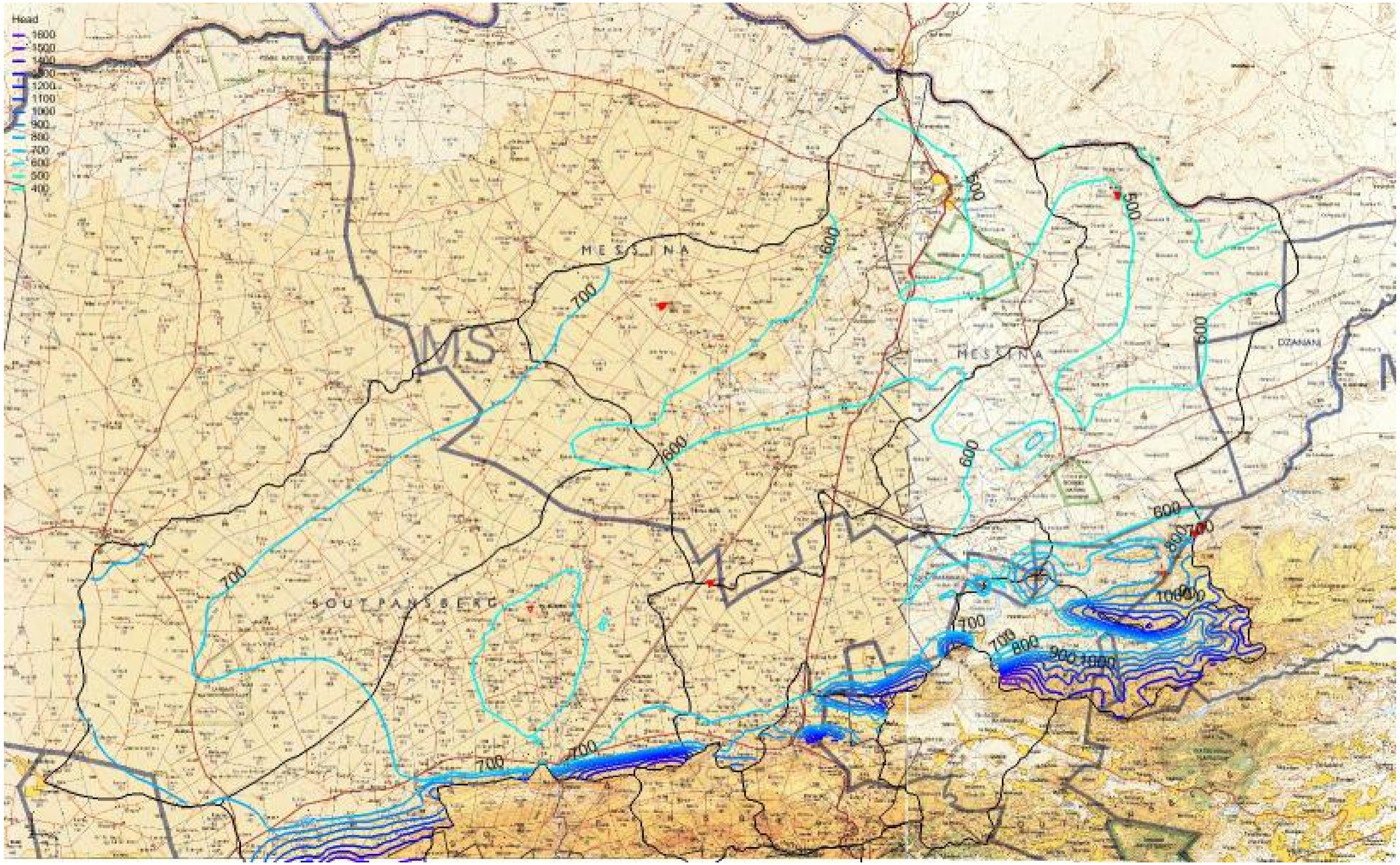


FIGURE 16: STEADY STATE WATER LEVELS UNDER CURRENT CONDITIONS (metres above mean sea level).

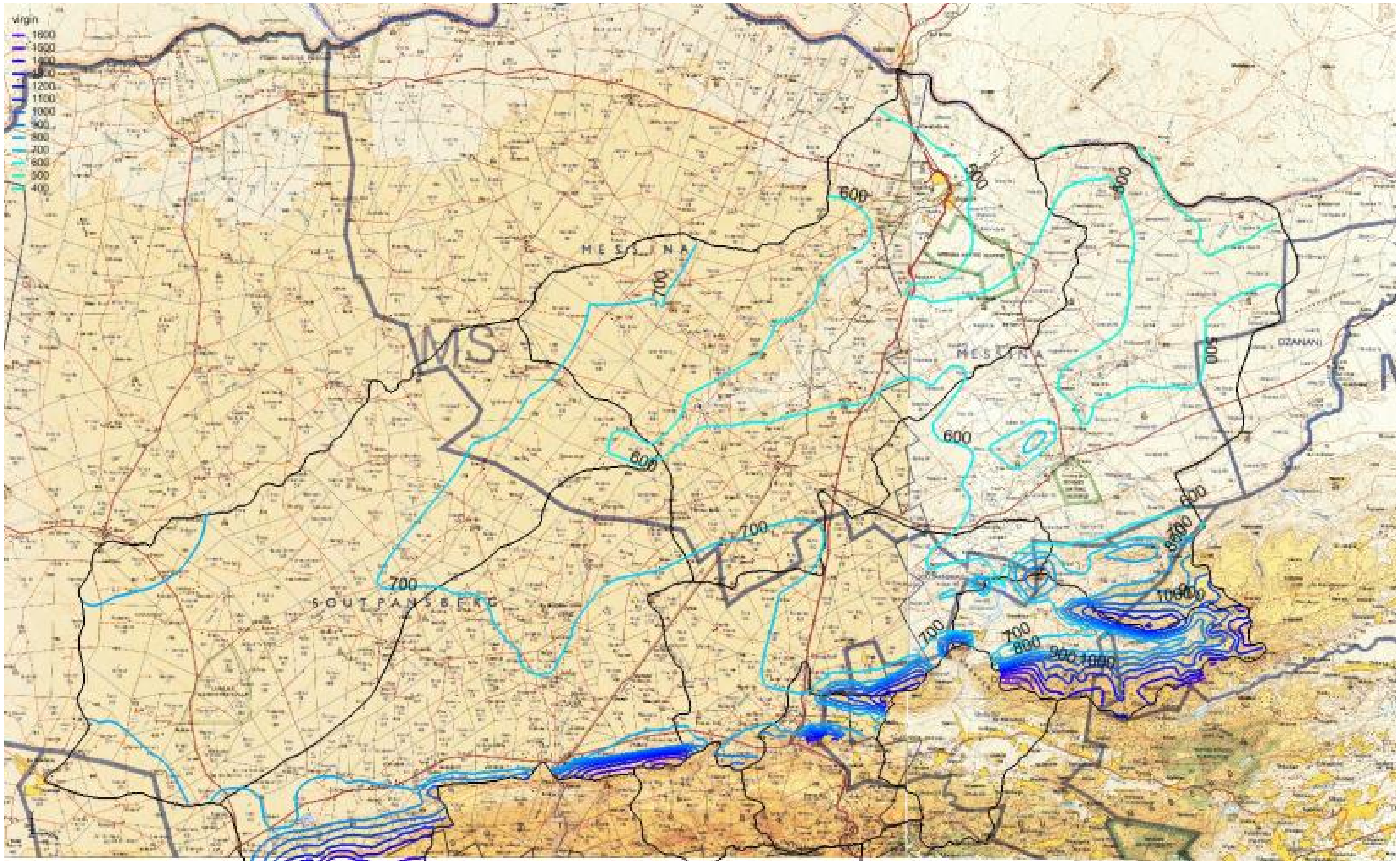


FIGURE 17: STEADY STATE WATER LEVELS UNDER VIRGIN CONDITIONS (METRES ABOVE MEAN SEA LEVEL).

6. GROUNDWATER FLOW MODEL

A numerical model was generated in order to quantify the impact of the proposed mine on the groundwater in the study area, and to determine inflows into the mine workings. Since many mines will be operated in conjunction, it was necessary to model a large area to determine cumulative impacts. The Makhado mine will be in operation before the Mopane project, and will impact on water levels. In addition, the Chapudi and Generaal projects will overlap with Mopane, hence all the projects must be considered in conjunction (see figure 18).

The USGS MODFLOW2000 Finite Difference groundwater model was used in the US Department of Defence GMS 9.0 (Groundwater Modelling System) interface to simulate and plot groundwater flow.

6.1 CONCEPTUAL MODEL

In every modelling study the natural system is represented by a conceptual model representing the best understanding of how the natural system operates. The development of a conceptual model includes identifying hydrogeological layers, boundaries and zones of similar properties that need to be differentiated. Subsequently, a numerical model is designed and constructed with equivalent but simplified conditions of the real world, in sufficient detail to meet the objectives of the modelling study and reproduce observed conditions. Transferring the real world situation into an equivalent conceptual model system, which can then be solved using existing program codes, is a crucial step in groundwater modelling. The following are considered in the development of a conceptual model:

- The known geological and hydrogeological features and characteristics of the area and their vertical and horizontal variations.
- The variations of permeabilities and storativities of the geological formations
- The recharge to the aquifers and its variability
- The static water levels/piezometric heads of the study area.

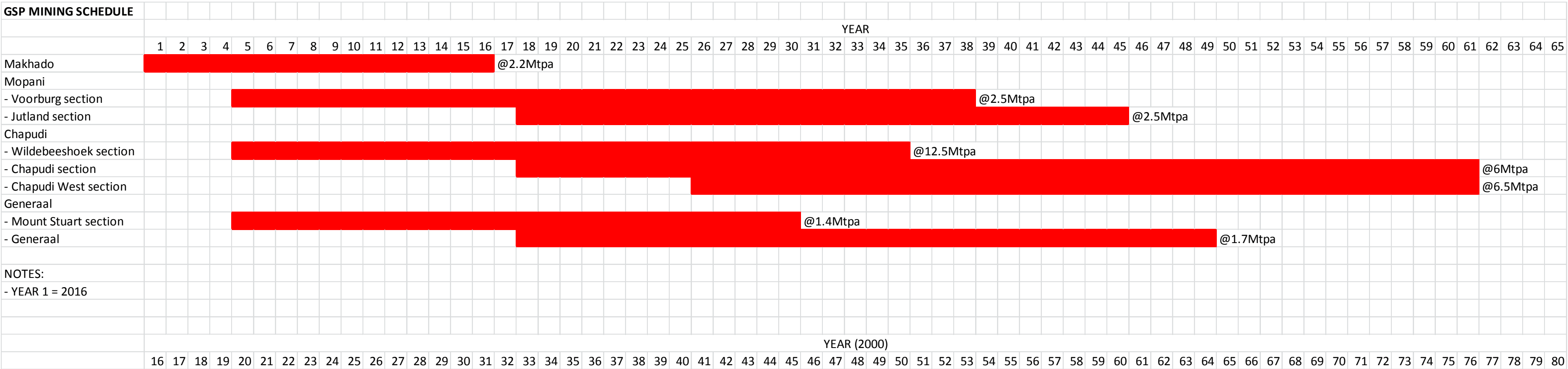


FIGURE 18: GSP MINING SCHEDULE

- The extent to which intended activities will interact with the geology and hydrogeology on the region so that the lateral and vertical boundaries of concern can be identified.
- The identification of the processes and interactions taking place within the study area that will influence the movement of groundwater, such as evapotranspiration from riverine zones, abstraction from boreholes, springs and baseflow to streams and rivers.
- Any simplifying assumptions necessary for the development of a numerical model and the selection of a suitable numerical code.

Due to the depth of mining (approximately 200 m) for the open pit mines and the dip of the strata, the model domain needs to be conceptualised as a 3 dimensional multilayer aquifer system, cut by fault zones. The faults need to be simulated using linear higher permeability zones, with major east north east permeable faults assigned a higher permeability than north south faults due to the tensional nature of ENE trending structures. These faults also need to be able to transmit water across the catchment boundary. However, due to such complexities and the large area covered by the GSP project and the number of mines in operation during the lifespan of the Mopane project, a regional 2 layer model was first developed to determine the cumulative impact of all the mines, from which local multi-layer models for each mine will later be developed once mining plans have been finalised.

Each geological formation was assigned its own permeability and storage parameters, and these were considered to decrease with depth due to reduced weathering and fracturing, hence the use of 2 layers, each 200 m thick, resulting in an aquifer depth of 400 m. Clastic sedimentary structures such as sandstones were assumed to have a more gradual decline in permeability with depth than non-clastic deposits like coal and mudstone. Basalts were given a high permeability due to the high yields of boreholes in basalt and the low hydraulic gradients present. Due to low borehole yields and the resistant nature of the rock, the mountainous region of the Soutpansberg was given a very low permeability.

Recharge was considered to vary, being lowest over the Karoo rocks due to low permeability mudstone layers, and slightly higher in the basalts and in Mobile Belt rocks overlain by Kalahari sands. Higher recharge in these zones was required to fit simulated water levels to observed water levels. The soils in the basalt are more permeable, and it is assumed the sand cover allows more percolation and less runoff, and allows rainwater to percolate below the evaporation zone. Recharge is significantly higher in the Soutpansberg outcrop areas due to higher rainfall and shallow soils.

Based on the observed hydraulic gradient, the aquifer was considered to discharge naturally towards the Nzhelele River, the Mufungudi, Kandanama and Nzhelele dam as baseflow, and via several springs identified on the geological map and in the field, and via evapotranspiration in the vicinity of the Mutamba, the Sand and the Brak Rivers and tributaries with significant alluvium, and in pans located north of the Soutpansberg in the western half of the study area.

In order to simulate interactions between surface and groundwater, perennial rivers were modelled as head dependent boundaries where perennial flow occurs. This implies that when aquifer water levels are above the level of the stream baseflow occurs, and when below, the river can recharge the aquifer. This allows boreholes and mining to increase losses from a river.

Water courses were considered as drains when the channels were ephemeral, and flowed only during major storm events, and considered not to recharge the aquifer. This allows baseflow for periods when aquifer levels are high, but not replenishment of the aquifer. Saline conditions in groundwater near ephemeral channels suggest that rivers do not recharge the aquifer, since dilution by fresher water from the river is not evident in the aquifer.

Rivers like the Sand, the Brak and the Mutamba contain significant alluvium, which is tapped in places by irrigators. These rivers were considered as drains, as river losses to the alluvium remains in the alluvium and is utilised by riverine vegetation and irrigators, and does not recharge the regional aquifer since hydraulic gradients are oriented towards the channels.

Where the rivers are perennial and where the alluvium is of a sandier and gravelly nature, good quality water in boreholes next to the river and the disappearance of flow in the river suggest the rivers recharge the aquifer. These lengths of river were treated as head dependent boundaries where water can flow from the river to the aquifer when groundwater levels are below the level of the river, and from the aquifer to the river when groundwater levels are above the level of the river.

It was considered necessary to include evapotranspiration to drain groundwater and prevent baseflow.

The reasons why these decisions were taken are the following:

- Without evapotranspiration, recharge to the aquifer would constantly induce groundwater discharge as baseflow under natural conditions. Natural recharge must discharge somewhere and the Mutamba, Sand, Brak and Nzhelele Rivers are the only receiving source in the catchment, however, they are ephemeral over much of their length.

- According to baseflow data in the GRAII (Groundwater Resource Assessment Phase II, a study commissioned by DWA), groundwater baseflow to surface water courses only exists along the Kandanama and Mufungudi, hence, natural recharge must be lost through riverine vegetation and spring discharge which is equal to at least the volume of recharge.

6.2 BOUNDARY CONDITIONS

The model domain is generally strongly influenced by boundary conditions. Boundaries control the flow direction and strongly influence the water balance of a numerical model; hence boundary conceptualisation is of critical importance.

Generally internal boundaries are fixed where known interchanges of water take place, and lateral boundaries should be sufficiently extended to zones where it is known no interchange takes place.

The model domain was envisaged as being a discrete interconnected unit bounded by various hydraulic boundaries:

- The catchment watershed containing all the Quaternary catchments where mining is planned was treated as a no flow boundary across which groundwater flow was assumed to be non-existent. The rationale behind this discretisation was that the interchange of water across the topographical divide is negligible. This served as the lateral boundary of the model domain.
- To avoid boundary condition problems, the model utilised a large model domain of 6605 km^2 (all of Quaternaries A71J and K, A72B, A80C, F and G, and part of A80E), well beyond the mining area to ensure impacts of mining would be within the model domain. It was necessary to include a portion of A80E, since that is the Quaternary catchment which contains the southern tributary of the Mutamba, and it flows into A80F.
- Major faults crossing the watershed and where major inflows are believed to occur, were treated as constant head boundaries, where the water level at the boundary is kept constant and water is allowed to enter or exit the system depending on head differences. These boundaries are sufficiently distant from the mine not to be impacted by water level drawdowns from mining. They occur where major faults enter the study area at Waterpoort along the Sand River, and along the Mutamba River at Masekwaspoort.
- The Nzhelele dam was treated as a constant head boundary
- Discharge to springs and pans were simulated using drains, which is a type of boundary that allows water to flow out of the aquifer when the water table is above the set elevation of the drain. The rate of drainage is dependent on the head difference between the elevation of the drain and the water table in that cell multiplied by the set drain conductivity. If the water table falls below the elevation of the drain, the drain dries up and discharge is terminated. Drain cells

were allocated where springs were identified. Drain conductivity was set between 0.01-1 m^2/day/m.

- The perennial Kandanama and Mufungudi rivers were treated as a head dependent river boundary, capable of discharging water to the aquifer, or receiving water, depending on the piezometric head in the aquifer in that cell. The Limpopo was also treated as a river boundary as the river recharges the alluvial sand aquifers located along its length. River conductance was calibrated to fit the water levels located adjacent to rivers, and ranged from 0.003-5 m^2/day/m.
- The ephemeral Nzhelele, Mutamba, Brak and Sand Rivers were treated as drains, capable of receiving water when groundwater levels exceed the base of the channel, but not contributing water to the aquifer. Drain conductance was 0.003-0.03, with smaller values along small tributaries.
- The alluvium along all the major channels were identified as green zones on Google Earth, were treated as an evaporation zone, where groundwater could be lost to vegetation. These were considered zones where evapotranspiration from groundwater occurs and were treated as head dependent boundaries where evapotranspiration occurs at a rate dependent on the aquifer water level. Evapotranspiration was allowed to occur to a depth of 4 m below the surface elevation. Significantly lower evapotranspiration was allowed outside these regions. Pans located at the foothills of the Soutpansberg, fed by runoff and seepage was also considered to be evaporation zones.
- Mine workings were treated as drain cells for all model layers where mining was taking place during the mining interval. Until mine plans are finalised, the pit footprint was assumed to be the drain, with depth progressing from surface to a depth of 200 m over the life of mine. The planned underground mine at Mount Stuart was treated as a drain in layer 2, progressing from surface to a depth of 400 m. This assumes inflows only take place at depth, and the upper layer is dewatered by water seeping down from surface to the lower layer. The drain conductance is equal to the coal conductivity, 0.05 m/d for open cast mines, and to 0.002 m/d for the underground mine. After mining stops the drains in the cells forming the pit were turned off, allowing water levels in the pit to recover.

- The elevation of linear boundaries, like the stream channels was interpolated from surface contours and linearly extrapolated.

Figure 19 shows the model domain, and the internal boundary conditions incorporated. Drainage channels were digitised from the topographic map, and are shown in green where considered ephemeral and as drains, and in blue where they are perennial and considered head dependant boundaries, capable of losing water to the aquifer.

Springs or fountains identified on the topographic and geological maps where treated as drains and are shown in green. Abstraction boreholes identified are shown as brown circles.

Topographic divides, which were considered no flow boundaries, across which groundwater does not flow, and served as the boundary of the model domain are shown as a black line.

Where faults cut across the model domain, allowing water to enter or leave the model domain, constant head boundaries were incorporated. These are shown in purple.

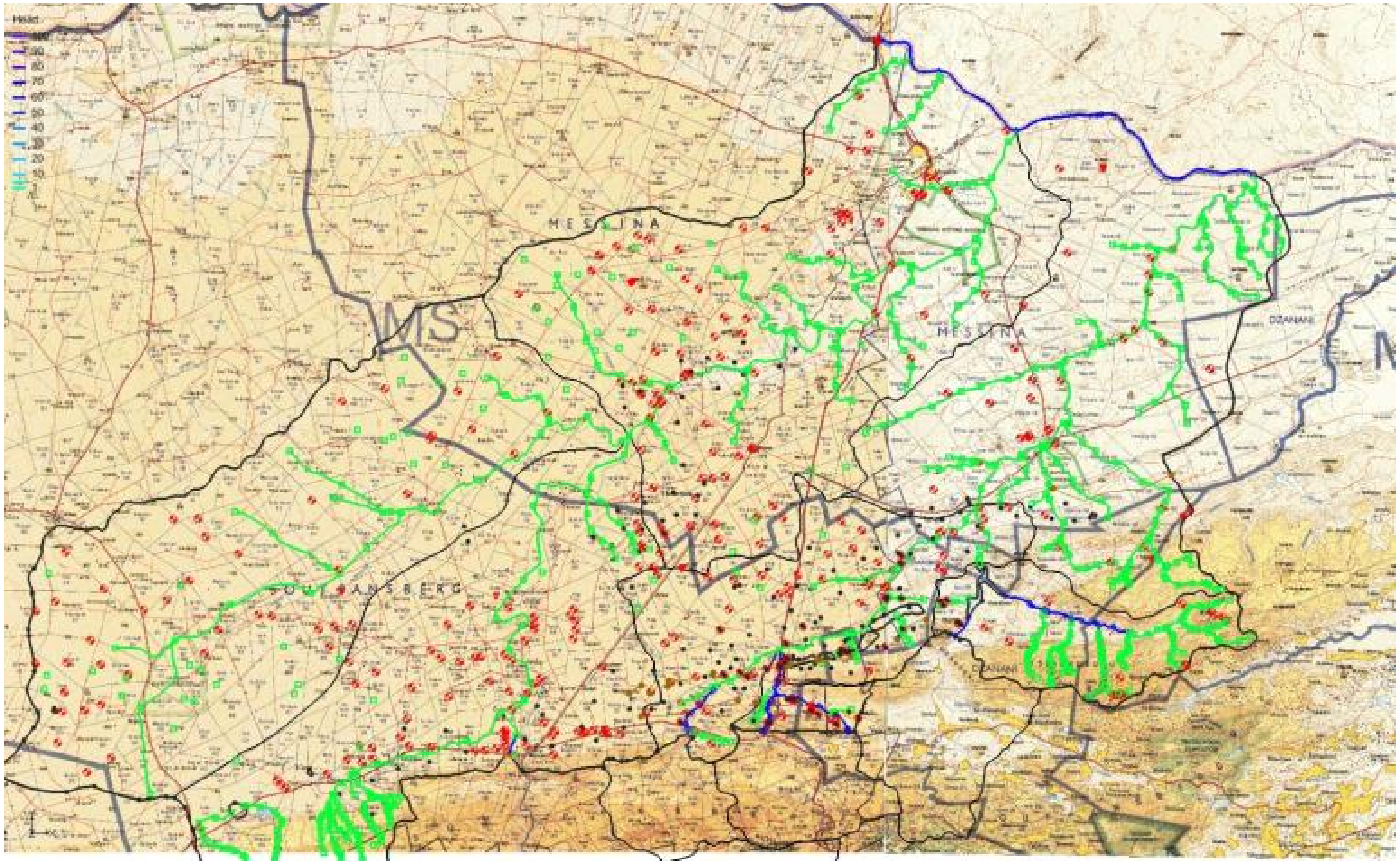


FIGURE 19: BOUNDARY CONDITIONS OF THE MODEL DOMAIN. BLUE = HEAD DEPENDENT RIVER, GREEN = DRAINS, BLACK = NO FLOW, PURPLE= CONSTANT HEAD, RED CIRCLES = EXISTING ABSTRACTION BOREHOLES

6.3 DISCRETISATION OF THE NUMERICAL MODEL

In a finite difference model the aquifer is represented by rectangular cell blocks and individual layers. Each cell is assigned a permeability, specific yield, specific storage, thickness and recharge parameter. Hydraulic heads in each cell of each layer and the exchange of water between cells and across boundaries is calculated simultaneously using finite difference mathematics until a finite solution is found within set convergence parameters. The model can be used to solve for heads under steady-state conditions, which are conditions that will occur when stability in water level and flow rates are reached, or for transient state conditions, which are flow rates and hydraulic heads that will exist after specific time intervals from an initial starting condition.

The regional aquifer was modelled as a 2 layer, 3 dimensional domain. Each layer was considered to be 200 m thick.

The grid was telescoped in the vicinity of the mining pits to provide greater resolution in zones where significant water level changes occur, as shown in Table 13.

Table 13: Grid development

	Base size (m)	Multiplier	Max. size (m)
Pits	100	1.5	1000

This results in cell sizes increasing outward from their base size by the multiplier up to the maximum size, giving a much finer resolution for head changes in the areas of interest, and in zones where steeper hydraulic gradients exist. For example, cells in the pits would be a minimum size of 100 x 100 m, increasing to 150 x 150 m, once outside the pit. The fine modelling interval allows the steep hydraulic gradients generated by dewatering to be represented. The domain was covered by 552 columns and 312 rows (Figure 20). The grid was oriented 65 degrees NE to be aligned with the orientation of rivers and major faults.

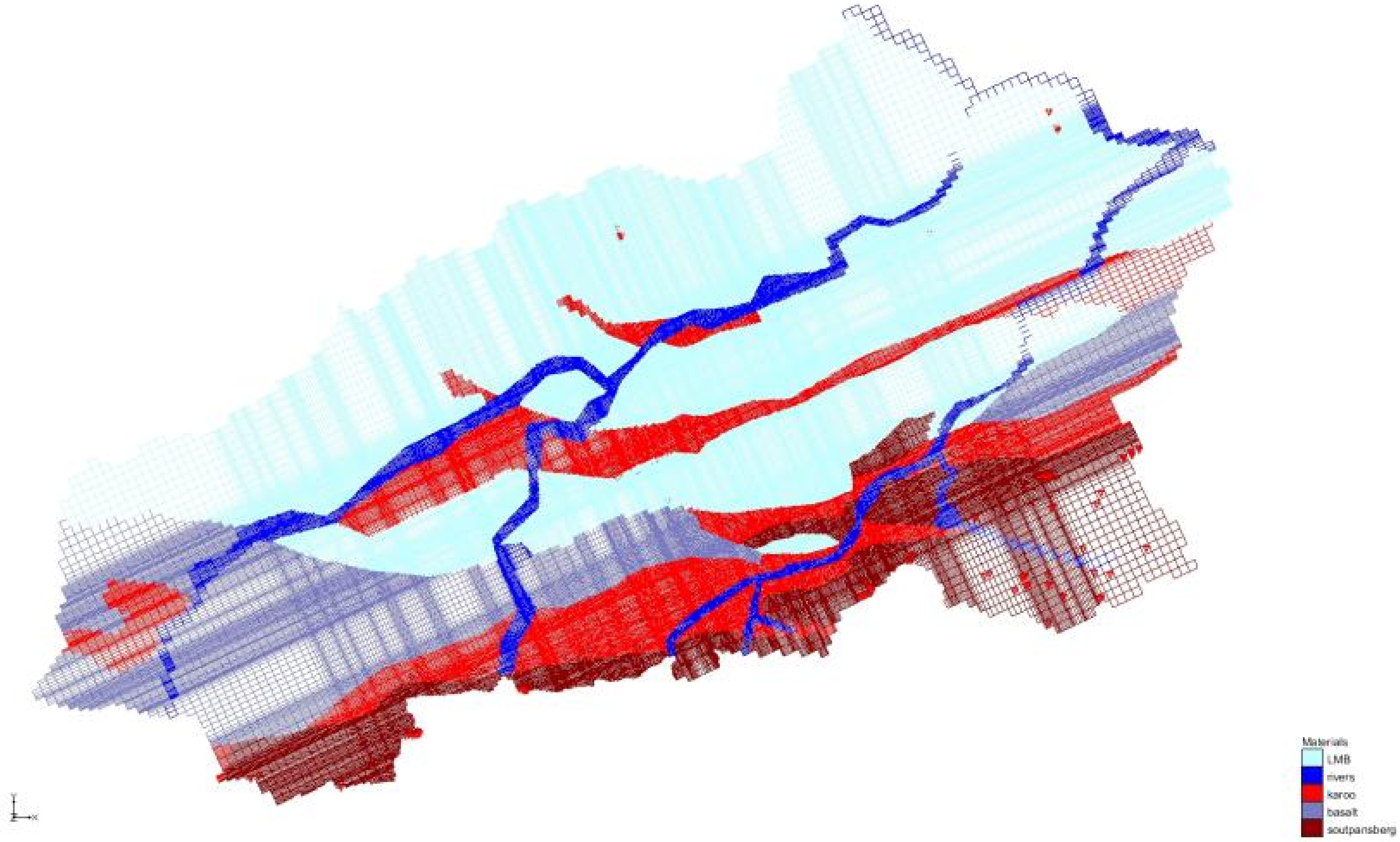


FIGURE 20: ACTIVE CELLS IN THE MODEL DOMAIN, CODED BY LITHOLOGY

The aquifer layer cells were set as confined, becoming unconfined when water levels dropped below the aquifer top. Horizontal anisotropy was set to 1 in the horizontal direction, meaning hydraulic conductivities are the same in the x and y plane, and 10 in the vertical direction, making vertical hydraulic conductivity 10% of the horizontal for flow between layers.

6.4 RECHARGE

Mean annual rainfall in the Quaternary catchments varies from 305-622 mm/a. Rainfall is significantly higher in the Soutpansberg and the catchments of the Kandanama and Mufungudi, hence recharge rates are highly variable, being high in the Soutpansberg, and lower to the north. Recharge also varies by geology due to the presence of low permeability mudstones in the Karoo and Kalahari sand cover in the north-western part of the study area, which reduces runoff and enhances recharge slightly. Recharge was simulated using a constant inflow into defined parameter zones and calibrated against borehole water levels in the steady state model. Recharge was higher in the Soutpansberg where higher rainfall and shallow soils occur and slightly less in regions of the Soutpansberg where vegetation indicates lower rainfall. Low recharge rates were applied to the plains north of the Soutpansberg.

Average recharge across the model domain is 4.7 mm/a, or 1.3% of rainfall. The recharge to the delineated recharge zones are shown in Table 14. Mine pits (brown were considered to have a high recharge of 255 mm/a post mining, declining to 73 mm/a after 3 years, then to 36 mm/a after 6 years (10% of rainfall) when rehabilitation is complete. Mine dumps were considered to grow from 0-3 years after start of mining, have a recharge rate of 73 mm/a, declining to 50 mm/a after the life of mine and rehabilitation.

Table 14: Recharge in mm/a

	Mining	Post mining	
		3 years	6 years
Mine pits	0	255	73
Soutpansberg, steep slopes, shallow soil	11-55	11	55
Soutpansberg, deeper soils	1-5	1-5	1-5
Karoo	0.5-6.5	0.5-6.5	0.5-6.5
Basalt	1.2-5	1.2-5	1.2-5
Limpopo Mobile Belt	1-6	1-6	1-6

6.5 EVAPOTRANSPIRATION

Evapotranspiration was assumed to occur from groundwater at a maximum rate of 5.5-25 mm/a) from evapotranspiration zones along rivers, if the water level was at surface, dropping linearly to zero if the water level dropped to 4 m below surface. Away from river channels the maximum evapotranspiration rate was set at 1.5 mm/a. The evapotranspiration rate was calibrated to ensure that no baseflow occurs in rivers known to be ephemeral.

6.6 GROUNDWATER ABSTRACTION

Groundwater abstraction was simulated by discharge boundaries in cells containing production boreholes. Groundwater abstraction was estimated from the DWA WARMS database of registered water use, and from a hydrocensus, however, it was found that the registered use of 46 Mm^3/a is much higher than recharge and that irrigated lands could not be observed to account for the registered water use. The following was concluded:

- The registered water use was not utilised every year
- Farmers along the Nzhelele scheme only utilise boreholes when surface water from the Nzhelele scheme isn't sufficient, hence don't utilise the entire registered use from groundwater
- Much of the groundwater use is from well points or caissons in alluvial sand, replenished during storm events and hence isn't abstraction from the regional aquifer.

Consequently the following resolution was undertaken:

- Irrigated lands were digitised from Google Earth as opposed to cleared irrigable lands in order to estimate water use. Water use was estimated at 7 880 m^3/ha/a due to the seasonal nature of crops.
- Lands located along channels where the hydrocensus indicated abstraction by caissons were not considered, as they assumed to utilise only alluvial water
- Lands along the Nzhelele had only a fraction of the estimated use met from boreholes
- Irrigation was only simulated during calibration if observed water levels in the NGDB were post 1985. The irrigation was subsequently turned on to derive present day water levels.

Actual water use was calculated as 6 Mm^3/a. In addition, the MODFLOW NWT package was utilised, which reduces borehole abstraction proportionally to keep water levels above a present level. A maximum water level of 100 metres below ground level was selected. The subsequent current groundwater abstraction simulated was 5.3 Mm^3/a.

6.7 PERMEABILITY AND STORAGE COEFFICIENTS

The surface elevation contours were utilised to form a TIN, from which the ground surface was derived. A 200 m depth below the surface was taken as model layer 1. The subsequent 200 m to a depth of 400 m was considered as layer 2. Permeabilities in m/day were assigned to geological zones (Table 15), differentiated by lithology, topography and the proximity to fault zones.

Permeability was calibrated to fit against observed water levels in a steady state model. Results of the packer tests undertaken in Karoo rocks and the coal also show that conductivities for layer 1 range from 0.003-0.08 m/day, which is within the range of calibrated values (Table 15).

Table 15: Hydraulic characteristics of layers

Layer	Permeability (m/d)	Transmissivity (m2/d)	Vertical anisotropy	Specific yield	Specific storage
Limpopo mobile belt					
Layer 1	0.001-0.009	0.2-1.8	10	0.001	0.00005
Layer 2	0.0005-0.001	0.1-0.2	10	$1.7x10^{-6}$	$1.7x10^{-8}$
Soutpansberg					
Layer 1	0.005-0.02	1-4	10	0.001	0.00005
Layer 2	0.001	0.2	10	$1.7x10^{-6}$	$1.7x10^{-8}$
Soutpansberg Range					
Layer 1	0.001-0.006	0.2-1.2	10	0.001	0.00005
Layer 2	0.0001-0.0005	0.02-0.1	10	$1.7x10^{-6}$	$1.7x10^{-8}$
Karoo					
Layer 1	0.03-0.08	6-16	10	0.001	0.00005
Layer 2	0.005	1	10	$1.7x10^{-6}$	$1.7x10^{-8}$
Clarens Formation					
Layer 1	0.02-0.05	4-10	10	0.001	0.00005
Layer 2	0.005	1	10	$1.7x10^{-6}$	$1.7x10^{-8}$
Basalt					
Layer 1	0.02-0.07	4-14	10	0.001	0.00005
Layer 2	0.005	1	10	$1.7x10^{-6}$	$1.7x10^{-8}$
Rivers					
Layer 1	0.06-0.08	12-16	10	0.001	0.00005
Layer 2	0.005	1	10	$1.7x10^{-6}$	$1.7x10^{-8}$

Mine fill					
Layer 1	1	200	10	0.1	0.0016

The specific yield value was calibrated from abstraction data collected during the bulk sample excavation of Makhado mine. The bulk sample pit was established over 60 days, during which pumped volumes to keep the cut dry were monitored. The elevation of the bottom of the bulk sample pit was set as a transient state drain in a 90 day transient state model. The specific yield was then calibrated so that inflows into the cut matched pumped volumes. The calibrated specific yield was adjusted downward, since the model layers in this simulation are 3 times thicker than those utilised as Makhado. The specific yield was calibrated so that similar pit inflows were derived for the Makhado mine pits in this study as in the Makhado modelling study.

6.8 HORIZONTAL BARRIERS

The presence of steeply dipping dolerite sills within the Karoo, which act as a low permeability barrier to northerly flow, was incorporated by using horizontal flow barriers. Observed water level differences of 20 m exist across this sill in the vicinity of Fripp. This was simulated as a horizontal flow barrier across both 4 layers. The barrier has a conductance value to restrict the flow of water across the barrier. The conductance value was calibrated to 5 x 10^{-6} to match water levels in observation boreholes on either side of the barrier.

Horizontal barriers were digitised into the model from existing geological maps. In the vicinity of the proposed mine, drilling data allowed the position of sills to be more accurately established.

6.9 INITIAL HEAD

In order to assess the transient state impact of mining on water levels and on the water balance, a model requires an initial hydraulic head distribution. This is usually achieved by calibration of a steady state model against observed water levels, which serves as the initial head distribution for the subsequent transient state model to simulate what will occur during mining and post-mining. Hence a steady state model is necessary prior to simulating impacts.

The simulated present day steady state flow model was assumed to represent pre-mining conditions with abstraction.

The resulting head distribution from the steady state model was used as the input into a transient state model starting in 2016 once mining begins and water levels begin to be affected.

6.10 MODEL SIMULATIONS

The simulations undertaken are shown in Table 16.

Table 16: Model simulations performed

Simulation	State	Time steps	Years	Purpose	Impacts
1	Steady			Model calibration,	Abstraction on farms with recent water levels
2	Steady	`		present day water levels	Addition of all abstraction
3	Transient	16	16	Impact of mining	Makhado life of mine, Voorburg, Jutland, Wildebeesthoek, Mount Stuart mine start ups
4	Transient	22	22	Impact of mining	Makhado closure and water level recovery, Voorburg, Wildebeesthoek, Mount

					Stuart life of mine, Generaal, Chapudi start up
5	Transient	11	11	Impact of Mining	Jutland, Chapudi and Generaal up to the closure of Generaal
6	Transient	17	12	Impact of Mining	Closure of all mines

6.11 MINING LEVELS AND INFLOWS

To simulate expected inflows, dewatering requirements and impacts on water levels, the pit extent were entered as drain polygons. The pit floor was linearly extrapolated from ground surface to 200 m depth over the life of the pit using a transient state drain elevation. The mining plan was utilised to determine the area being mined. Drain conductance was set at 0.05, similar to an average Karoo permeability.

Annual time steps were utilised to calculate inflows into the mine workings.

To simulate post mining water levels, the drain polygons were removed, allowing the workings to fill to the decant level, which was identified as the lowest point of the pit surface using Google Earth. Decant points were created by setting a high permeability drain at the appropriate location and elevation. The pit conductivity and specific yield were set as mining fill (Table 15).

Mine pits were considered to have a high recharge of 255 mm/a after being filled, declining to 73 mm/a after 3 years, then to 36 mm/a after 6 years (10% of rainfall) when rehabilitation is complete. Mine dumps were considered to grow from 0-3 years after start of mining, have a recharge rate of 73 mm/a, declining to 36 mm/a after the life of mine and rehabilitation.

6.12 MODEL CALIBRATION

Calibration is the process whereby model parameters and boundary conditions are systematically altered in numerous consecutive simulations until simulated groundwater levels and flows match observed field measurements to within an acceptable error margin. Calibration under known conditions is critical if the model is to be used to forecast scenarios for which no observed data is available.

The trial and error manual calibration method was utilised.

Calibration of the model was based on water levels in 965 observation boreholes identified in the original and subsequent hydrocensus, in the NGDB, and the GRIP database and newly drilled boreholes. 657 boreholes were historic water levels from the NGDB, while remainder were verified in the field from the Makhado and current hydrocensus surveys.

Water levels utilised for calibration were taken at various moments in time, especially from older boreholes in the NGDB, hence, depending on the date when borehole monitoring was undertaken, variations in water levels may exist. Some of the water levels were historic and considered un-impacted by recent abstraction, hence in the vicinity of these water levels, abstraction was excluded.

Measured water levels below ground surface had to be converted to absolute water levels in terms of metres above mean sea level (mamsl). Absolute calibration of water levels is hindered by the fact that errors exist in absolute observed water levels. These can be attributed to:

- Errors in borehole elevation obtained from Google Earth
- Errors in borehole position for historic NGDB boreholes
- Deviations in water level seasonally (± 3 m) due to the different times at which water levels were taken.

- Variations in pumping cycles and local impacts by abstraction on water levels

The results of the calibration are shown in Figures 21-23.Calibration statistics are:

Mean Residual (Head)	-1.367645824981
Mean Absolute Residual (Head)	9.3788558502275
Root Mean Squared Residual (Head)	14.497181873258

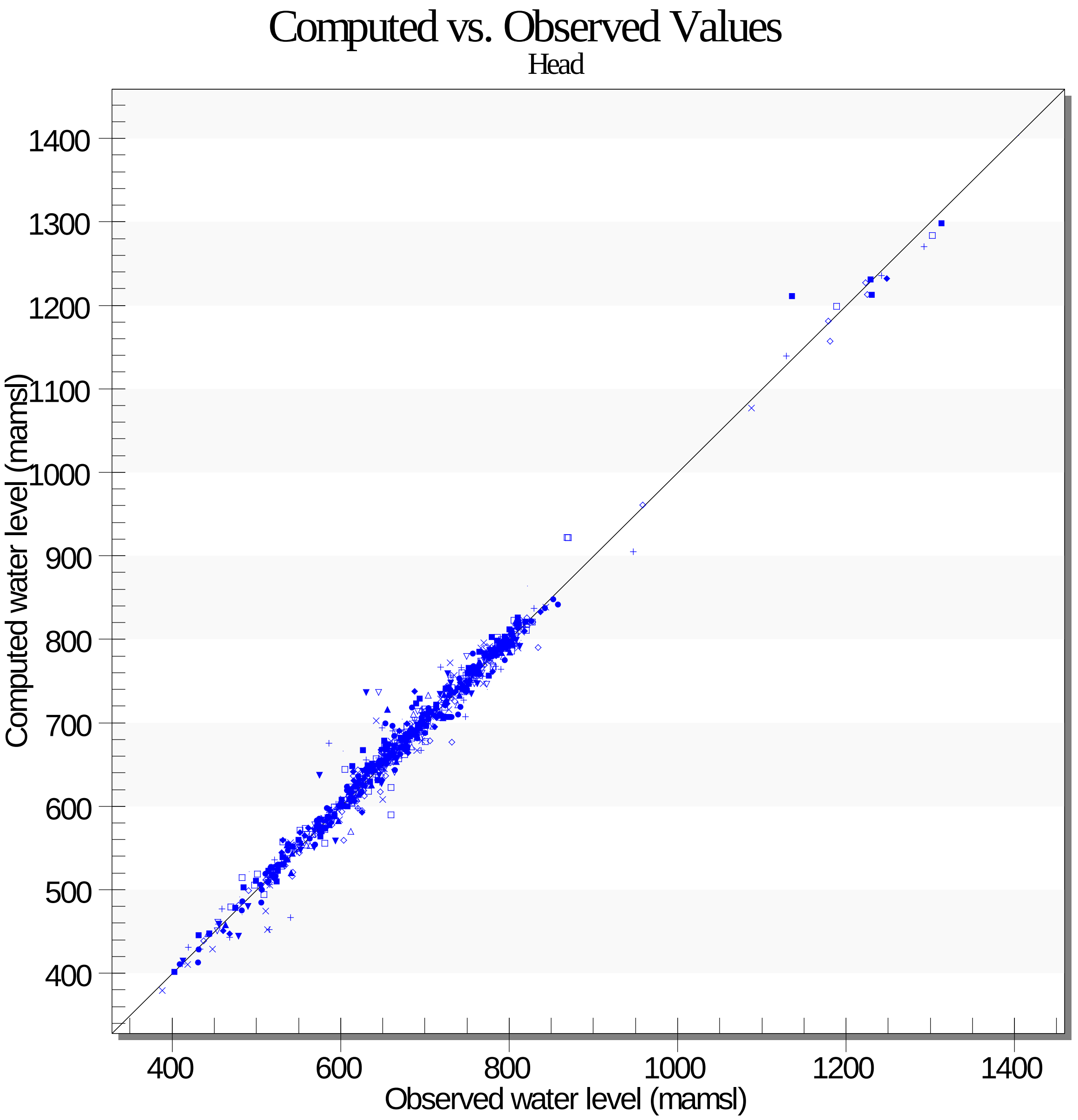


FIGURE 21: OBSERVED VERSUS SIMULATED WATER LEVELS IN METRES

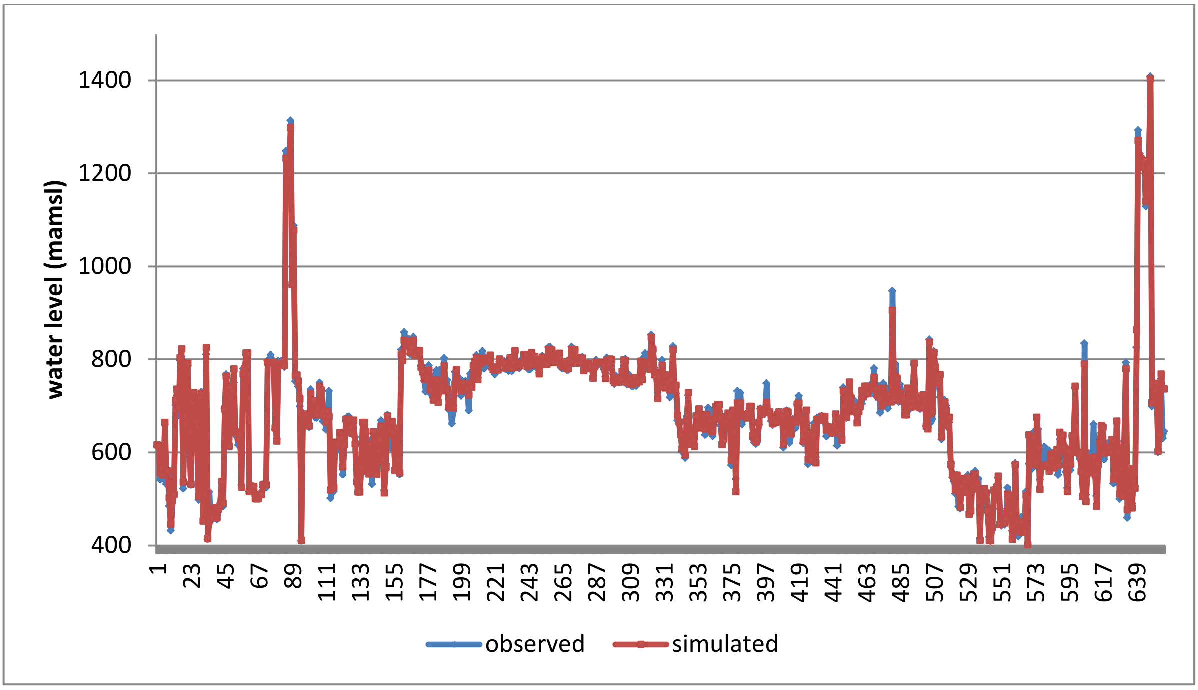


FIGURE 22: CALIBRATION AGAINST NGDB BOREHOLES IN THE CATCHMENT

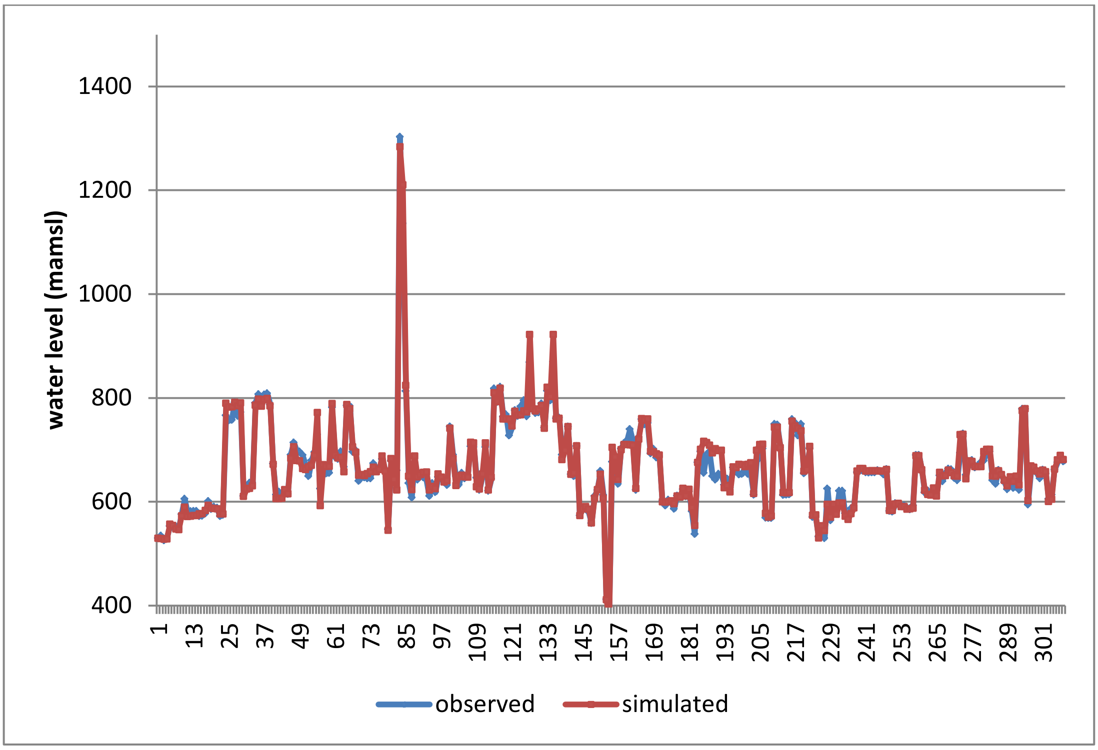


FIGURE 23: CALIBRATION AGAINST HYDRO-CENSUS IN THE VICINITY OF THE MOPANE MINE

The residual error plot (figure 24) shows no systematic error in heads, with some over and some under simulated. High lying boreholes with water level elevations above 1200 metres above mean sea level show a slight positive residual head, suggesting water levels can be up to 20 m too low.

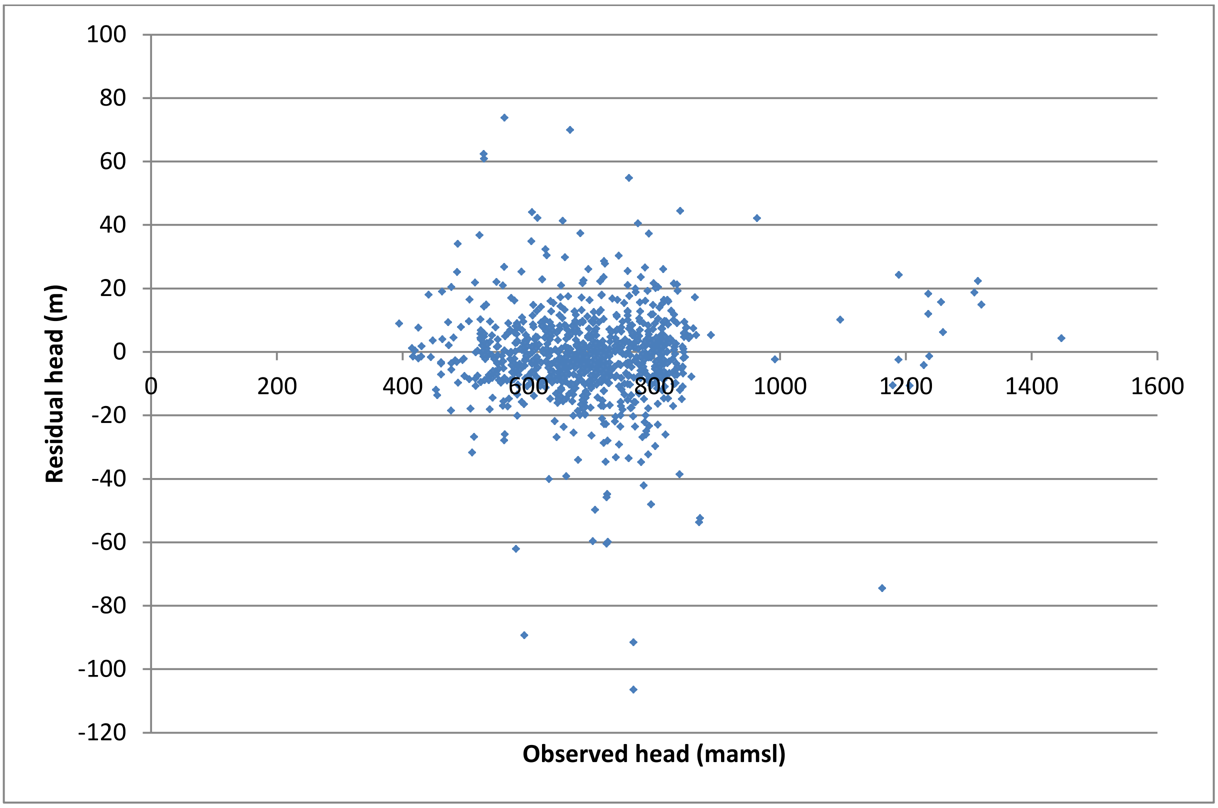


FIGURE 24: RESIDUAL ERROR OF SIMULATED VERSUS OBSERVED VALUES

A plot of residual head versus water levels in metres below ground level (mbgl) shows that boreholes with water levels below 60 mbgl have water levels over simulated (figure 25). These include many historic water levels from the NGDB impacted by abstraction which was not considered in the survey of present abstraction.

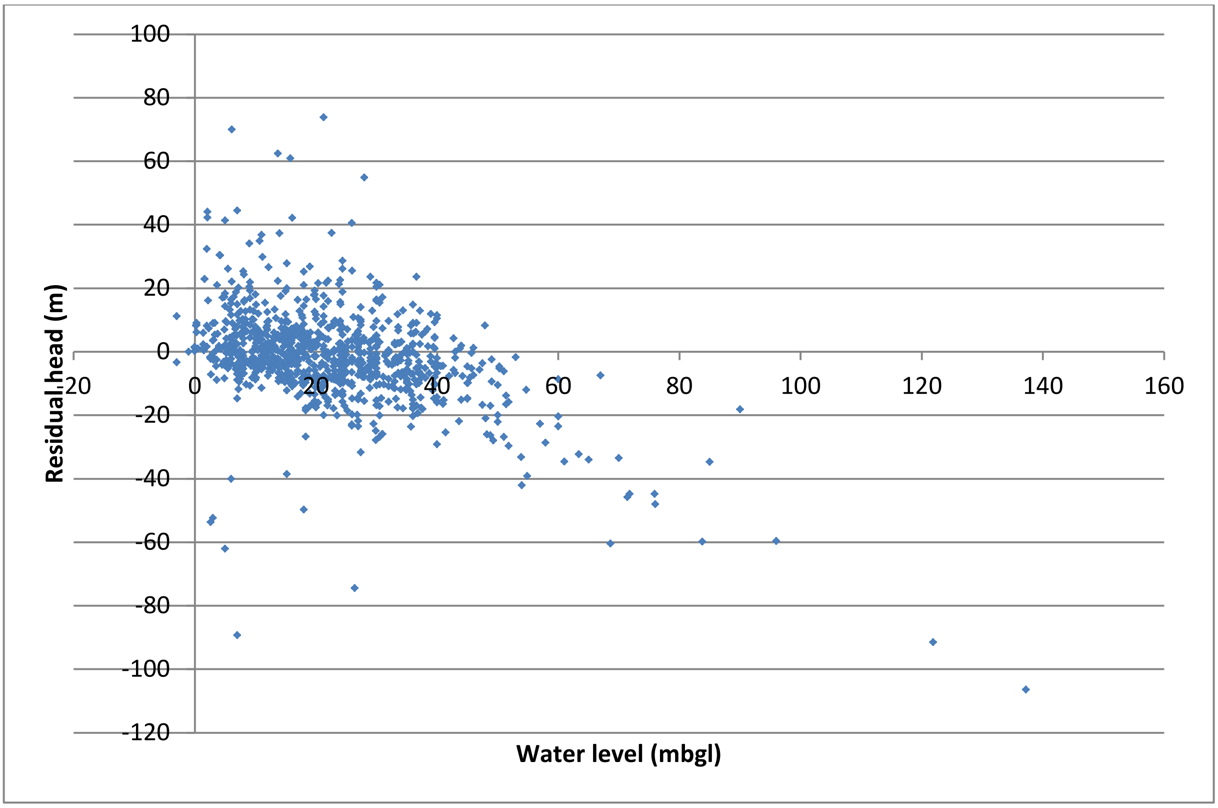


FIGURE 25: RESIDUAL HEAD VERSUS WATER LEVELS BELOW GROUND SURFACE

Model calibration was also undertaken via water balance per Quaternary catchment, to ensure recharge and discharge figures approximate the water balance published in other sources.

7 MODEL RESULTS

Modelling results are expressed as water level drawdowns from a pre-existing condition, or as a water balance, which is a calculation whereby the inflows and outflows of a groundwater system are determined. This is done by considering all the external and internal groundwater gains and losses in the aquifer such as:

Inflow: - groundwater flow into a specific area as a result of difference in gradients, groundwater recharge as a result of rainfall infiltration and losses from rivers.

Outflow: - groundwater leaving the system through the defined flow boundaries of the model due to the hydraulic gradient, borehole abstractions, baseflow to rivers and springs, and evapotranspiration.

7.1 WATER BALANCE

7.1.1 STEADY STATE - PRE MINING CONDITIONS

The water balance of the entire aquifer under natural conditions and present is shown in Table 17. Inflows from rivers occur from the perennial tributary flowing northward to the Mutamba from the Soutpansberg. This tributary loses water to the aquifer due to pumping on Windhoek, Eckland and Overwinning, and flow disappears before it reaches the Mutamba. Inflows also occur along the Tshipise fault and other faults entering the study area from the west and south. Outflows from the aquifer to rivers occur in the south, where the tributary of the Mutamba is perennial and fed by baseflow. Outflow from the study area occurs eastward along the Tshipise fault, and other faults, and to the Nzhelele dam. Evapotranspiration losses occur in alluvium along the Mutamba. Outflow also occurs to numerous springs and water courses as spring flow.

Table 17: Steady State water balance prior to mining

Flow Component	Inflow (m^3/d)	Outflow (m^3/d)
Virgin Conditions		
Faults	768	701
Rivers	2700	11501
Nzhelele dam	186	1681
Evapotranspiration		49485
Springs and ephemeral channels		26438
Recharge	86155	0
Abstraction	0	0
Total	89809	89810
Current Conditions		
Faults	3105	170
Rivers	3517	8725
Nzhelele dam	187	1567
Evapotranspiration		47820
Springs and ephemeral channels		20542
Recharge	86155	0
Abstraction	0	14510
Total	92964	93335

7.1.2 TRANSIENT STATE – MINING CONDITIONS

The water balance of the aquifer during mining is altered due to inflows into the pits, which impact on water levels, and consequently on the aquifer water balance. The simulated water balance of the aquifer is shown in Table 18 for the following years:

Year 4: prior to the start of Voorburg, with Makhado 4 years in operation

Year 16: final year of Makhado in operation, Voorburg, Mount Stuart and Wildebeesthoek in operation

Year 17: Closure of Makhado

Year 30: Voorburg, Jutland, Wildebeesthoek, Mount Stuart, Chapudi and Chapudi west, Generaal in operation

Year 38: Voorburg, Jutland, Generaal, Chapudi and Chapudi west in operation

Year 49: Chapudi, Chapudi west and Generaal in operation

Year 61 Last year of Chapudi, Chapudi west in operation

Table 18: Simulated water balance of the aquifer at various stages of the mine

Flow Component	Inflow (m^3/d)	Outflow (m^3/d)
Year 4		
Storage	1465	594
Faults	3454	199
Rivers	3513	8670
Nzhelele dam	189	1548
Evapotranspiration	0	47719
Springs and ephemeral channels	0	20440
Recharge	86155	0
Abstraction	0	14862
Voorburg	0	0
Makhado	0	745
Total	94777	94776
Year 16		
Storage	8483	290
Faults	3469	198
Rivers	3556	8438
Nzhelele dam	346	1214
Evapotranspiration	0	47198

Springs and ephemeral channels	0	18743
Recharge	86155	0
Abstraction	0	14343
Voorburg	0	2186
Other Mines	0	9472
Total	102009	102082
Year 17		
Storage	7210	11683
Faults	3470	197
Rivers	3562	8408
Nzhelele dam	357	1212
Evapotranspiration	0	47190
Springs and ephemeral channels	0	18615
Recharge	92710	0
Abstraction	0	14467
Voorburg	0	1983
Jutland	0	
Other Mines		3667
Total	107309	107422
Year 30		
Storage	9757	3672
Faults	3558	186
Rivers	3581	8323
Nzhelele dam	385	1205
Evapotranspiration	0	46729
Springs and ephemeral channels	1	19710
Recharge	87200	0
Abstraction	0	14350
Voorburg	0	2880

Jutland	0	2381
Other Mines		7162
Total	104483	104598
Year 38		
Storage	7660	5850
Faults	3755	170
Rivers	3614	8198
Nzhelele dam	358	1207
Evapotranspiration	0	46590
Springs and ephemeral channels	0	17698
Recharge	87200	0
Abstraction	0	14120
Voorburg	0	2552
Jutland	0	3200
Other Mines		3040
Total	102589	102624
Year 49		
Storage	6558	6901
Faults	4134	157
Rivers	3659	8039
Nzhelele dam	332	1213
Evapotranspiration	0	46432
Springs and ephemeral channels	0	16127
Recharge	89405	0
Abstraction	0	16354
Voorburg	0	0
Jutland	0	2238

Other Mines		6548
Total	104089	104010
Year 61		
Storage	3324	9914
Faults	4083	157
Rivers	3688	7975
Nzhelele dam	311	1219
Evapotranspiration	0	46157
Springs and ephemeral channels	0	19190
Recharge	91725	0
Abstraction	0	14258
Voorburg	0	0
Jutland	0	0
Other Mines		4833

7.2 IMPACTS OF MINING

The impacts of mining on the water balance are shown in Figure 26.

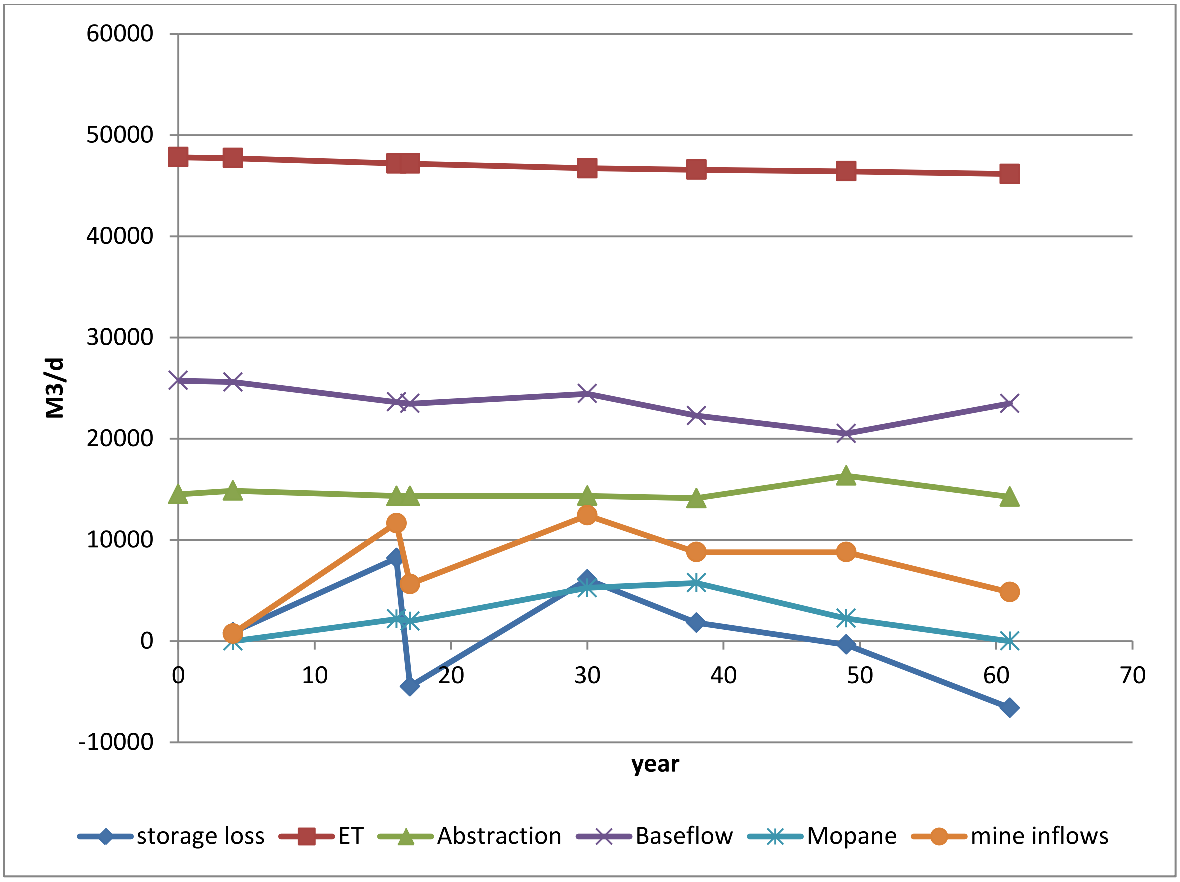


FIGURE 26: MINE ABSTRACTION FROM THE AQUIFER AND IMPACT ON THE AQUIFER

Evapotranspiration from riverine areas is impacted and decreases from 47.8 Ml/d to 46.4 Ml/d. This reduction occurs largely along the river channels, where drawdown of the water level reduces the availability of shallow groundwater.

Abstraction of groundwater for existing users is reduced from 14.5 Ml/d to a minimum of 14.1.

The bulk of inflows into the pits and to boreholes originate from storage losses from the aquifer, which rises to 8.1 Ml/day by the end of the life of mine of Makhado. They subsequently decline due to the refilling of Makhado and the closure of Mount Stuart underground mine and Wildebeesthoek. Inflows into mines peak at 12.4 Ml/d when all mines except Makhado are in operation, then decline to 8.7 Ml/d by the end of the life of Mopane. During the peak inflows, 5.2 Ml/d are inflows into the Mopane mines.

Mine inflows exclude direct rainfall into mine workings, and surface runoff which is not diverted. This is because such inflows are not part of the average daily inflow, and occur only during storm events, which are highly variable. Post mining, recharge to the pits is included in the water balance, since this volume will not be removed as storm water and will replenish the pits.

7.3 INFLOWS INTO VOORBURG AND JUTLAND PITS

Inflows into Voorburg increase to 2.9 Ml/d in mining year 30, 26 years after the pit starts, which were simulated assuming a progressive deepening of the pit. Inflows into Jutland increase to 3.2 by year 38, before starting to decline.

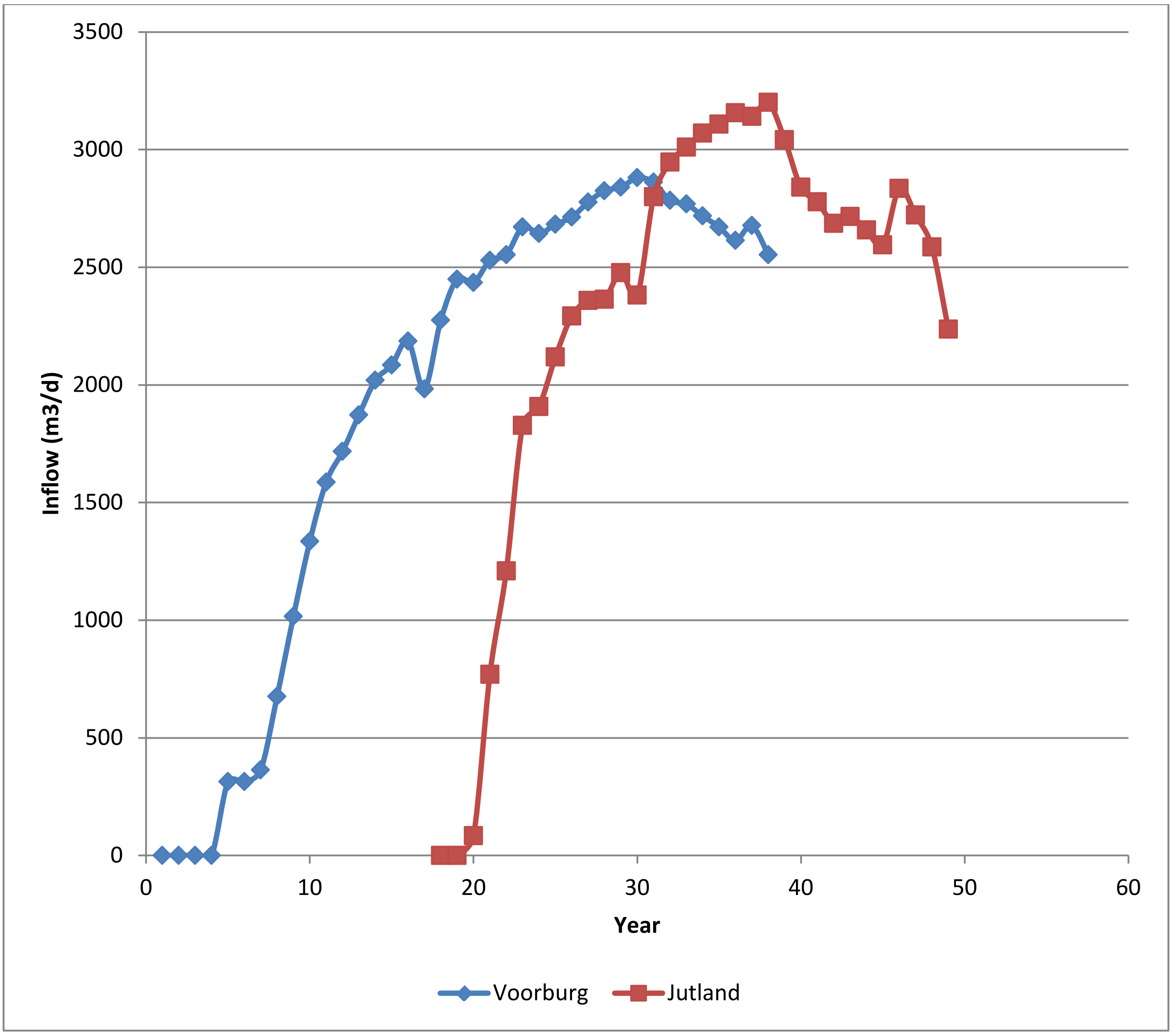


FIGURE 27: INFLOWS INTO PIT

7.4 DRAWDOWN

Drawdown is the measure of water level decline taken from a bases point, in this case prior to commencement of mining i.e. year 2013. Drawdown of the water level after mining commences is shown for various periods of time in Figures 28-31.

Significant drawdown in water level of over 5 m occurs by year 16, 12 years after the start of Voorburg, to a radius of 5-6 km. By mining year 38, 49, and the end of life of mine the Mopane mines, significant drawdown occurs for a radius of up to 25 km, and the impacts from Mopane, Generaal and Mount Stuart, and Chapudi are cumulative and overlap.

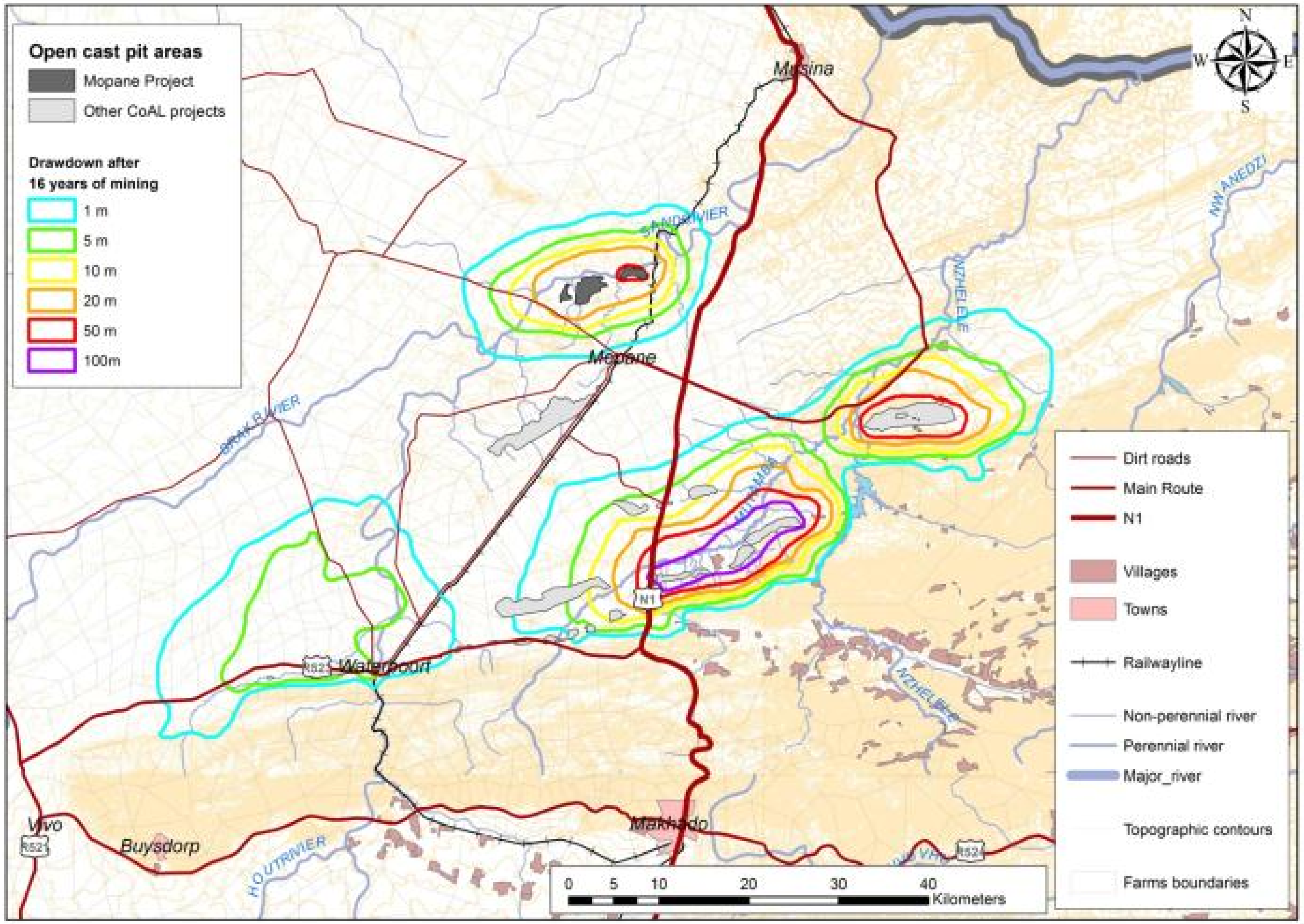


FIGURE 28: DRAWDOWN IN MINING YEAR 16

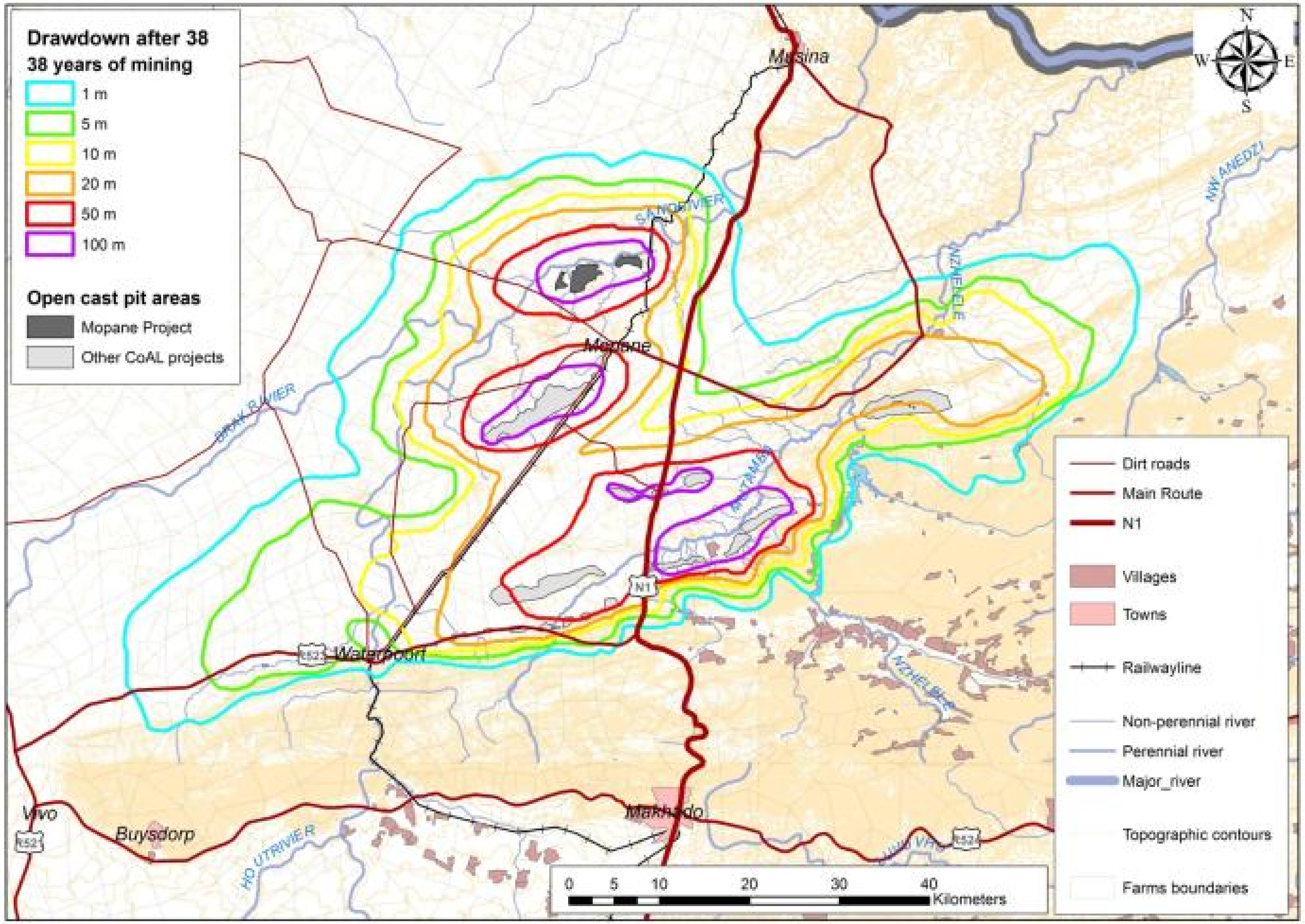


FIGURE 29: DRAWDOWN IN MINING YEAR 38

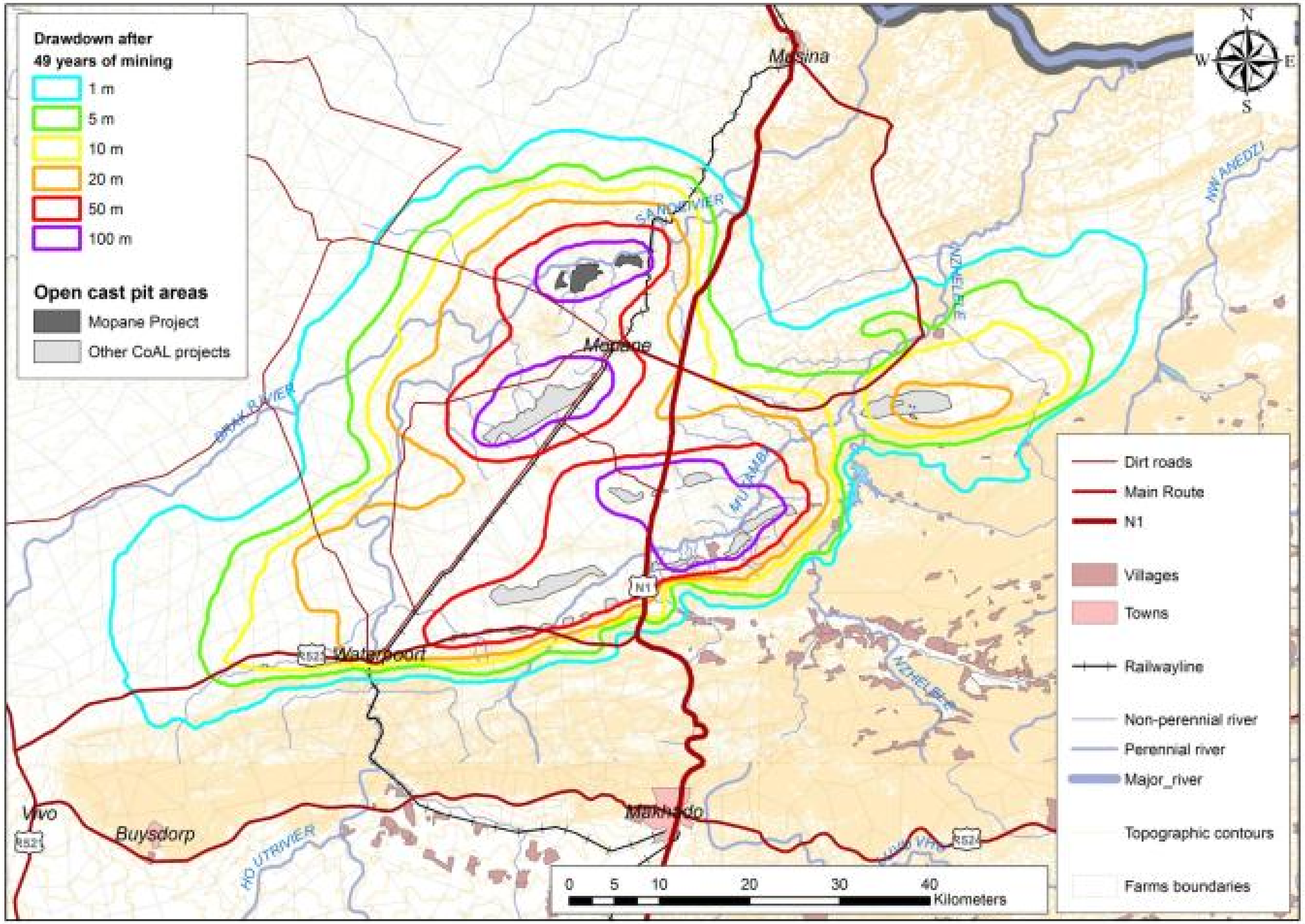


FIGURE 30: DRAWDOWN IN MINING YEAR 49

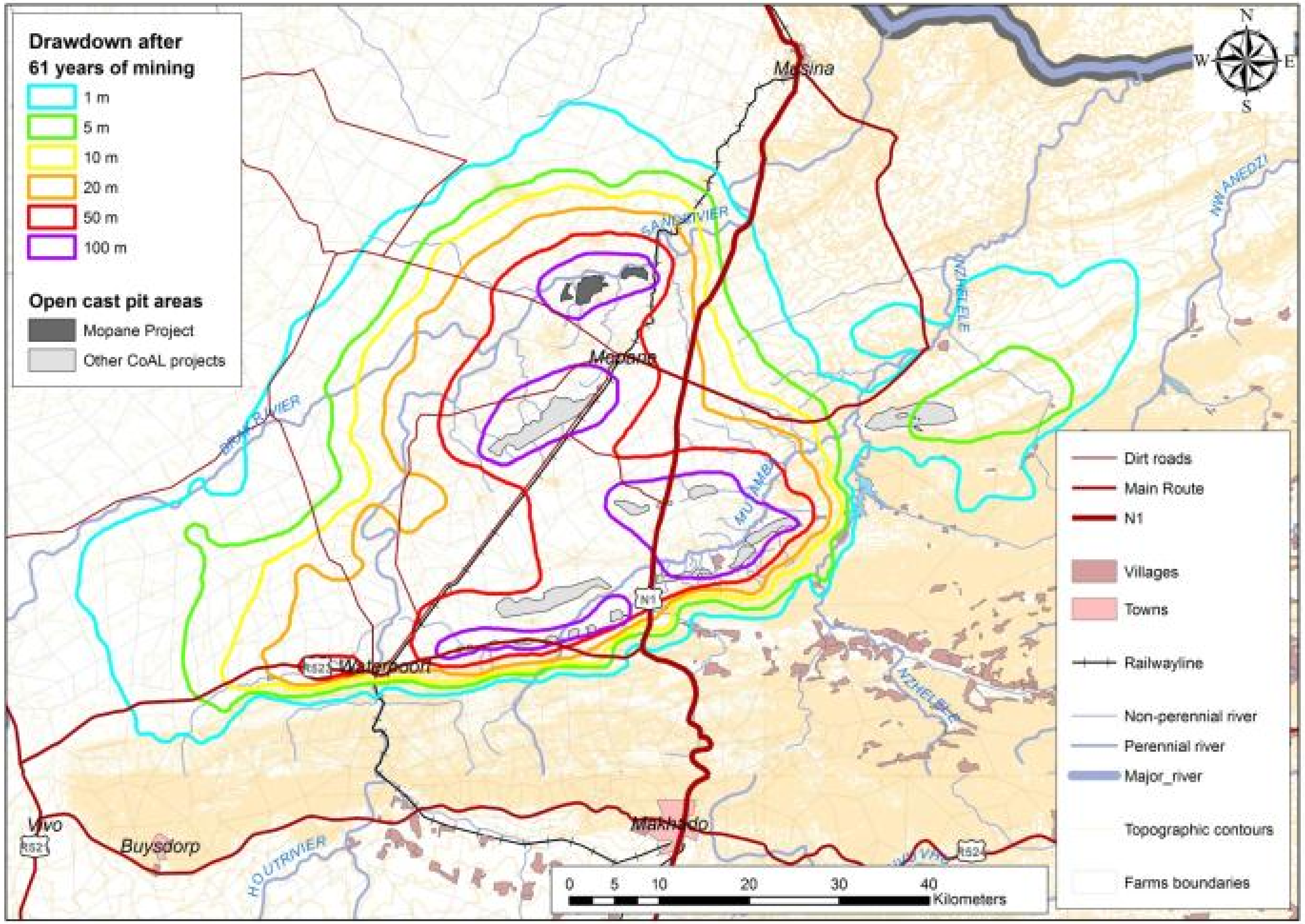


FIGURE 31: DRAWDOWN IN MINING YEAR 61

8 SHORTCOMINGS AND LIMITATIONS

Although, all available data was collected and utilised to develop the groundwater model, and ensure that the model presents the actual situation as accurately as possible, some limitations can be noted:

- Limited and inaccurate data on actual groundwater usage, hence abstraction estimates are based on hectares observed under irrigation. Registered and claimed water uses do not correlate with observed water use based on lands under irrigation. Since recharge to the area is low, abstraction estimates have a significant impact on water levels.
- Current water levels were only obtained from a local hydrocensus. Due to the cumulative impacts of several mining projects, current water levels need to be obtained over a broad area covering the entire impacted area
- Data collected in a relatively wet period
- Aquifer storage data based solely on best estimate and inflows into the bulk sample pit undertaken at Makhado. Similar data is required at Voorburg to calibrate projected inflows.

9. FURTHER RECOMMENDED WORK

To further improve the conceptual model and validate the conclusions made in this report, several items require additional work:

- Monitoring: Establishment of monitoring piezometers near where initial mine workings will commence. Transient state parameters of mining are at present best estimates based on data collected during the box cut exploration at Makhado. Predictions cannot be calibrated without data collected after mining commences. Water level changes once open bit mining begins should be used to further refine storage parameters in the groundwater model and drain conductance's used for the mine workings. These estimates will affect projections of inflows at other mines and the cumulative impacts of all mining operations in the region.

- Verification of inflows and water levels by monitoring is required to validate model after mining commences.
- Verification of abstractions especially from irrigation farmers.
- Derivation of local more detailed multilayer models at a monthly time scale for each mine once a more detailed mining plan becomes available.
- Model Sensitivity analysis: Once the model is complete with all the required information, supported by monitoring data, a sensitivity analysis needs to be undertaken to determine how sensitive the model results are to parameters with some uncertainty. This involves simulations with parameter values increased and reduced to determine how it affects the calibration results, and the confidence in the selected parameter values
- Model Verification: Model verification means comparing model results against an independent data set from that which the model was calibrated against. Monitoring data can be used, as well as the extended model data, and additional data to be obtained from farmers private records not previously submitted to the consulting team.

10. GROUNDWATER IMPACT ASSESSMENT FOR THE MOPANE PROJECT

Mining at Mopane will involve open cast mining along extended open cuts down to 200m below surface, along the southern bank of the Sand River north of Mopane village (Voorburg Section) and southwest of Mopane village (Jutland Section).

Groundwater flow will be intersected by these pits when below the water table. The water flowing into the pits will need to be pumped out (dewatered) for safe mining operations to continue. The water pumped from the pits will be used on the mine for process water in the plant and dust suppression. The dewatering will result in a lowering of the water table (cone of depression) around the mine pits, extending for up to 25 kilometres at the life of mine. This is because water is taken mostly from aquifer storage, as recharge in the area is low and unable to sustain the dewatering. The north-east striking faults such as the Voorburg and Jutland (Bosbokpoort) faults are far more transmissive resulting that the cone of depression is elongated along their axis.

Impacts as a result of this could be significant. These, in order of significance, include:

- Reductions in water available for abstraction and discharge i.e. lower borehole yields or drying up of boreholes and the spring at Voorburg within the radius of influence.
- Contamination of aquifers down gradient due to seepage from the rehabilitated pits, discard dumps, stock piles and dirty water dams.
- A reduction in water available for evapotranspiration. Groundwater dependant floral species (trees with deep root systems) could be affected as the water table drops. Riverine vegetation is mostly sustained from surface flows and water stored in the alluvial deposits, however shallow groundwater may be important during extended dry periods.

The classification of all environmental impacts identified is assessed in terms of: -

- their duration,
- their extent,
- their probability,
- their severity.

The above will be used to determine the significance of impact without any mitigation, as well as with mitigation (table 19).

Table 19: Environmental risk and impact assessment criteria

DURATION		
Short term	6 months	1
Construction	36 months	2
Life of project	16 years	3
Post rehabilitation	Time for re-establishment of natural systems	4
Residual	Beyond the project life	5
EXTENT		
Site specific	Site of the proposed development	1
Local	Farm and surrounding farms	2
District	Makhado Municipal district	3
Regional	Vhembe region	4
Provincial	Limpopo Province	5
National	Republic of South Africa	6
International	Beyond RSA borders	7

PROBABILITY		
Almost Certain	100% probability of occurrence – is expected to occur	5
Likely	99% - 60% probability of occurrence – will probably occur in most circumstances	4
Possible	59% - 16% chance of occurrence – might occur at some time	3
Unlikely	15% - 6% probability of occurrence – could occur at some time	2
Rare	<5% probability of occurrence – may occur in exceptional circumstances	1
SEVERITY		
Catastrophic (critical)	Total change in area of direct impact, relocation not an option, death, toxic release off-site with detrimental effects, huge financial loss	5
Major (High)	> 50% change in area of direct impact, relocation required and possible, extensive injuries, long term loss in capabilities, off-site release with no detrimental effects, major financial implications	4
Moderate (medium)	20 – 49% change, medium term loss in capabilities, rehabilitation / restoration / treatment required, on-site release with outside assistance, high financial impact	3

Minor	10 – 19% change, short term impact that can be absorbed, on-site release, immediate contained, medium financial implications	2
Insignificant (low)	< 10 % change in the area of impact, low financial implications, localised impact, a small percentage of population	1

RISK ESTIMATION (Nel 2002)					
	SEVERITY				
PROBABILITY	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Critical (5)
Almost certain (5)	H	H	E	E	E
Likely (4)	M	H	H	E	E
Possible (3)	L	M	H	E	E
Unlikely (2)	L	L	M	H	E
Rare (1)	L	L	M	H	H

E	Extreme risk – immediate action required, detail considerations required in planning by specialists – alternatives to be considered	4
H	High risk – specific management plans required by specialists in planning process to determine if risk can be reduced by design and management and auditing plans in planning process, taking into consideration capacity, capabilities and desirability – if cannot, alternatives to be considered, senior management responsibility	3
M	Moderate risk – management and monitoring plans required with responsibilities outlined for implementation, middle management responsibility	2
L	Low risk – management as part of routine requirements	1

IMPACT SIGNIFICANCE	
Negligible	The impact is non-existent or insubstantial, is of no or little importance to any stakeholder and can be ignored.
Low	The impact is limited in extent, even if the intensity is major; whatever its probability of occurrence, the impact will not have a significant impact considered in relation to the bigger picture; no major material effect on decisions and is unlikely to require management intervention bearing significant costs.

Moderate	The impact is significant to one or more stakeholders, and its intensity will be medium or high; therefore, the impact may materially affect the decision, and management intervention will be required.
High	The impact could render development options controversial or the entire project unacceptable if it cannot be reduced to acceptable levels; and/or the cost of management intervention will be a significant factor in project decision-making.
Very high	Usually applies to potential benefits arising from projects.

Risk is a combination of the probability, or frequency of occurrence of a hazard and the magnitude of the consequence of the occurrence (Nel 2002). Risk estimation (RE) is concerned with the outcome, or consequences of an intention, taking account of the probability of occurrence and can be expressed as P (probability) x S (severity) = RE. Risk evaluation is concerned with determining significance of the estimated risks and also includes the element of risk perception. Risk assessment combines risk estimation and risk evaluation (Nel 2002).

Potential impacts were identified and assessed by considering the criteria as outlined in table 19.

The significance of each impact was determined "without mitigation" and "with mitigation", taking into consideration alternatives, preventative and mitigation measures.

The groundwater risk and impact assessment is provided in Table 20.

Table 20: Impacts on groundwater

Impact	Extent	Duration	Severity	Probability	Risk estimation	Without mitigation	Mitigation
Reductions in water available for abstraction and discharge	4	5	4	5	4	**Extreme** - Drawdown from mining extends to surrounding farms (up to 15kms). Utilisation of this water is low, but it is an only source of supply. The spring at Voorburg will probably dry up.	Provision of alternative water supply. Implement ASR to limit drawdown cone
Contamination of aquifers down gradient due to seepage from the rehabilitated pits, discard dumps, stock piles and dirty water dams.	2	5	2	3	3	**Moderate** - the Karoo aquifer is already high in sulphates and salts	Placing of carbonaceous material at the bottom of the pit. Lining of discard dumps and dirty water dams.
A reduction in water available for evapotranspiration.	3	5	2	3	3	**Moderate** – riverine vegetation is mostly supported by surface flow filling the alluvial voids.	Implement ASR to limit drawdown cone

11. MITIGATION MEASURES PROPOSED

The following mitigation measures should be considered to address the impacts of the proposed mining:

- Revise the mining schedules of the proposed GSP mines to limit the cumulative impacts
- Enter into negotiations with surrounding land owners impacted regarding compensation or alternative water supply
- Implement Aquifer Storage and Recovery (ASR) to minimise depletion of aquifer storage thus limiting the extent of the drawdown cone.

12. MONITORING AND MANAGEMENT

Monitoring of groundwater water levels, water quality, inflows and pumping volumes is necessary to determine if the groundwater system is reacting as predicted. The monitoring programme should be audited for compliance to the stated objectives and adapted when and where required. It must be noted that the monitoring programme is a dynamic system changing over the different life cycle phases of the mine. A proper data and information management system should also be established to ensure that the monitoring is done effectively and that the information created is best utilised for the management of the mine. The following monitoring components have been identified:

- Monitoring Climate: rainfall, rainfall intensity and evaporation would be required
- Monitoring of water levels should be done up gradient and down gradient of the mining area, along geological structures. Continuous recorders can be installed on selected boreholes and monthly readings taken at other boreholes.
- Groundwater Quality to be monitored in all the aquifers surrounding the mine, and in the pits, area should be done on a quarterly basis. All macro elements should be determined.
- Inflows to the opencast and underground areas should be monitored by means of measuring the volume of water pumped out. Measurements should be done on at least a monthly basis

- Any leachate formed should be monitored for quantity and quality on at least a monthly basis. Sulphates, pH and trace metals need to be included in the quality analysis
- All abstraction including dewatering, irrigation, plant and domestic use, needs to be measured on at least a quarterly basis.

It is recommended that a monitoring committee be established and that these monitoring activities be done in conjunction with the neighbouring farmers in order to obtain a greater regional perspective and ensure transparency.

13. LEGAL CONSIDERATIONS

The approval of the mining right application is dependent on the compliance with various legislative requirements. With respect to groundwater these would include the following, (National Water Act, Act 36 of 1998, Section 21):

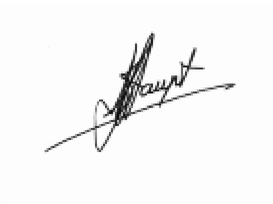
-21a) taking water from a water resource

-21d) engaging in a stream flow reduction activity (any activity that can impact on the flow or reserve of a water course);

-21e) engaging in a controlled activity (any activity deemed by the minister to have a detrimental impact on a water resource such as irrigation with water containing waste);

-21g) disposing of waste in a manner which may detrimentally impact on a water resource;

-21g) Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people.



8 November 2013

Signed for the Team **Date**

Team	Person	Qualifications	Professional Registration SACNASP
Responsible Director	C Haupt	BSc(Hons)	Geology (400031/94)
Report and modelling by	K. Sami	MSc	Geology and Hydrology (400043/01)
Assisted by	P Wilken	BSc(Hons)	Geology (400038/97)
Assisted by	E Mmbi	BSc(Hons)	In training

APPENDIX A

STATEMENT OF INDEPENDANCY AND PROJECT TEAM CV'S

WSM LESHIKA
CONSULTING (PTY) LTD
ENGINEERS, HYDROGEOLOGISTS, ISD PRACTITIONERS & PROJECT MANAGERS

POLOKWANE
Postnet Suite no 8 | Private Bag X9676 | Polokwane | 0700
2 Rhodesdrift Avenue | Hampton Court | Polokwane | 0699
Tel: 015 296 1560
Fax: 015 296 4158
Email: polokwane@wsmleshika.co.za

TO WHOM IT MAY CONCERN

DECLARATION

We the undersigned hereby declare that, as professionally registered Scientists, employed by WSM Leshika Consulting (Pty) Ltd, an independent consultancy firm, that we have prepared the report entitled "Mopane Project, Groundwater Flow Impact Assessment" free from influence or prejudice.

C J Haupt BSc(Hons) Pr.Sci.Nat. (400031/1994)
Hydrogeologist
Responsible Director

K Sami MSc Pr.Sci.Nat (400043/2001)
Hydrogeologist
Associate

P Wilken BSc(Hons) Pr.Sci.Nat. (400098/1997)
Hydrogeologist
Associate

WSM LESHIKA CONSULTING (Pty) Ltd is a multi-disciplinary firm of consultants whose core business is to provide comprehensive and professional consulting services through the following specialist divisions:

- Civil & Agricultural Engineering
- Hydrogeology and Geotechnical Investigations
- Project Management
- Hydrology and hydraulic structures

BACKGROUND

WSM Leshika has a staff compliment of over 30 professionals and 19 administrative staff members with offices that service Limpopo, Gauteng, E Cape, North West and Mpumalanga Provinces in South Africa. Our pool of professional staff enhances the potential of the Company's ability to provide top class engineering and scientific services to our valued clients. Our personnel have worked extensively throughout Africa, South Africa and internationally, providing consulting services to various government departments, non-governmental organisations, industries and mines.

SERVICES AND EXPERTISE PROVIDED

Our professional team, many of whom have more than 30 years' experience in their field provided the following technical specialist skills to the Mopane Coal Project:

TECHNICAL EXPERTISE PROVIDED

- Groundwater Specialist Services

KEY PROFESSIONAL STAFF

Carel Haupt Pr.Sci.Nat. (Director, Principal Hydrogeologist)

Carel Haupt is a registered natural scientist with more than 30 years' experience. He has a post graduate degree in Engineering Geology specialising in the evaluation of ground water potential and hydrogeological mapping. He has worked on numerous groundwater development projects, developing groundwater resources for water supply to mines, towns and villages, hydrogeological evaluations for mines and the design and development of monitoring systems for groundwater wellfields. He is the director responsible for all the Hydrogeological aspects of the Mopane Project. He is a founder member and director at WSM Leshika Consulting and has held the position of Chairman of the Ground water Division of the Geological Society of South Africa as well as an executive member of the South African Chapter of the International Association of Hydrogeologists.

Karim Sami Pr.Sci.Nat. (Principal Hydrogeologist)

Karim Sami is registered as a geological and hydrological scientist with the South African Council of Natural Scientific Professions. He has a Master's Degree in Hydrology from Trent University in Canada and has 22 years' work experience throughout Africa. He specializes in groundwater development and has published internationally on ground water exploration, ground water recharge estimation, groundwater surface water interactions, borehole and aquifer test pumping, borehole and aquifer sustainable yield evaluation, groundwater geochemistry, saturated and unsaturated zone hydraulics, rural water supply implementation and planning, hydrological modeling, environmental tracers for hydrogeology, acid rock drainage and contamination from mining activities. He is responsible for the hydrogeological modeling and impact assessment for the Mopane Project. Karim is an associate at WSM Leshika Consulting.

Pierre Wilken Pr.Sci.Nat (Principal Hydrogeologist)

Pierre graduated with an honours degree in geology at Rhodes University, Grahamstown South Africa in 1986 and has 27 years' experience. He has worked over Africa in the geological and hydrogeological fields and has specialized in ground water exploration and development, data manipulation using GIS, ground water recharge estimation, borehole and aquifer test pumping, borehole and aquifer sustainable yield evaluation, ground water geochemistry and geophysical surveys. Pierre is responsible for the data collation, geological interpretation, mapping and water quality evaluation for the Mopane Project. He is an associate at WSM Leshika Consulting.

CONTACT DETAILS

POLOKWANE HEAD OFFICE

Postnet Suite 8, Private Bag X9676

2 Rhodesdrift Avenue,

POLOKWANE 0700

Tel: 015 296 1560

Fax: 015 296 4158

E Mail: polokwane@wsmleshika.co.za

TSHWANE OFFICE

P O Box 39942

623 Rubenstein Street

MORELETA PARK 0044

Tel: 012 997 6760

Fax: 012 997 6768

E Mail: tshwane@wsmleshika.co.za