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Hydrogeological Evaluation of the Duel Proposed Coal Mining Area in the Vhembe District of Limpopo Province

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HYDROGEOLOGICAL EVALUATION AT THE DUEL PROPOSED COAL MINING AREA IN THE VHEMBE DISTRICT OF LIMPOPO PROVINCE

GROUNDWATER IMPACT ASSESSMENT REPORT

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DECLARATION

We the undersigned hereby declare that as employees of WSM Leshika Consulting (Pty) Ltd which is an independent consultancy firm, we have prepared the following report

The Duel Coal Project
Groundwater Assessment
For the Environmental Impact Assessment
April 2019

According to requirements of applicable Acts, inter alia the National Water Act, Act 36 of 1998 and concomitant Regulations, free from external influence.

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EXECUTIVE SUMMARY

WSM Leshika Consulting (Pty) Ltd was appointed by Jacana Environmentals C.C. to conduct the hydrogeological impact assessment of the proposed The Duel open pit and underground coal mining operation in the Limpopo Province, with specific reference to potential inflows into the pit and impact on water levels. Most of the investigations were conducted in 2016 with a verification census conducted in March 2019 and a report update in July 2019.

The proposed The Duel Coal Project is situated on the remainder of the farm The Duel 186 MT, some 45 km south of Musina. It lies within the Makhado Local Municipality of the Vhembe District of Limpopo Province (figure 1-1). The proposed mining area is located within the Nzhelele drainage basin, 11 km west of the Nzhelele dam. It is situated immediately east of the Makhado mining right area.

It is assumed mining at the Duel will occur after mining at Makhado, to piggyback on the infrastructure developed for the much larger Makhado operation. Consequently, impacts from the Duel represent a combined regional impact from mining operations in the area. This report describes the existing groundwater status and the potential regional impact within the mining right application (MRA) area and the surrounding area; however, the impacts do not arise from operations at the Duel alone but are the cumulative impact of all mining operations.

The proposed mine consists of an open pit operation, which will extend to a maximum of 270 m below ground surface, followed by underground operations. The mining plan envisages 24 years of open pit mining. Several other mining operations are planned in the area; hence it is not possible to look at impacts of the Duel in isolation, but as a combined impact of all mining operations.

The project is to prepare the geohydrological components of an Environmental Authorisation including: a description of the geohydrological environment; Prediction of the environmental impacts of the proposed activity on the geohydrological regime of the area; and propose mitigation measures based on physical, hydraulic and hydro-geochemical information as gathered and predicted in the preceding phase.

Land ownership in immediate surroundings consists of private owners and government. The government land consists of two farms occupied by 3 villages. Approximately 57 ML/annum is abstracted from groundwater currently from the area making up the two-farm buffer zone around the MRA area. Nearly half this volume is for water supply to communities on the farm Telema adjacent to The Duel project. Groundwater is the sole source of supply to domestic users, consequently a critical resource. Impacts on the already stressed Nzhelele Dam are also to be considered.

The study area is characterised by highly variable but generally poor groundwater quality typical of arid environments with elevated salts, especially in the Karoo strata where mining is planned.

Mining at the Duel will involve open cast mining along extended open cuts down to 270m below surface, as well as underground mining.

The Duel sits on a local groundwater divide between groundwater drainage to the east towards Nzhelele dam and west towards the Mutamba River. The depth to groundwater is 25-40 mbgl. Some localized dewatering is evident east of The Duel and groundwater levels have dropped 20 m from natural conditions. This is due to pumping around Makushu village, where low yielding boreholes are being extensively utilised.

Groundwater flow will be intersected by the open 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 for dust suppression. Due to the extent of mining operations planned for the Greater Soutpansberg area, impacts must be seen as cumulative rather than independently for each mine.

The impacts of mining on the water balance will include:

- Abstraction of groundwater for existing users will be reduced from 1794 Kl/d to 1350 Kl/d due to the lowering of the water table as a result of the cumulative impact of mining. Abstraction will be reduced on the farm Telema for communities reliant on groundwater by 130 Kl/d; the farm Martha/Boas utilising 75 Kl/d will be impacted by lowering groundwater levels; the farms Gray and Nairobi where groundwater is used for stock watering will also have potential abstraction reduced.
- Water level drops at Makushu on the farm Telema, adjacent to The Duel reach 60 mbgl.
- Inflows to the Nzhelele Dam from groundwater will reduce from 1100 m^3/d to 750 m^3/d.
- The total dewatering volume required at The Duel from mines will vary from 750 m^3/d to 2000 m^3/d. The bulk of inflows represent the volume lost from aquifer storage (dewatering). The remainder of inflows represent groundwater flow intercepted by the pits, which would have discharge elsewhere, such as the Nzhelele Dam.
- The coal at the Duel is generally below 2% sulphur and pyrite can be 15% by weight. ABA tests indicate sulphur is less than 1% in the waste rock, including carbonaceous material and the % sulphur can rise to 0.18-0.28% at depths below 150 m. Two core samples indicate a Nett positive and a nett negative NNP, however the acid generating rock all occurs at below 150 m, hence if this waste rock is deposited at the bottom of the pit after Life of Mine, where it will be submerged, AMD will be mitigated.
- The migration of the contaminant plume from the interim discard dump during mining, which is the dump containing carbonaceous material and which poses the most risk of contaminants is directed towards the pit, hence does not pose a risk to surrounding properties. The plume from the waste rock, containing the low sulphur rock from the overburden migrates towards the pit and westwards towards Martha. Westward and eastward migration is curtailed by the cone of depression created by the pit.

- 25 years after Life of Mine, the contaminant plume from The Duel is oriented towards the Makhado Project East Pit due to the residual cone of depression remaining in the pit.

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

- Enter negotiations with surrounding landowners and communities impacted regarding compensation or alternative water supply.
- Coordinate mining with the Makhado Project East pit to simultaneously mine and benefit from the combined cone of depression, minimising combined inflows, total abstraction volumes and the duration of significant impact

To minimise acid generation and manage leachate the mining plan proposes to:

- Deposit mine wastes in the open pit, controlling the migration of high sulphate leachate.
- The horizons that are potentially acid generating, the coal middlings and carbonaceous mudstones should be placed at the bottom of the pit, where they will be submerged below the water table, preventing oxidation
- Interim stockpiling of carbonaceous material should be on lined dumps with a leachate collection system
- Grass cover should be re-established, as soon as possible after top soiling to minimise infiltration of water through residue material
- Monitoring boreholes should be installed in appropriately selected sites prior to commencement of mining to detect changes in water quality and water levels with time.

The verification census done in March 2019 was conducted to determine if any significant changes occurred in the hydrogeological regime. The boreholes selected for verification were around the direct mining area where the greatest impacts from mining were expected (Mon-11) and away from the mining area to the north to verify regional data (Mon 13 and Nak-2).

The results of the verification census showed that little has changed in terms of the hydrogeology of the area. Water levels and water quality are similar and are within the expected seasonal fluctuations. The evaluation previously done is thus still valid.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation or Acronym	Definition
ABA	Acid Base Accounting
DMR	Department of Mineral Resources
DTM	Digital Terrain Model
DWS	Department of Water and Sanitation
EIA	Environmental impact assessment
GRAII	Groundwater resources assessment phase II
GRIP	Groundwater Resources Information Project
ha	Hectares
LMB	Limpopo Mobile Belt
mamsl	Metres above mean sea level
mbgl	Metres below ground level
Ma	Million years ago
MAE	Mean Annual Evaporation
MAP	Mean annual rainfall
MIA	Mining Infrastructure area
MODFLOW	Modular groundwater flow numerical model
MPRDA	Mineral and Petroleum Resources Development Act (Act 28 of 2002)
MRA	Mining right application
Mtpa	Million tonnes per annum
NGA	National groundwater archive
ROM	Run of Mine
RMF	Regional Maximum Flood
WQT	Water Quality threshold
WR2012	Water resources south Africa 2012

LIST OF DEFINITIONS

Aquifer hydraulic properties	The properties of permeability and specific yield, or transmissivity and storativity that determine the rate at which an aquifer transmits water, and the volume of water it releases from storage
Baseflow	The contribution of subsurface water to surface water channels to maintain dry season flows
Blow Yield	The maximum rate at which water is blown from a borehole by an air compressor after drilling. Commonly assumed to be the maximum inflow rate into that borehole
Groundwater baseflow	The contribution to baseflow from the regional aquifer
Interflow	The contribution of subsurface water to surface water courses as baseflow before entering the regional aquifer
Cone of depression	The area affected by the abstraction of groundwater in terms of a drop in water level from the rest water level
Drawdown	The depth to which the groundwater level is drawn down below the original water level in response to abstraction
Harvest Potential	the maximum volume of ground water that may be abstracted per area without depleting the aquifers. It is based on estimated mean annual recharge and a rainfall reliability factor, which gives an indication of the possible drought length.
Permeability	The rate at which a permeable material transmits a fluid, expressed as a length per unit time
Recharge	Rate of ingress or replenishment of water into an aquifer expressed as a volume or depth per unit of time
Residual drawdown	Drawdown remaining after abstraction stops relative to a static or natural water level

Storativity	The volume of water released from storage per unit decline in hydraulic head
Transmissivity	Rate at which an aquifer transmits water under a gradient of 1, commonly expressed as m^3/d/m width

GROUNDWATER SPECIALIST REPORT FOR THE PROPOSED THE DUEL COAL PROJECT

1. INTRODUCTION AND TERMS OF REFERENCE

1.1. Terms of Reference

WSM Leshika Consulting (Pty) Ltd was appointed to conduct the hydrogeological impact assessment of the proposed The Duel open pit and underground coal mining operation in the Limpopo Province, with specific reference to potential inflows into the pit and impact on water levels. Most of the investigations were conducted in 2016 with a verification census conducted in March 2019 and a report update in July 2019.

1.2. Background

The proposed The Duel Coal Project is situated on the remainder of the farm The Duel 186 MT, some 45 km south of Musina. It lies within the Makhado Local Municipality of the Vhembe District of Limpopo Province (figure 1-1). The proposed mining area is located within the Nzhelele drainage basin, 11 km west of the Nzhelele dam. It is situated immediately east of the Makhado mining right area.

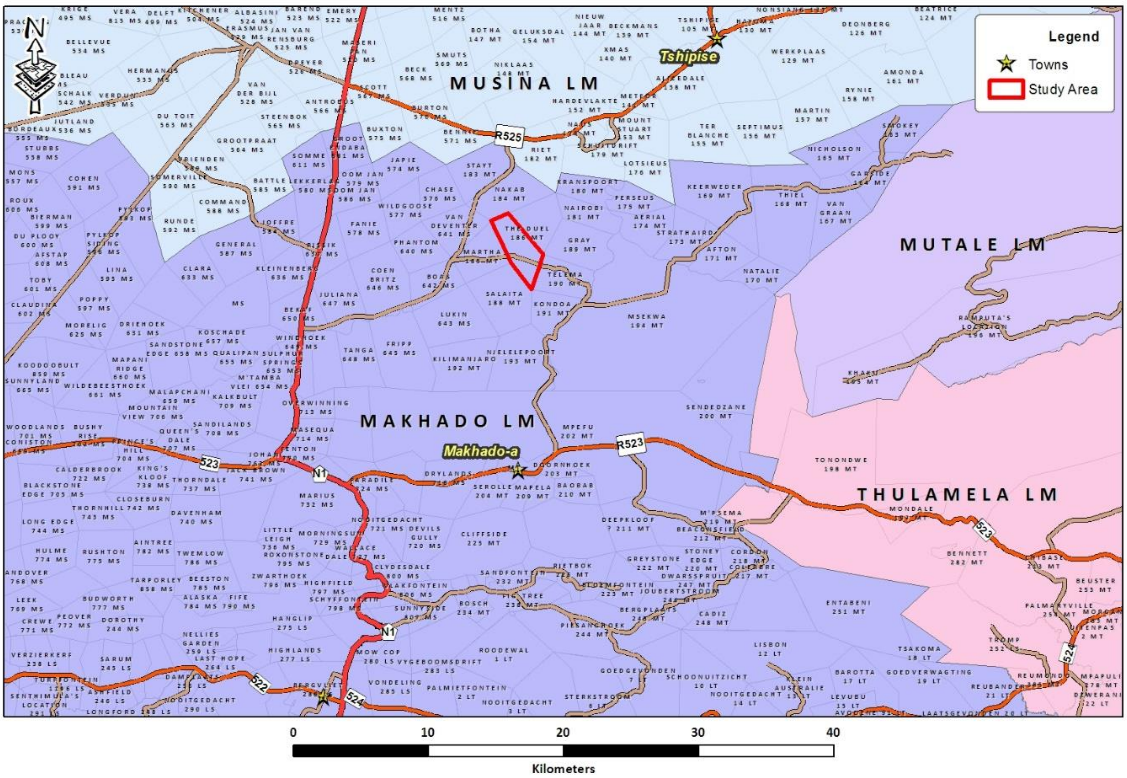

Figure 1-1 Locality of the Duel

In terms of Section 16 of the Mineral and Petroleum Resources Development Act (MPRDA), 2002 (Act 28 of 2002), a Prospecting Right (PR No: LP 1041 PR) was granted to Thandululo Coal Mining (Pty) Ltd (Reg. No: 2007/000084/97) on 07 November 2007, on the farms Lotsieus 176 MT, Kranspoort 180 MT, Nairobi 181 MT and The Duel 186 MT). The duration of this permission to explore was for 5 years after which a renewal application can be submitted to the Department of Mineral Resources (DMR). On 30 October 2012 the Directors of Thandululo Coal Mining (Pty) Ltd elected to cede the PR to Subiflex (Pty) Ltd (Reg. No: 2010/019233/07). The execution of this cession took place on 14 January 2013 and the Notarial Deed of Cession was registered with the Mineral and Petroleum Titles Registration office in Pretoria on the 27th of May 2013. Subiflex (Pty) Ltd submitted a Mining Right Application (MRA) for coal on the Remaining Extent of the farm The Duel 186 MT and is proposing to develop an underground and opencast coal mine.

It is assumed mining at the Duel will occur after mining at Makhado, to piggyback on the infrastructure developed for the much larger Makhado operation. Consequently, impacts from the Duel represent a combined regional impact from mining operations in the area. This report describes the existing groundwater status and the potential regional impact within the mining right application (MRA) area and the surrounding area; however, the impacts do not arise from operations at the Duel alone but are the cumulative impact of all mining operations.

1.3. Description of Project

The farm The Duel 186 MT, subdivided into two parts of which the MRA only covers the Remaining Extent portion, is a privately-owned farm used for game ranching. The areal extent of the property 888.5039 ha and the current surface owner is the Clint Howes Family Trust.

The proposed mine consists of an open pit operation, which will extend to a maximum of 270 m below ground surface, followed by underground operations. The mining plan envisages 24 years of open pit mining (figure 1-2).

The envisaged mining method for the open pit area is a conventional drill and blast operation with truck and shovel, load and haul. Underground mining operations will commence from Year 10 onwards for a period of 5 years. Access will be from selected positions in the open pit and the coal will be mined through the long-wall methodology to a depth of 730 m. After underground activities have been completed, the access to the underground areas will be closed followed by the final rehabilitation of the open pit.

The proposed infrastructure to be developed includes:

- Coal Handling Processing Plant;
- Overburden Waste Dump;
- Temporary Discard Dump;
- Haul roads;

- Pollution Control Dams;
- Raw water storage facility and distribution systems;
- Access road; and
- Auxiliary infrastructure includes a workshop and store, office and change house, electrical power supply and security fencing.

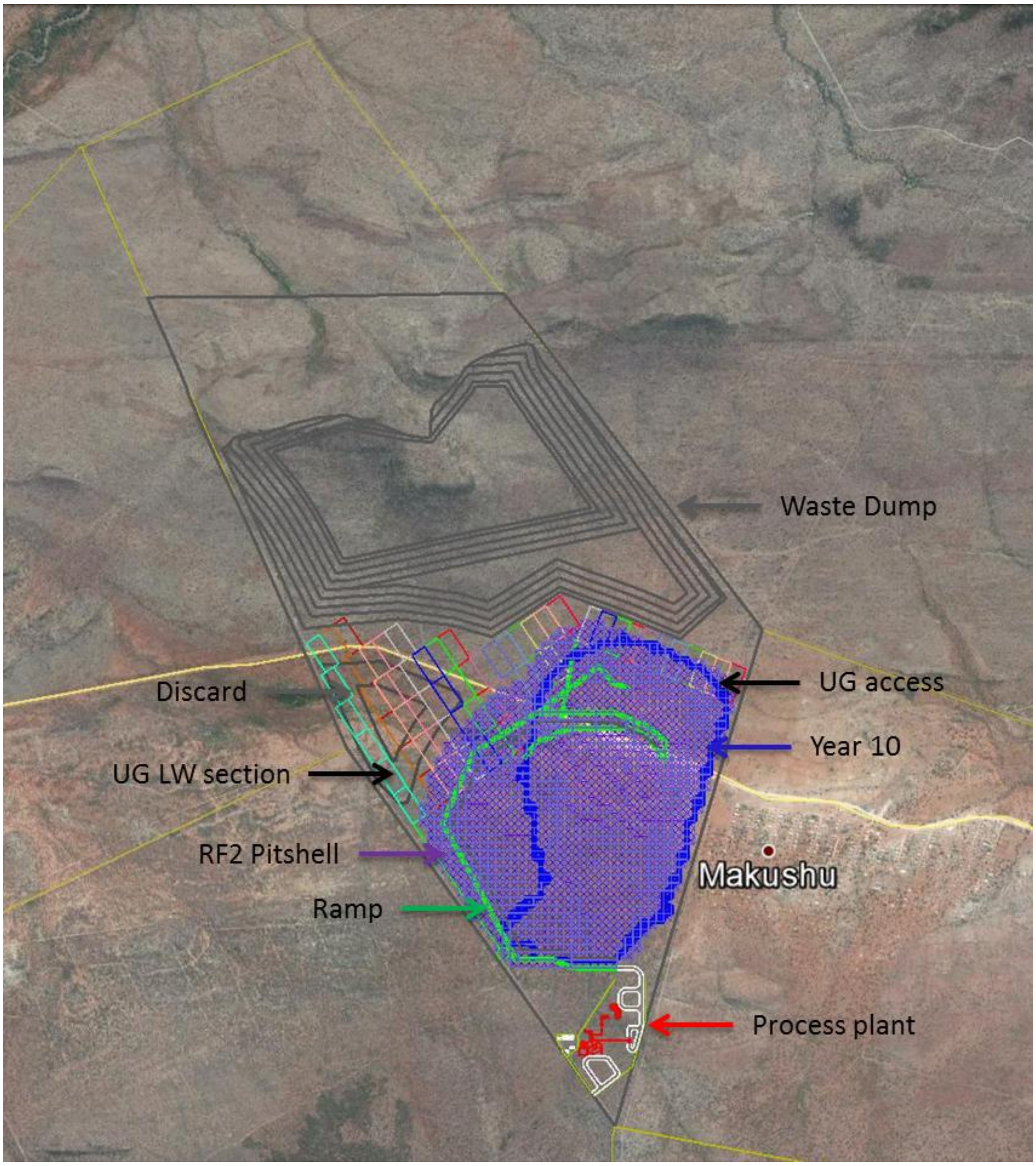

Figure 1-2 Open pit and underground layout and associated infrastructure

The proposed activities that could impact on groundwater include (figure 1-3):

- Abstraction of groundwater for dewatering and mine water use (fire protection, washdown, dust suppression, processing, potable water)

- A coal processing plant
- Overburden waste dump
- Temporary discard dump
- Pollution control dams
- Sewage

The ROM production rate is 2.4 Mtpa for the first 14 years after which an increase of ROM to 3.6 Mtpa can be sustained by the remaining amount of waste stripping required. The underground development starts in year 9 and production the year after in year 10, an average production rate of 1.2 Mtpa can be maintained for years 10 to 13 with a ramp down in year 14. A total Long wall advance of approximately 5800 m can be expected.

The final discard material from the plant will be disposed of in the mined-out open pit. In the event that the pit is unavailable due to existing mining activities, the discard material will be placed on an interim surface discard dump, from where it will be reclaimed and dumped into the mined-out open pit towards the end of the mine life as part of the rehabilitation of the mining site.

Several other mining operations are planned in the area; hence it is not possible to look at impacts of the Duel in isolation, but as a combined impact of all mining operations. The extent of proposed mining operations in the region is shown in figure 1-4.

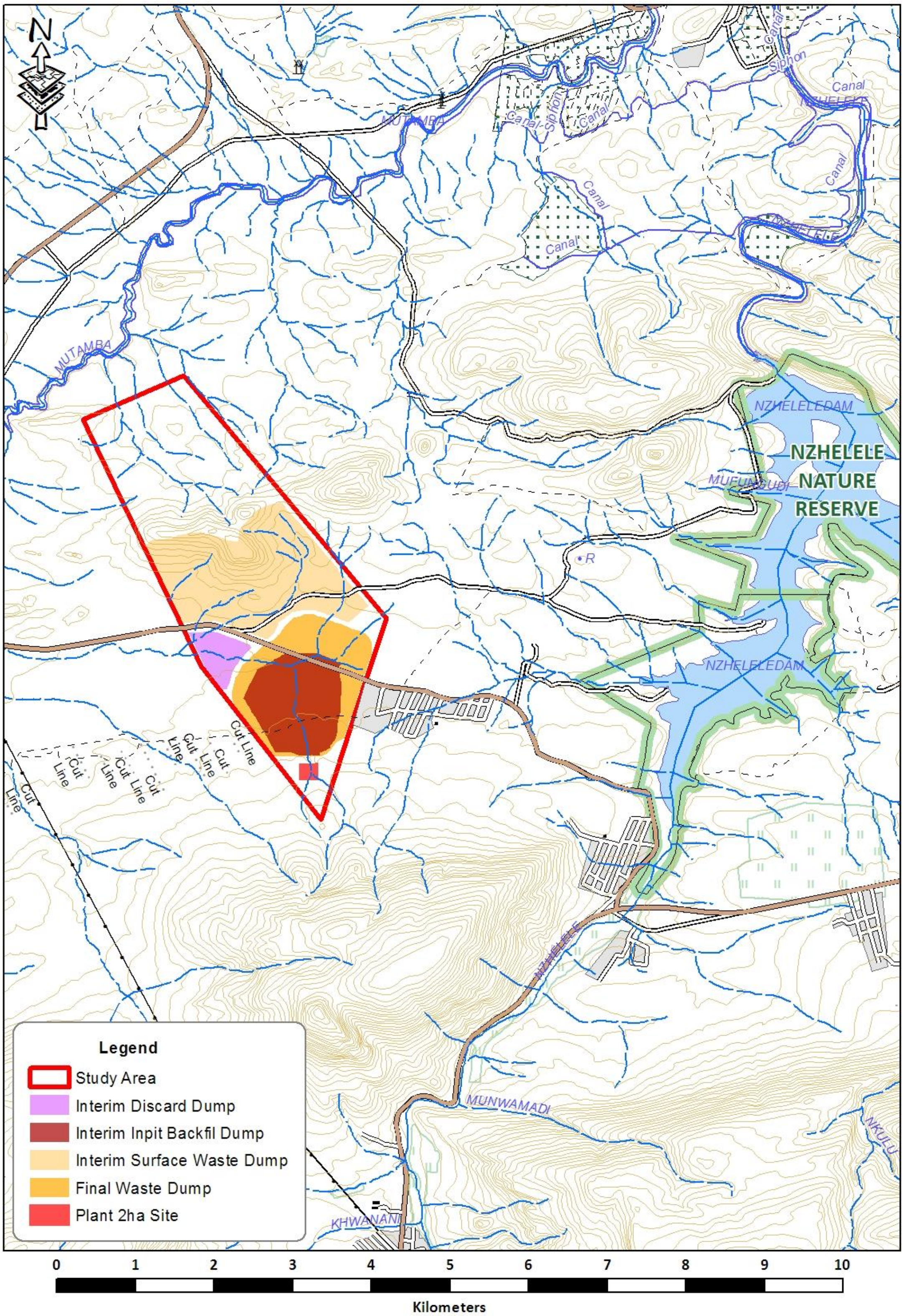

Figure 1-3 Mine infrastructure that could impact on groundwater

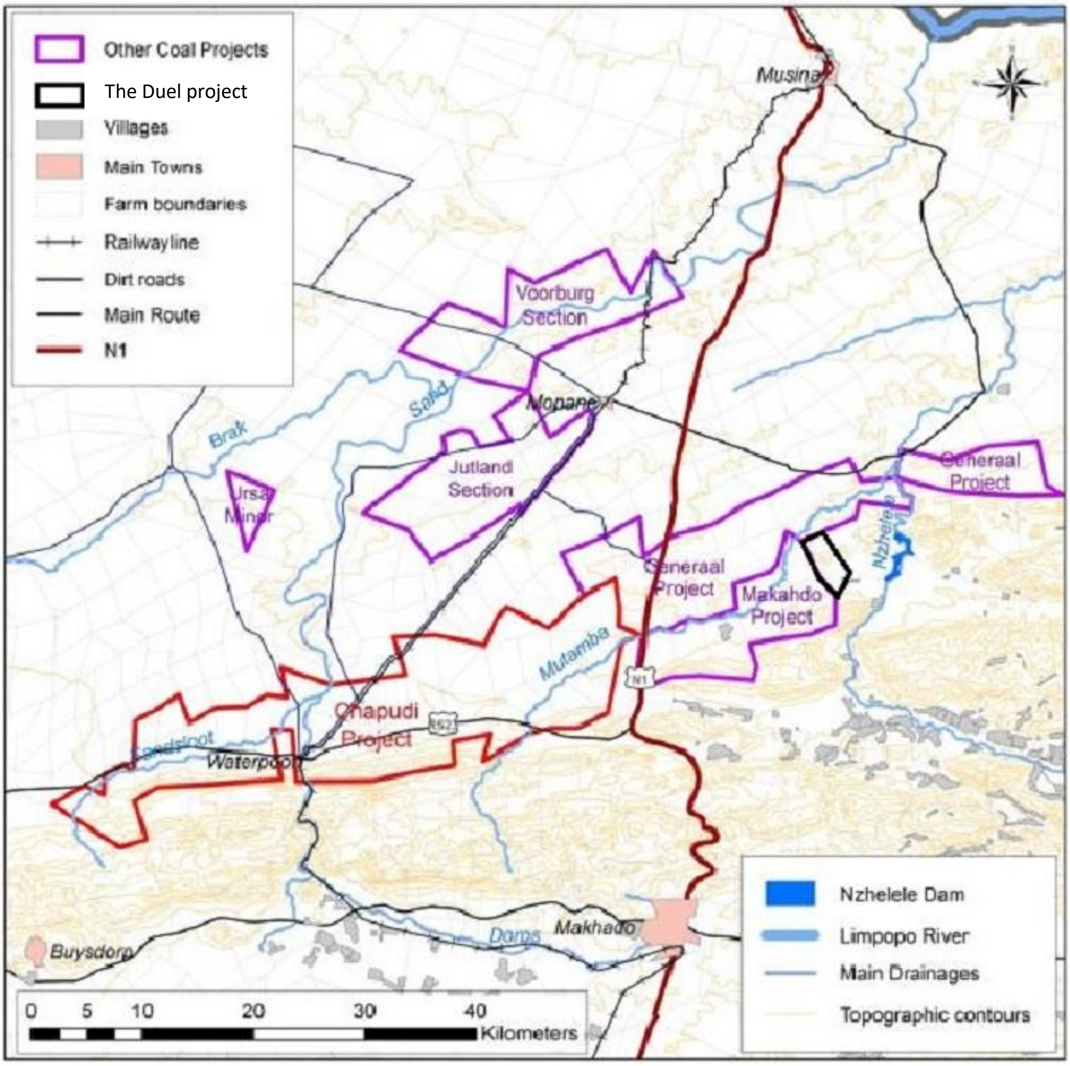

Figure 1-4 Other proposed coal mining operations in the region

1.4. Mining Methodology

1.4.1. *Open pit mining*

The open pit will be mined through conventional open pit methods, namely truck and shovel. The process for mining method involves stripping, drilling, blasting, loading and hauling of overburden to the waste dump and ROM stockpile or processing plant area.

The mine will operate 365 days per annum on a 24-hour basis with shifts rotating on 2- by 12-hour duration 7 days a week.

The height of the mining benches is usually determined according to physical characteristics of the mineralisation. The decision regarding the bench height to be used is very much dependent on the ore body and the distribution thereof in the host rock. For the open pit operation at The Duel Coal Project, drilling and blasting would be performed on 10 m and 15 m high benches, the height will be driven by the lead and lag per elevation lift. The pit high wall areas can be mined in 15 m benches whereas sections of the pit floor will be more suitable to a 10 m bench height approach. Drilling would require drill rigs that could drill up to 15 m benches. Diesel-powered truck and shovel operations, in combination with an effective drill and blast plan, are well understood, highly flexible and have significant manufacturer support. At this stage of the project, a standard drill, blast, truck shovel operation would be considered the lowest operating risk mining method, in terms of both cost and productivity. As such, the diesel-powered heavy-duty truck and shovel operation has been selected as the base case for this study. The loading conditions are expected to correspond closely to a large-scale open pit site; a maximum pit depth of 270 m is envisaged.

1.4.2. *Underground mining*

The longwall mining method would be applied to all of the possible UG reserves at The Duel Coal Project. The UG Longwall (LW) mining has been split into an upper and lower section. The upper LW section will be accessed directly from the pit high wall in year 10. A spiral ramp access will be initiated from the ramp system in the South Western section of the pit (figure 1-5).

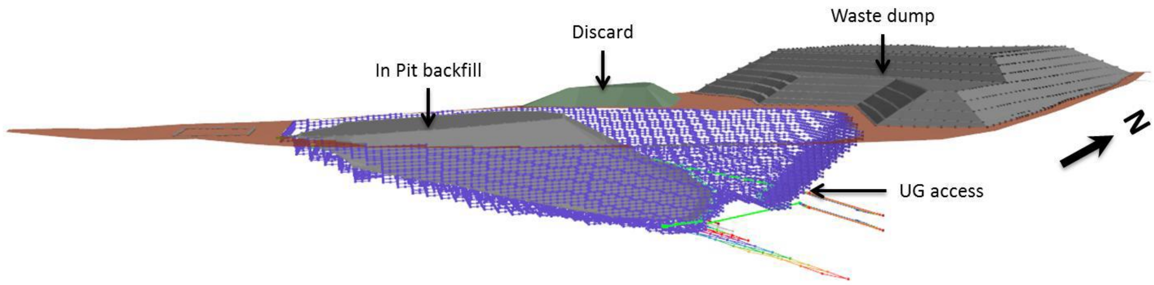

Figure 1-5 Cross section of underground mining

Development mining is where the underground roadways are constructed in preparation for longwall mining. The roadways provide access for men, machinery, ventilation air, water, electricity, communication systems and coal clearance conveyors. Typically, five metres wide and three metres high, the roadways are constructed down the length of the longwall panel which is usually over two kilometres long. Coal is cut by a continuous miner to form the roadways and the roof is secured using steel mesh and roof bolts. The main purpose of development mining is to form the rectangular blocks (longwall panels) that will be removed by the longwall miner. At the Duel Coal Project, the longwall panels are 190 metres wide and up to 1.3 kilometres long, while the shortest is 0.25 km. The coal seam is 130 metres below the surface at its shallowest point and 730 metres below the surface at the deepest point.

1.5. Mine Scheduling

The schedule runs over a period of approximately 24 years at a ROM production rate of 2.4 Mtpa for the first 14 years after which an increase of ROM to 3.6 Mtpa can be sustained by the remaining amount of waste stripping required. A ramp up period over the first two years of production has been accounted for. A pre-strip year of 10.5 Mt of which 0.5 Mt ROM would be stockpiled has been planned. The second year will gradually increase production to 75% of the full production output that would be realised from year 3.

The underground development starts in year 9 and production the year after in year 10, an average production rate of 1.2 Mtpa can be maintained for years 10 to 13 with a ramp down in year 14. A total Long wall advance of approximately 5800 m can be expected. Underground yields are higher than the open pit as a selected mining cut can be mined.

1.6. Waste Dumps

The following waste sites are to be considered from a project footprint of 554.8 ha (figure 1-6):

- Open pit area: 200 ha
- Interim discard dump: 30 ha
- Overburden dump 250 ha
- Plant area: 75 ha

In pit waste dumping will be utilised and the remaining waste accommodated in interim dumps during mining. The final waste dump will cover the pit and rise to 710 mamsl, 40-50 m above the original ground surface.

The total tonnage of waste rock generated is shown in figure 1-7. Total tonnage is 776 M tonnes.

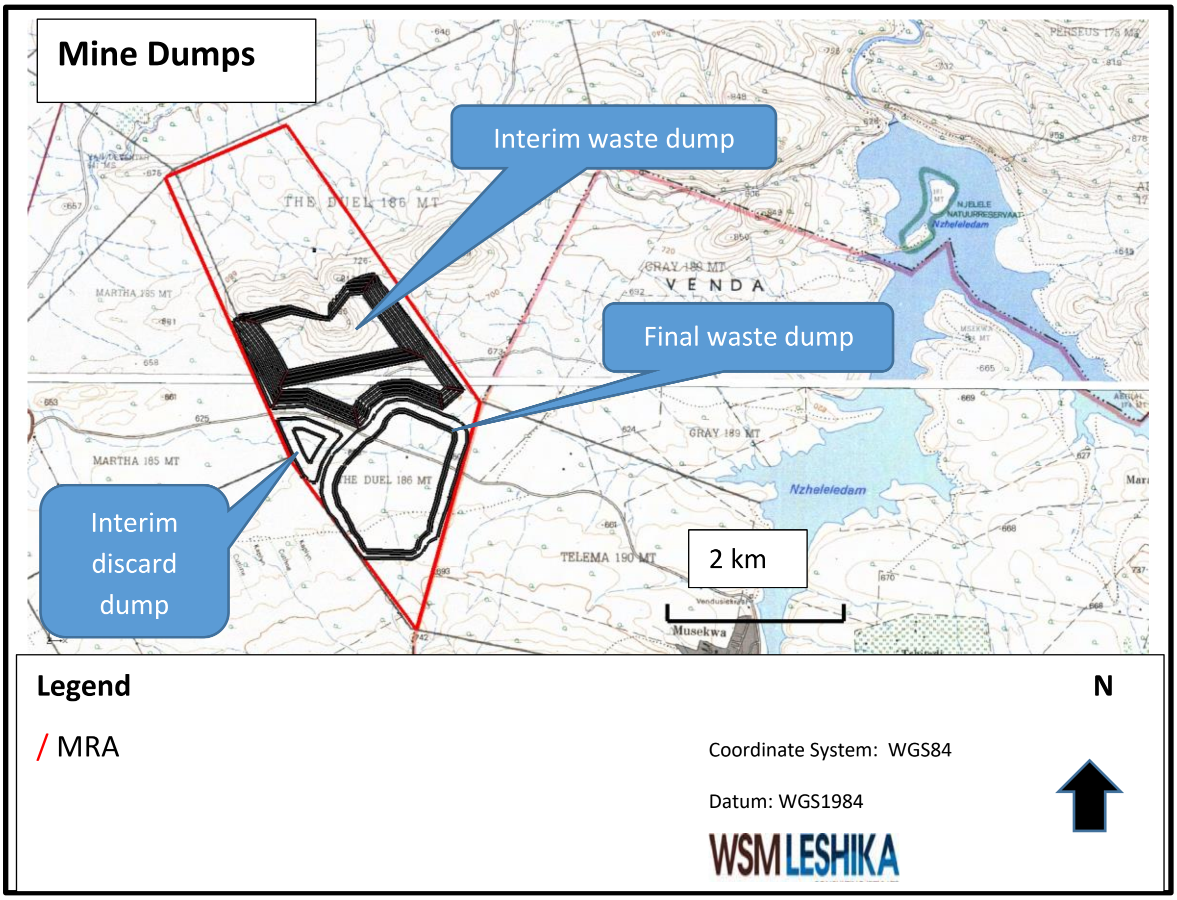

Figure 1-6 Location of waste dumps

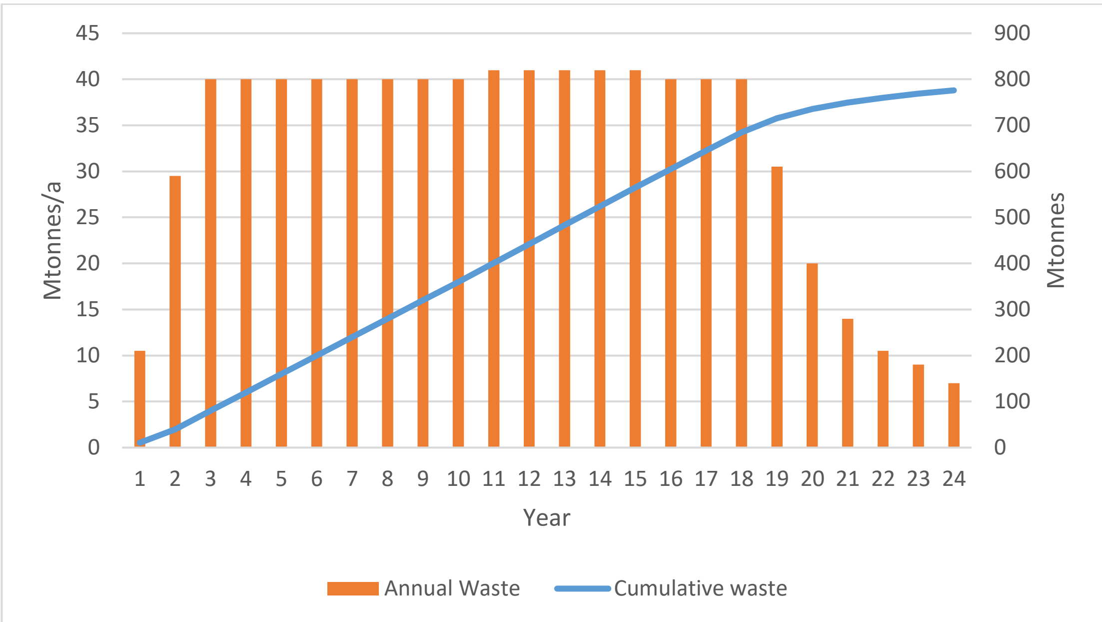

Figure 1-7 Waste rock generation

1.7. Applicable Legislation

1.7.1. *South African Legislative and Standards Frameworks*

The methodology followed in the impact assessment is largely prescribed by the legal requirements, as elaborated on in the Department of Water and Sanitation's best practice guidelines. In this regard the following Acts and guideline documents are of relevance:

- Mineral and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002) and relevant regulations which deals primarily with the equitable management of the nation's mineral and petroleum resources.
- National Environmental Management Act (NEMA) (Act 107 of 1998) and relevant regulations. The main aim of the NEMA is to provide for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment.
- National Water Act (NWA) (Act 36 of 1998) and relevant regulations.
- Government Notice No. 704 (GN 704) (4 June 1999) on the use of water for mining and related activities aimed at the protection of water resources.
- South African Water Quality Guidelines (2nded) Volume 1: Domestic Use; Volume 7: Aquatic Ecosystem, DWAF (1996).

1.7.2. *RELEVANT SECTIONS OF THE NATIONAL WATER ACT (ACT 36 OF 1998)*

The following Sections of the NWA described below are regarded as important, but other sections may also be applicable in the proposed development:

Section 1.(1) of the NWA defines the following interpretations:

(i) "aquifer" means a geological formation which has structures or textures that hold water or permit appreciable water movement through them;

(ii) "borehole" includes a well, excavation or my artificially constructed or improved underground cavity which can be used for the purpose of—

a) Intercepting, collecting or storing water in or removing water from an aquifer;

b) Observing and collecting data and information on water in an aquifer; or

a) Recharging an aquifer;

(iii) "catchment", in relation to a watercourse or watercourses or part of a watercourse, means the area from which all rainfall will drain into the watercourse or watercourses or part of a water course, through surface flow to a common point or common points;

(iv) "Pollution" means the direct or indirect alteration of the physical, chemical or biological" properties of a water resource so as to make it:

(a) Less fit for any beneficial purpose for which it may reasonably be expected to be used: or

(b) harmful or Potentially harmful to the welfare health or safety of human beings; to any aquatic or non-aquatic organisms; to the resource quality: or to property;

Section 19 states that the person who owns, controls, uses or occupies land on which any activity or process is or was undertaken, or any other situation exists which causes, has caused or is likely to cause pollution of a water resource is responsible for taking all reasonable measures to prevent such pollution from occurring, continuing or recurring.

Section 21 broadly defines "water use" to include:

(a) taking water from a water resource:

(b) storing water:

(c) impeding or diverting the flow of water in a watercourse:

(d) engaging in a stream flow reduction activity contemplated in section 36;

(e) engaging in a controlled activity;

(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit:

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

(h) disposing in any manner of water which contains waste from. or which has been heated in. any industrial or power generation process;

(i) altering the bed, banks. course or characteristics of a watercourse:

(j) 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: and

(k) using water for recreational purposes,

Section 22(1) regulates the use of water:

- Without a license:
  - If the water use is permissible under Schedule 1 of the Act;
  - If the water use is permissible as a continuation of an existing authorised use (s32-s35);
  - If the water use is permissible in terms of a General Authorization issued under s39;
- If the water use is authorized by a license under the NWA; or
- If the responsible authority dispensed with a license requirement in terms of 22(3).

Section 41 sets out the procedures for applying for a water use license (WUL).

1.7.3. *GOVERNMENT NOTICE NO. 704 (4 JUNE 1999) ON THE USE OF WATER FOR MINING AND RELATED ACTIVITIES AIMED AT THE PROTECTION OF WATER RESOURCES*

Summary of the Government Notice:

Mining and associated infrastructure development is guided by the provisos in the GN, particularly regulations 3, 4, 6 and 7, which are described as follows:

- **Regulation 3** – this regulation states that the Minister may in writing authorize an exemption from the requirements of Regulations 4, 5, 6, 7, 8, 10, or 11 on his or her own initiative or on application, subject to conditions determined by him or her.

- **Regulation 4** – this regulation addresses the locality of developments, where estimated flood zone widths are set as buffer zones for development, or zone widths are prescribed. These include the following:
  - No facility, including residue deposits, dam, reservoir to be located within the 1:100-year floodline or within 100m from any watercourse, borehole or well.
  - No underground or opencast mining or any other operation or activity under or within the 1:50-year floodline or within a horizontal distance of 100m, whichever is the greatest.
  - No disposal of any residue or substance likely to cause pollution of a water resource in the workings of any underground or opencast mine.
  - No placement of any sanitary convenience, fuel depots or reservoir for any substance likely to cause pollution within the 1:50-year floodline.

- **Regulation 7** – this regulation addresses the measures to protect water resources and includes the collection and re-use, evaporation or purification of water containing waste; measures to be taken to minimize the flow of any surface water into any mine or opencast workings; prevention of erosion or leaching of materials from any stockpile; ensuring that process water is recycled as far as practicable.

2. INVESTIGATION OBJECTIVES

2.1. Objective

The project is to prepare the geohydrological components of an Environmental Authorisation:

- Description of the geohydrological environment.
- Prediction of the environmental impacts of the proposed activity on the geohydrological regime of the area.
- Propose mitigation measures based on physical, hydraulic and hydro-geochemical information as gathered and predicted in the preceding phase.

2.2. Scope of Work

The geohydrological assessment consisted of:

- Detailed site inspection for the mapping of relevant geohydrological features
- Data collection of existing information from topographical maps, ortho-photos, geological maps, hydrological information, meteorological information, borehole information.
- Borehole/spring census in the area to assess groundwater utilisation by neighbours
- Groundwater flow modelling to predict the long-term impacts on the receiving environment and to quantify expected mine inflows
- Collection of water quality samples for geochemical analysis, including macro and micro constituents
- Collection of geological samples for XRF, XRD and Acid Base Accounting analysis
- Contaminant transport modelling to predict the migration of contaminants
- Assessment of the possible environmental impacts and to conceptualise mitigation measures.
- Recommendation for groundwater monitoring

2.3. Deliverables

The report was to provide information on the groundwater resources of the study area, including:

- location and use of all groundwater abstraction systems i.e. boreholes, wells and springs
- aquifer characteristics and conceptual model of the groundwater regime
- present depth to water table and historical water level fluctuations
- groundwater resource evaluation which would include estimates of recharge and storage capacities
- groundwater availability
- groundwater quality
- aquifer vulnerability
- groundwater/surface water interaction
- numerical groundwater model
- groundwater balance pre-, during and post mining
- evaluation of potential inflows into the proposed mining area

- geochemistry and potential pollution plumes
- evaluation of the impact of mining on the groundwater system
- shortcomings and limitations of the results
- recommendations for further work and the implementation of a monitoring system

3. INVESTIGATION METHODOLOGY

3.1. Hydrogeology

The methodology followed consisted of:

- A site inspection for the mapping of relevant geohydrological features such as water users and receiving water bodies;
- The collection of existing information from: topographical maps, satellite imagery and geological maps;
- The collection of recharge and baseflow data from the GRAII data base (Groundwater Resources Assessment II), meteorological information from WR2012 (Water Resources of South Africa 2012), borehole data from the NGA;
- A borehole/spring hydrocensus of the area to assess groundwater utilisation by neighbours and borehole water levels;
- The undertaking of pumping tests to determine aquifer characteristics;
- The collection, analysis and evaluation of groundwater chemistry data (quality & quantity);
- The collection of geological samples for geochemical analysis;
- Groundwater flow and transport modelling utilising the MODFLOW and MT3D groundwater models to determine the groundwater balance, the piezometric surface and flow orientation, and to predict the potential area of impact;
- An assessment of the possible environmental impacts;
- A conceptualisation of mitigation measures for the identified impacts;
- Formulating recommendations for a groundwater monitoring network.

3.2. Hydrochemistry

Core analysis and leach tests from cores located in the vicinity of the Duel were undertaken during the Makhado investigation (CoAL, 2011). This geochemical investigation included:

- Alkalinity, paste pH and paste EC determinations
- Acid Base Accounting, to determine whether the materials are acid producing

- Na/Cl leach testing for readily available metals
- “Acid Rain leach testing, to determine the medium to long term leaching behaviour of the materials in an aqueous environment
- “TCLP leach testing, to determine the total leachable fraction for inorganic analytes.

Alkalinity was determined using the USEPA Standard Operating Procedure for GLNPO Total Alkalinity (1992). The pH and EC methods were derived from MEND (1991).

The acid base accounting protocol of MEND (1991) was used in this study.

Total carbon and sulphur concentrations were determined by Eltra CS 800 Carbon and Sulphur Analyser.

The Distilled water leach test was undertaken to determine the presence and concentrations of chemicals of concern that are weakly bound to the sediment, and which would thus be more likely to report to the environment should the chemistry of the sediments be disturbed. The procedure utilises 1 g of sediment extracted at room temperature for one hour with 8 mℓ sodium chloride solution (95 g/ℓ NaCl, pH 7).

The Acid rain and TCLP leach solutions were analysed by ICP-MS (MerckVI) by Perkin Elmer ELAN 6000 ICP-MS, Perkin Ekmer ELAN 9000 ICP-MS and Perkin Elmer ELAN DRC II ICP-MS and by ion chromatography by Dionex QIC Ion Chromatograph.

The Acid Base accounting, XRD and XRF analysis was done during this investigation from core samples obtained on The Duel

4. SITE DESCRIPTION

4.1. Locality

The project area is located in the magisterial district of Vhembe, in the Limpopo Province, approximately 45 km south of Musina, and 35 km NE of Louis Trichardt (54 km by road) (figure 4-1) on the Remaining Extent of the farm The Duel 186 MT.

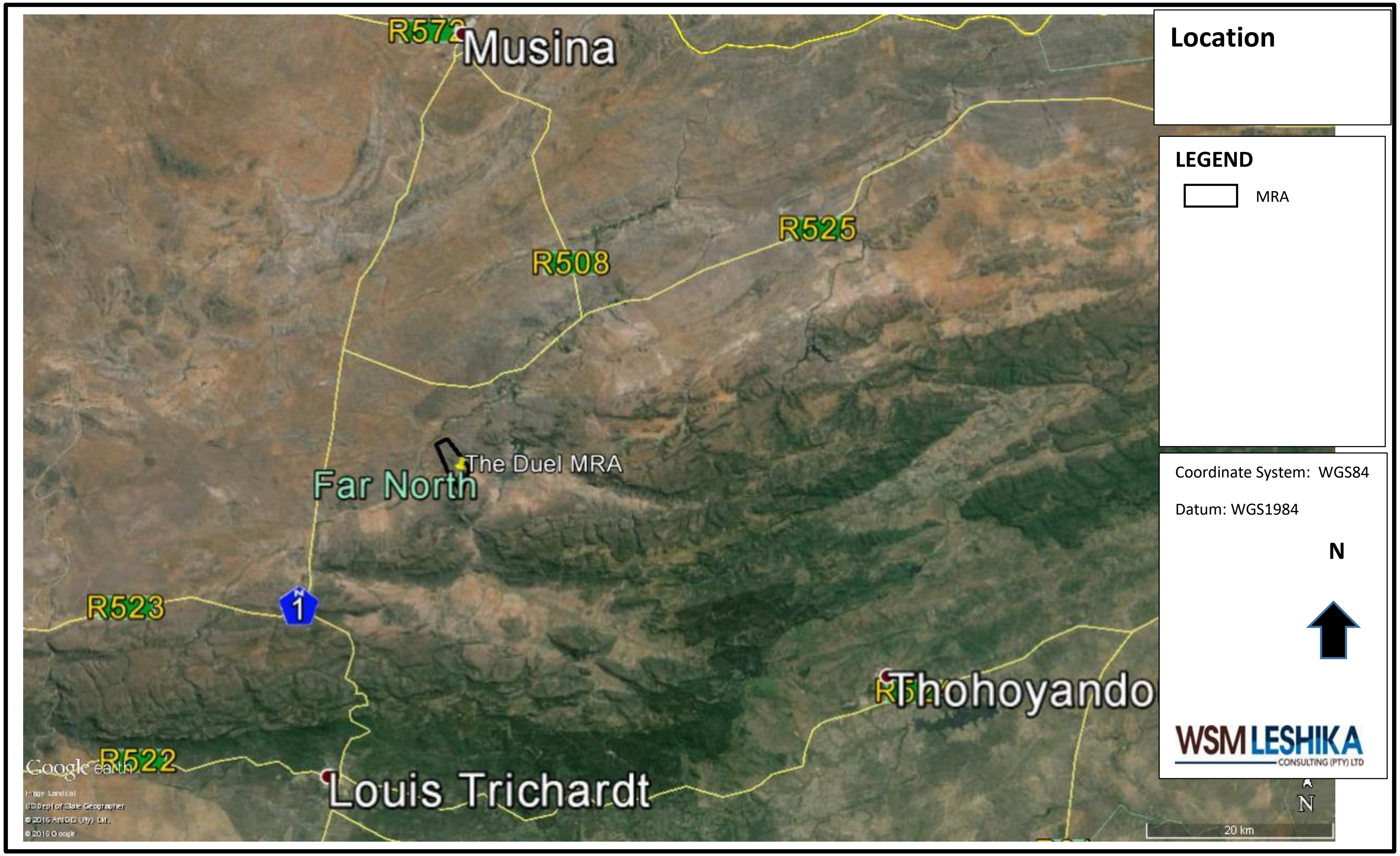

Figure 4-1 Location of the Duel

The site is accessed via the N1 or the R525, via the dirt road to Nzhelele dam and Musekwa. The mine is at 22 ^{0}45’ 28”S, 30^{0}02’ 23”E. The farm The Duel 186 MT is subdivided into two parts of which the MRA only covers the Remaining Extent portion, is a privately-owned farm used for game ranching. The areal extent of the property 888.5039 ha and the current surface owner is the Clint Howes Family Trust (figure 4-2).

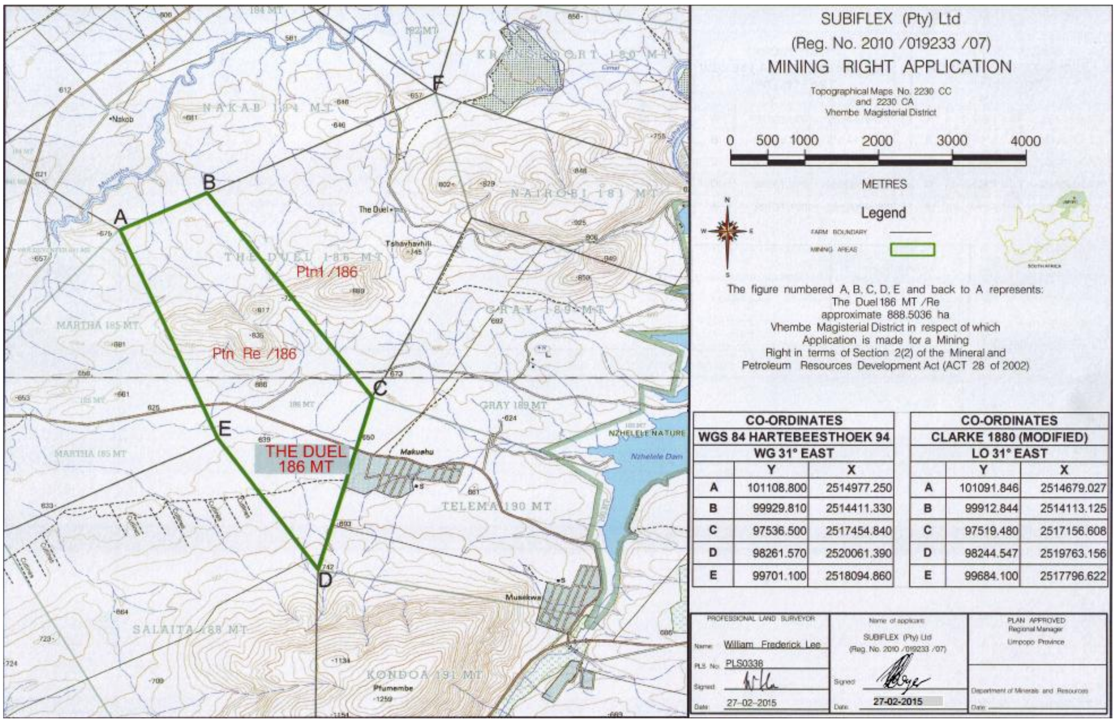

Figure 4-2 MRA of the Duel coal project

The nearest town is Tshipise, 20 km to the NE by road, and the nearest settlement is Makushu, 50 m to the SE. The Nzhelele Nature Reserve is situated immediately to the east of the MRA area, with the Nzhelele Dam situated roughly 4 km further to the east. The area surrounding the mine mainly consists of game farms for hunting and ecotourism and the village of Makushu to the south-east (figure 4-3). Some of the properties are also focused on mixed farming, with a mixture of livestock, game and irrigated agriculture. The site also lies directly to the east of the Makhado mining right area. The Mutamba River flows to the NE west and north of the MRA.

Hunting, game trading and eco-tourism is an established socio-economic driver in the area. There are a number of properties utilised for trophy (for local and foreign tourists) and biltong hunting with ecotourism spin-off activities.

4.2. Topography

The regional gradient is to the NE, with the Mutamba River draining the catchment in which the Duel is located (figure 4-4). The mine pit itself is located on a local gradient towards the west, towards the Mutamba, which drains NE towards the Limpopo.

The pit area lies on relatively flat land between 643-680 mamsl (figure 4-5).

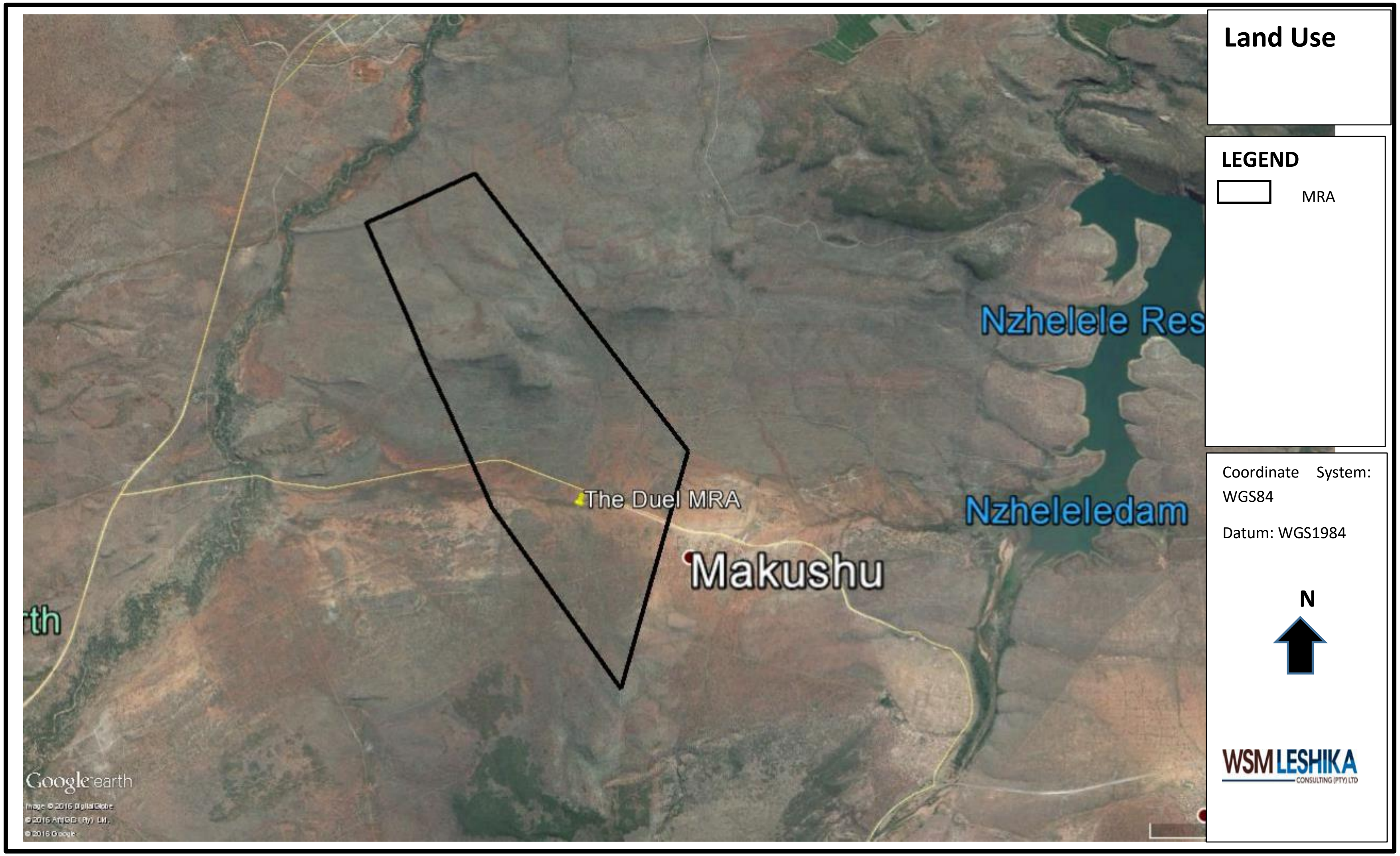

Figure 4-3 Land use in the vicinity of the Duel

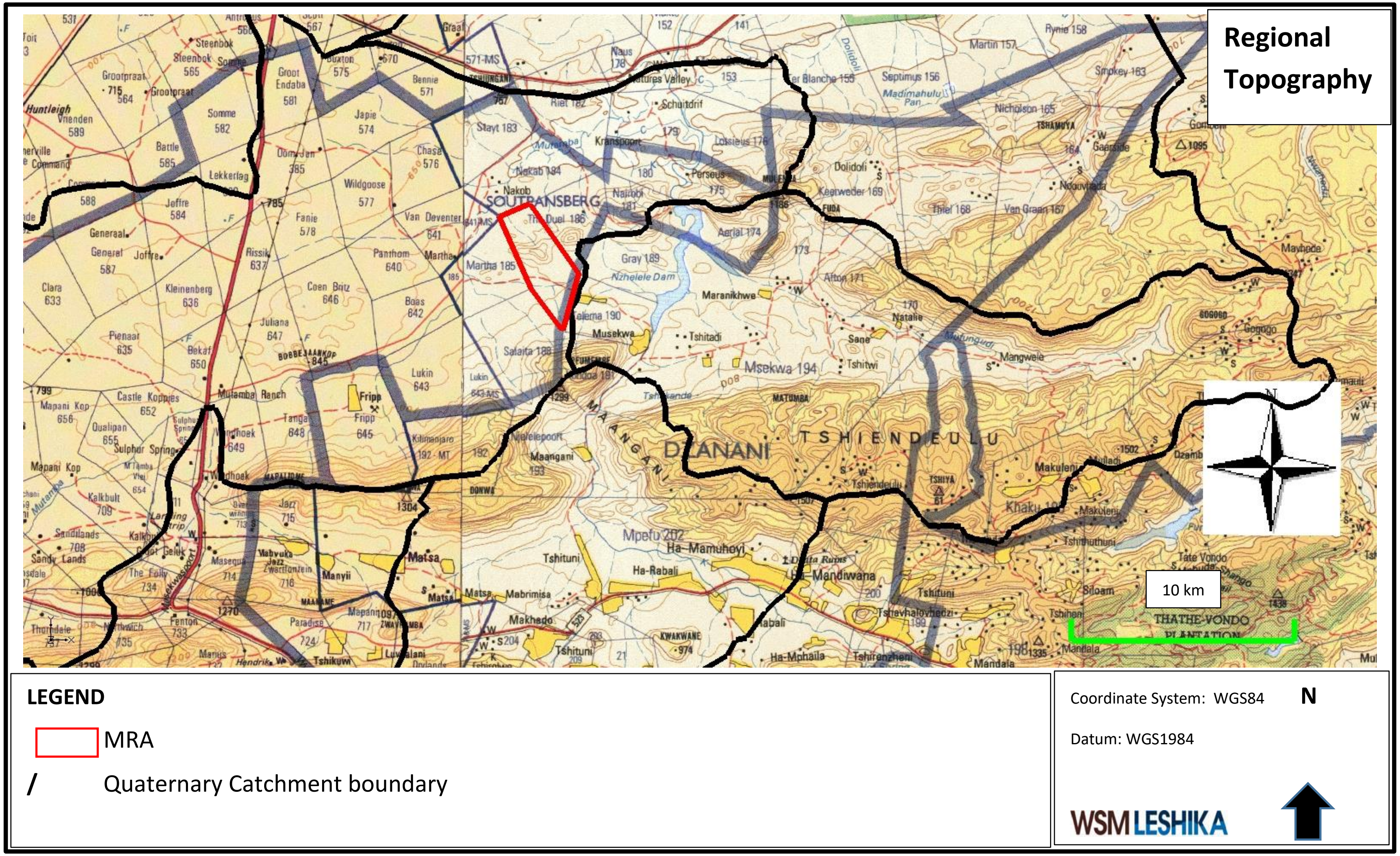

Figure 4-4 Regional topography

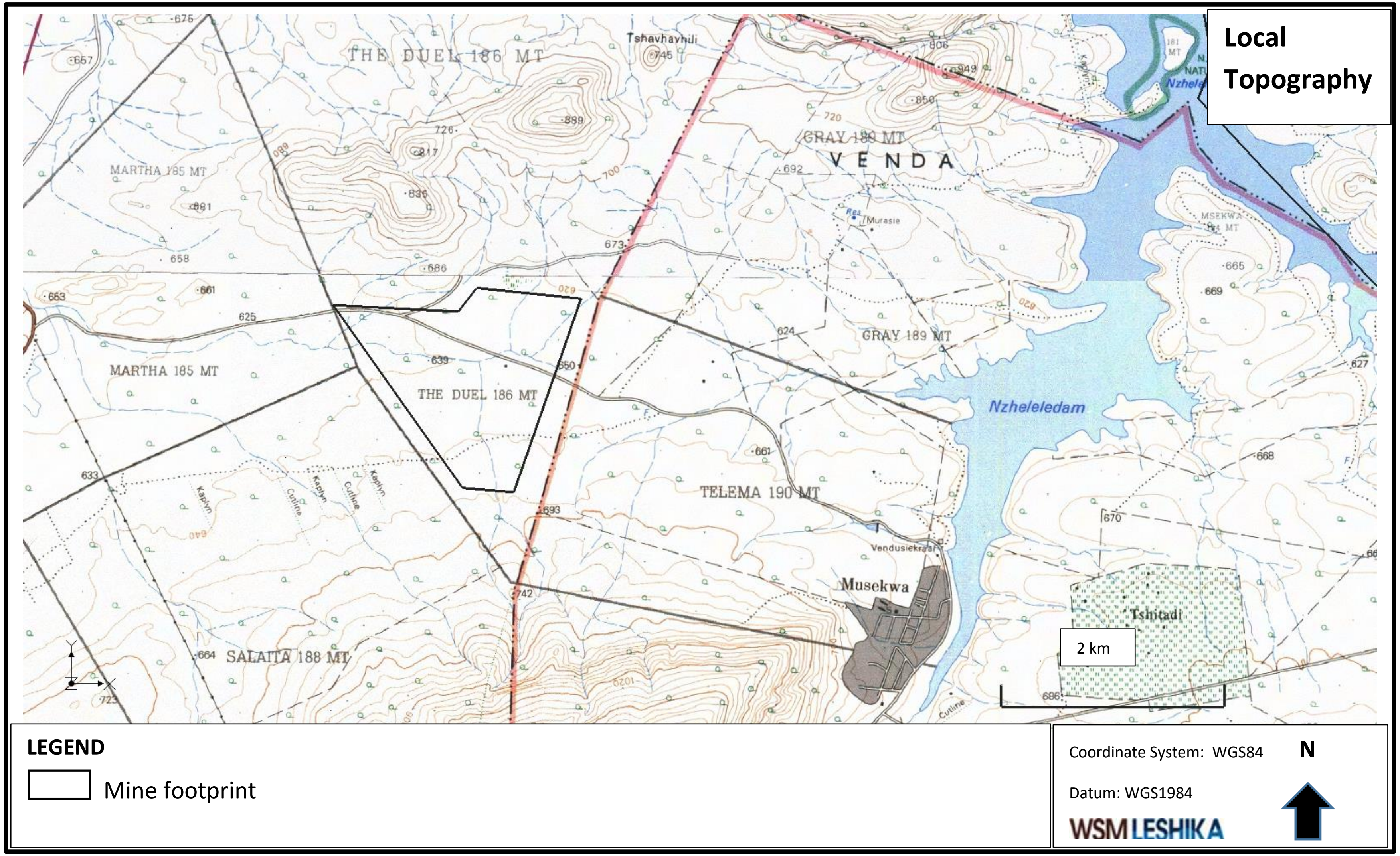

Figure 4-5 Local topography around the footprint of the mine pit

The topography of the study area is largely controlled by the underlying geology. Intermittent low hills occur regionally, and the area is bounded in the south by the Soutpansberg Mountains. The Mutamba River valley is underlain by the relatively young Karoo deposits and the mountain range is made up of Soutpansberg quartzite and lavas which are considerably older and more weather resistant. The Clarens sandstone forms a range of hills with vertical cliffs on the northern bank of the river. The slope rises at an inclination of 1:24 towards the mountains to the south, steepening to 1:3 up the mountain face.

4.3. Climate

4.3.1. *Regional Climate*

The Duel Coal Project area is situated in a hot 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.

North of the Soutpansberg rainfall decreases to between 400-500 mm (figure 4-6). High precipitation occurs on the Soutpansberg which creates high local runoff.

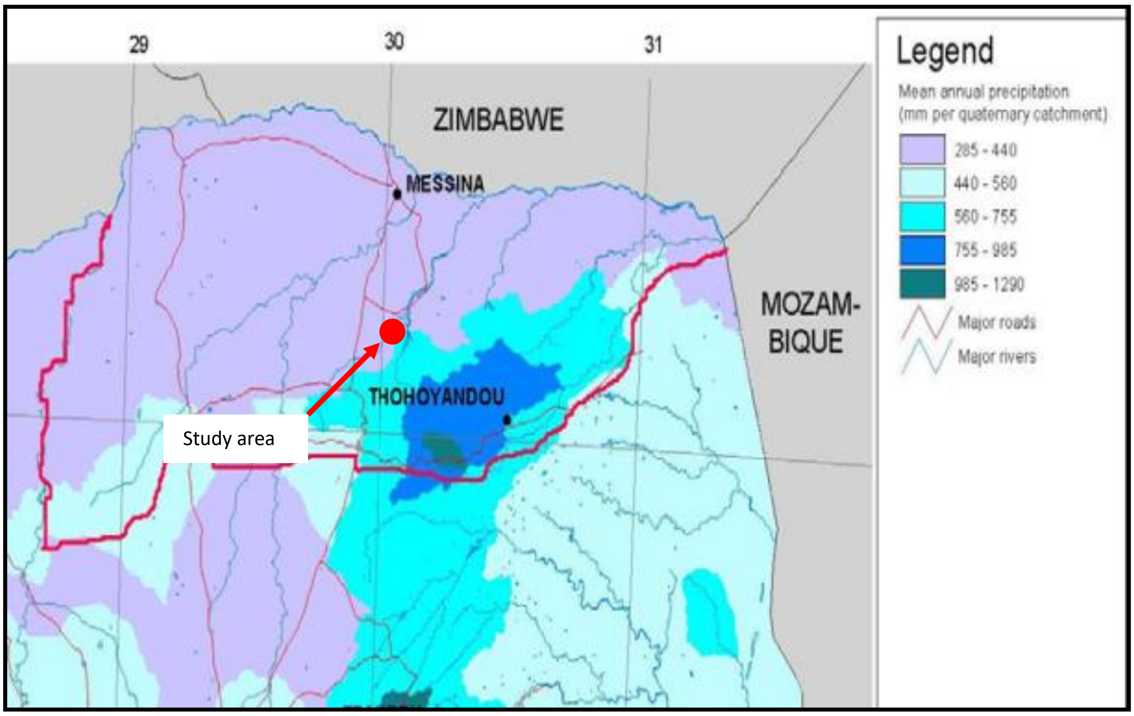

Figure 4-6 Distribution of mean annual precipitation in Limpopo Province

The mountains give rise to wind patterns that play an important role in determining local climates. These wind effects include wind erosion, aridification and air warming.

The area is characterised by cool, dry winters (May to August) and warm, wet summers (October to March); with April and September being transition months

4.3.2. *Mean annual precipitation and mean monthly rainfall*

The rainfall data from WR2012 for Rainfall Zone A8A and Quaternary A80F covers the period 1920 to 1989. A total of eight rainfall gauges were used in compiling the average rainfall and for most of the period three or more gauges had usable data. The rainfall station records available in A80F are shown in table 4-1. The rainfall data has been extrapolated to 2010 in WR2012.

The mean and maximum monthly precipitation values for quaternary catchment A80F in which the MRA area is located, is shown in figure 4-7. The annual rainfall is shown in figure 4-8.

The mean annual rainfall is 388 mm/a from 1920-1989. 85% of rainfall falls between October and March (figure 4-7).

Rainfall is highly variable and has been recorded as varying between 187 mm/a and 1038 mm/a (figure 4-8), with 6-8 year cycles of wet and dry periods. Based on the annual rainfall pattern, return periods of droughts were calculated using a Generalised Extreme Value Distribution (figure 4-9). The 100-year drought is approximately 186 mm/a.

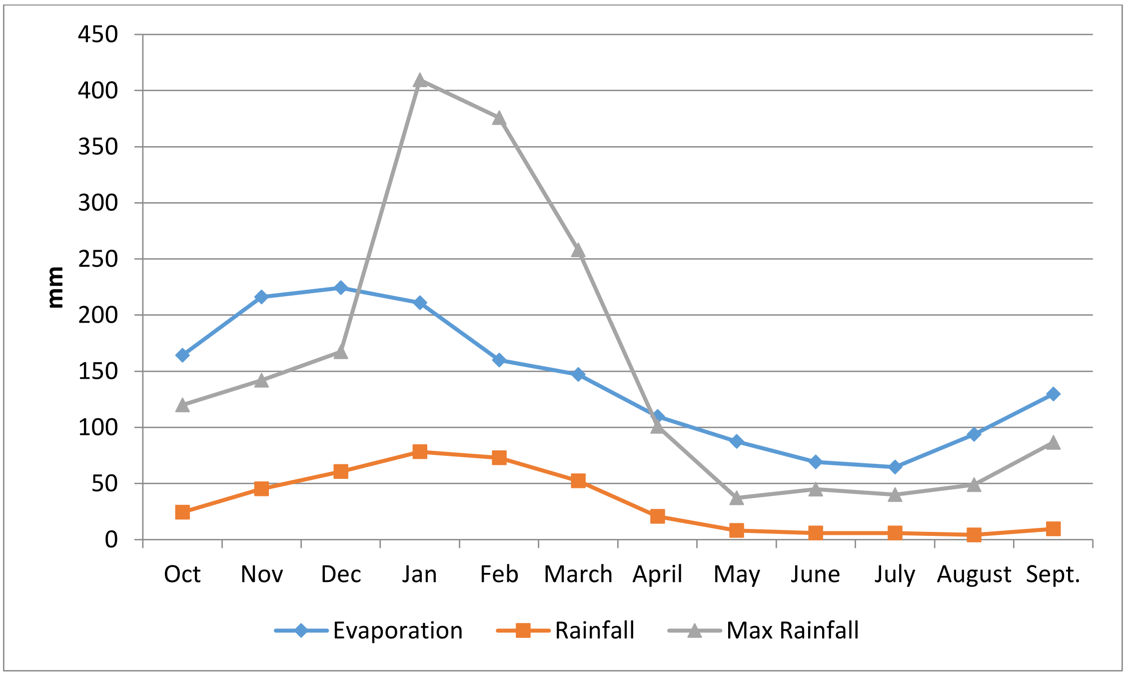

Figure 4-7 Monthly rainfall and evaporation

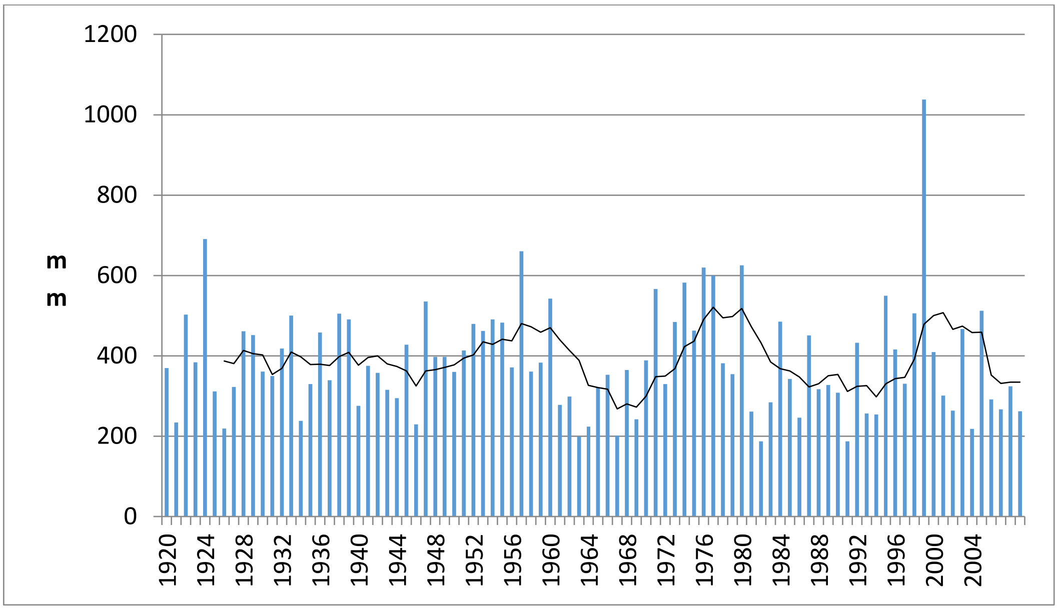

Figure 4-8 Annual rainfall and 7 year moving average

Table 4-1 Rainfall data

Station Number	Years of record	Latitude	Longitude	MAP (mm)
765/708	1978-1989	22.48	29.48	373
765/825	1927-1962	22.45	29.58	338
766/133	1933-1954			318

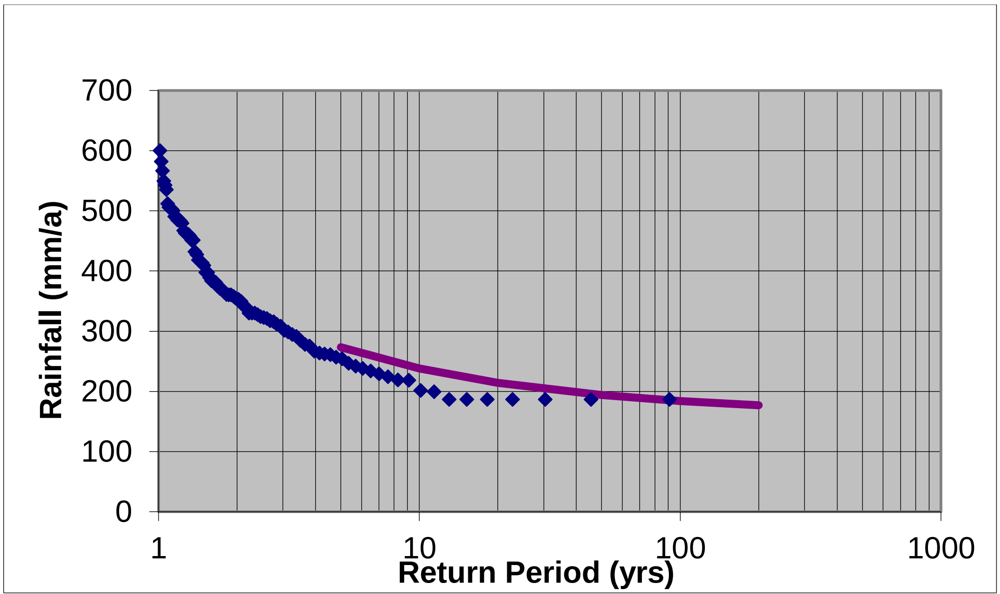

Figure 4-9 Drought rainfall Return period

4.3.3. *Temperature*

Average monthly minimum and maximum temperatures for the Tshipise weather station (No. 0766277 1) some 20 km north-east of the MRA area is shown in Table 4-2. 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 4-2 Average temperature for Tshipise Weather Station for period 1920 to 1963

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)

4.3.4. *Evaporation*

The Mean annual S-pan evaporation is 1750 mm/a.

Evaporation data taken from the WR2012 Study shows that the mean annual S-pan evaporation for quaternary catchment A80F is 1750 mm. Catchment potential evapotranspiration exceeds rainfall in all except in exceptionally wet months (figure 4-7). Table 4-3 shows the monthly evaporation patterns (as percentages of the annual).

Table 4-3 Monthly evaporation patterns for quaternary catchment A80F (Symons Pan)

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

4.4. Drainage

The study area is situated in the quaternary catchment A80F of the Mutamba River, near the watershed with A80C (figure 4-10). A80F extends over an area of 630 km^2 and the Mutamba flows from SW to NE through the centre of the catchment. The Mutamba River joins the Nzhelele River at the outlet of the catchment, downstream of the Nzhelele dam. A80C flows into the Nzhelele dam. The upper reaches of the Mutamba River (catchments A80D and A80E) flow off the mountainous terrain to the south with a relatively high rainfall (MAP of 622mm) and run-off. In comparison the plains to the north of the mountains and in catchment A80F have a relatively low rainfall (388mm MAP) with very little run-off reaching the river. Runoff that does occur is therefore generated mostly from the upper sub-catchments.

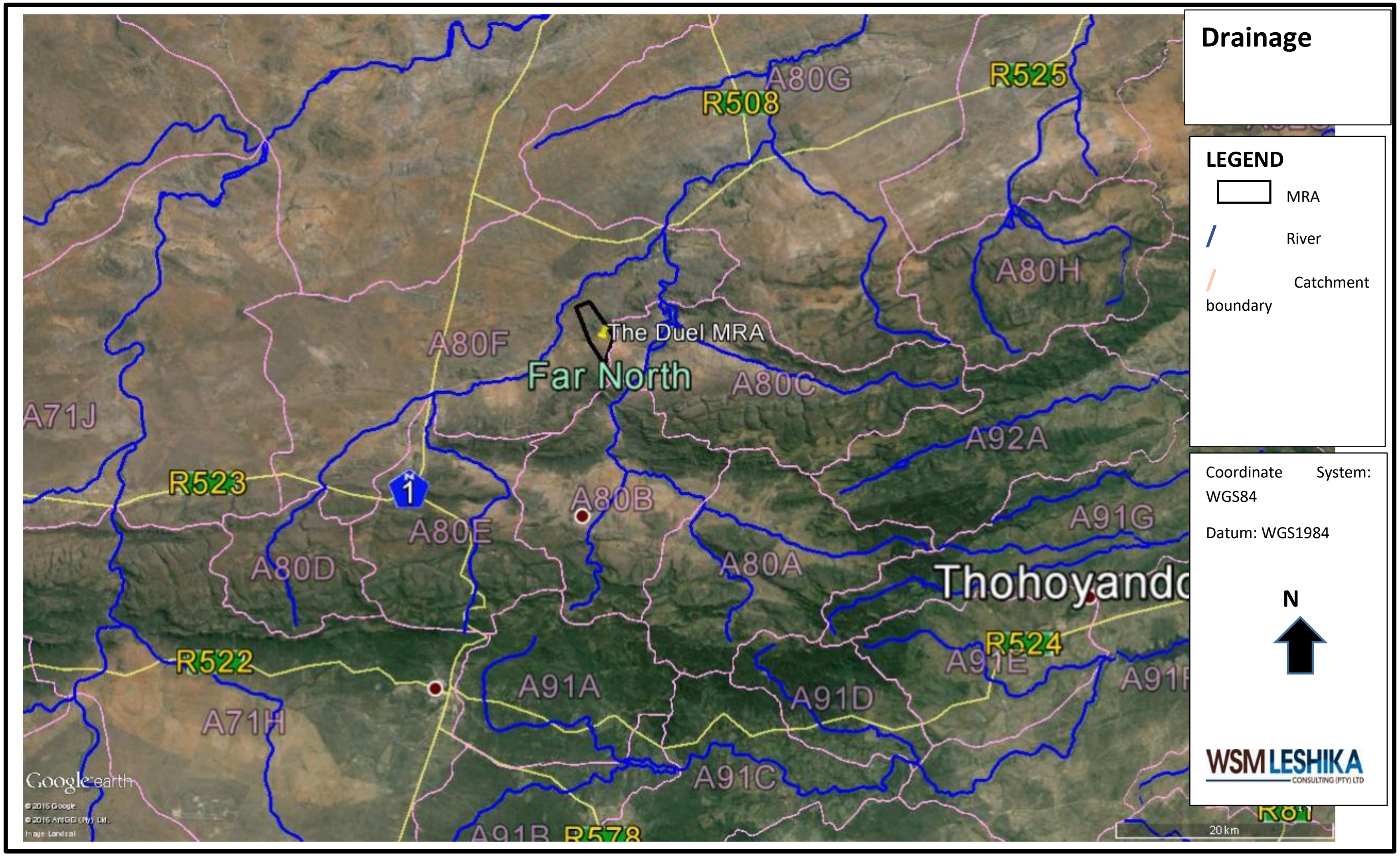

Figure 4-10 Drainage network

Parts of A80F are endoreic, with internal drainage that does not flow into the Mutamba. The nett catchment area that contributes runoff is 491 km^2 (WR2012).

The quaternary catchment to the south-west, A80E, loses water to the underlying aquifer before it enters A80F, as flow in the river disappears before it reaches the Mutamba River. This is corroborated by groundwater quality data, which shows significantly fresher water near this tributary than in the remainder of the Karoo aquifer underlying the Mutamba main channel. Water losses from the main channel of the Mutamba to the regional aquifer appear to be minimal, since water quality in the Karoo aquifer shows a progressive salinization northward towards the Mutamba, with no dilution effects from inflows of fresh water from the Mutamba. River losses therefore remain in the alluvium, to be utilised by riparian vegetation.

The natural Mean Annual Runoff generated in A80F is 8.3 mm/a, or 4.06 million m^3/a.

No significant impoundments or abstractions for water supply or irrigation are recorded in the catchment. There is also no water use for alien vegetation or afforestation.

4.5. Soils and Vegetation

The soils consist of sandy loams. These are of the form:

Leptosols. Shallow soils over hard rock or highly calcareous material but also deeper soils that are extremely gravelly and/or stony. Leptosols are generally free draining soils.

Luvisols. Soils in which clay is washed down from the surface soil to an accumulation horizon at some depth. The soils are most common in flat or gently sloping land in cool temperate regions and in warm regions with distinct wet and dry seasons. Most Luvisols are well drained but shallow ground water may occur in depression areas.

The vegetation is classified as Tropical Bush and Savannah (Bushveld) under the Acocks veld types, with Musina Mopane Bushveld and Soutpansberg Mountain Bushveld as the main vegetation types. The typical vegetation occurring within the study area is characterized by medium to high shrub dominated savannah, with scattered trees and a dense field layer.

5. GEOLOGY

5.1. General Geology of the Area

The regional geology consists of 3 main lithological groups i.e. The Limpopo Mobile Belt, the Soutpansberg Group and the Karoo Sequence rocks:

The Limpopo Mobile Belt (LMB) basement occurs as an up thrown block on the farms Juliana, Coen Britz and Boas and is comprised of meta-quartzite, mafic granulite and amphibolite. It forms the gneissic basement on which the overlying strata (Soutpansberg Group and the Karoo Sequence) were 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 3200Ma (million years) to 2000Ma.

The LMB gneisses are made up of intra-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.

<u>The Soutpansberg/Waterberg Group</u> strata were deposited into rift basins controlled by these major fault systems between 1900 Ma and 1600 Ma. The strata consist of basaltic lavas, arenites and shales attaining a maximum preserved thickness of 5000m. Dip direction is to the north and can vary from 20° to 80°. The strata form the mountainous and hilly terrain in the study area. The strata in the south, dip northwards at 25 - 30º becoming more variable northwards with dips ranging between 10 and 45º. The Soutpansberg strata have been duplicated by normal faulting, resulting in the parallel sets of E-W trending mountain ranges. The Soutpansberg Group is represented in the study area by the following (from oldest to youngest);

i) The Wylliespoort Formation - pink quartzite and forms the backbone of the Soutpansberg mountain ranges.

ii) The Musekwa Formation - amygdaloidal basalt with minor clastic and pyroclastic rocks.

iii) The Nzhelele Formation – red shale, shaley sandstone and quartzite.

<u>The Karoo Sequence</u> strata were deposited on LMB basement and/or Soutpansberg Group strata between 300 – 180 Ma. Karoo deposits are preserved in the same reactivated 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).

<u>Quaternary Deposits</u> occur in two localities near the study area i.e.

1. Along the banks of the Mutamba river consisting of alluvial sand and pebbles.
2. At the base of the Soutpansberg range where it consists of boulder conglomerate with a fine sandy matrix and was formed by the reworking of slope scree.

The Duel lies within the *Soutpansberg Coalfield,* which is situated north of the Soutpansberg Mountain Range in the Limpopo Province and stretches for ± 190km from Waterpoort in the west to the Kruger National Park in the east. The Soutpansberg Coalfield can be divided into 3 separate coal fields i.e. the Mopane Coalfield, the Tshipise Coalfield and the Pafuri Coalfield (Figure 5-1).

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 of Africa Limited mining projects (Figure 5-1). The Mopane Coalfield, lies between the towns of Mopane and Waterpoort in the west and is the target of 2 mining projects:

- The Chapudi Project
- The Mopane Project

The Tshipise Coalfield, stretching east of the town of Mopane to Tshipise and is the target of 2 further mining projects:

- The Makhado Project
- The Generaal Project

The Duel Coal Project is located within this coal field. The property is situated on the eastern boundary of the Makhado Project.

5.2. Local Geology

The Duel Coal Project area is underlain by Karoo sediments (figure 5-2) deposited unconformably on Soutpansberg strata (figure 5-3). The Karoo sediments terminate along its northern limit against a normal faulted contact with Soutpansberg strata and forming an on-lapping sedimentary contact along the southern margin. For purposes of representation the Karoo Sequence is divided into Lower Karoo, Middle Karoo, the Clarens Formation and the Letaba basalts.

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

- Tshidzi Formation; a 10m thick basal conglomerate/diamictite and can be correlated to glacial Dwyka Tillite in the main Karoo basin. These strata are not always present.
- The Madzoringwe Formation; 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.
- The Mikambeni Formation overlying the above consists of dark grey mudstone and shale with subordinate sandstone attaining an approximate thickness of 140 m. 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;

- The Fripp Sandstone Formation consists (10 – 20 m thick) 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. The Fripp is an easily identifiable marker in the core separating the middle Karoo sediments from the carbonaceous lower Karoo.
- The Solitude Formation; is a 110 m thick inter-layered grey and purple shale with minor sandstone and grit intercalations.

- The Klopperfontein Formation (10 – 20 m thick) resembles the Fripp Sandstone Formation as coarse, feldspathic “gritty” sandstone.
- The overlying Bosbokpoort consists of red very fine sandstone and dark red silty mudstone.
- The fluviatile Red Rocks Member (150 m thick) of the overlying Clarens Formation for the purposes of this explanation is grouped with the Middle Karoo strata.

The Tshipise Member (150 m thick) of the Clarens Formation caps the underlying fluvial sediments with aeolian sands as the final expression of sedimentary deposition in an ever increasingly arid environment.

The Letaba basalt caps 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. There is no basalt in the study area, but dykes and sills of the same age were intersected in the exploration drilling.

Dolerite dykes and sill cause disruption of the host rock and can act as aquifers. Dolerite sills and dykes served as feeders to the basalt lava stage of Karoo Sequence deposition. The dolerite dykes in the study area have a WNW, NE and EW trend. Secondary fracturing associated with dykes and sill intrusion could be water bearing.

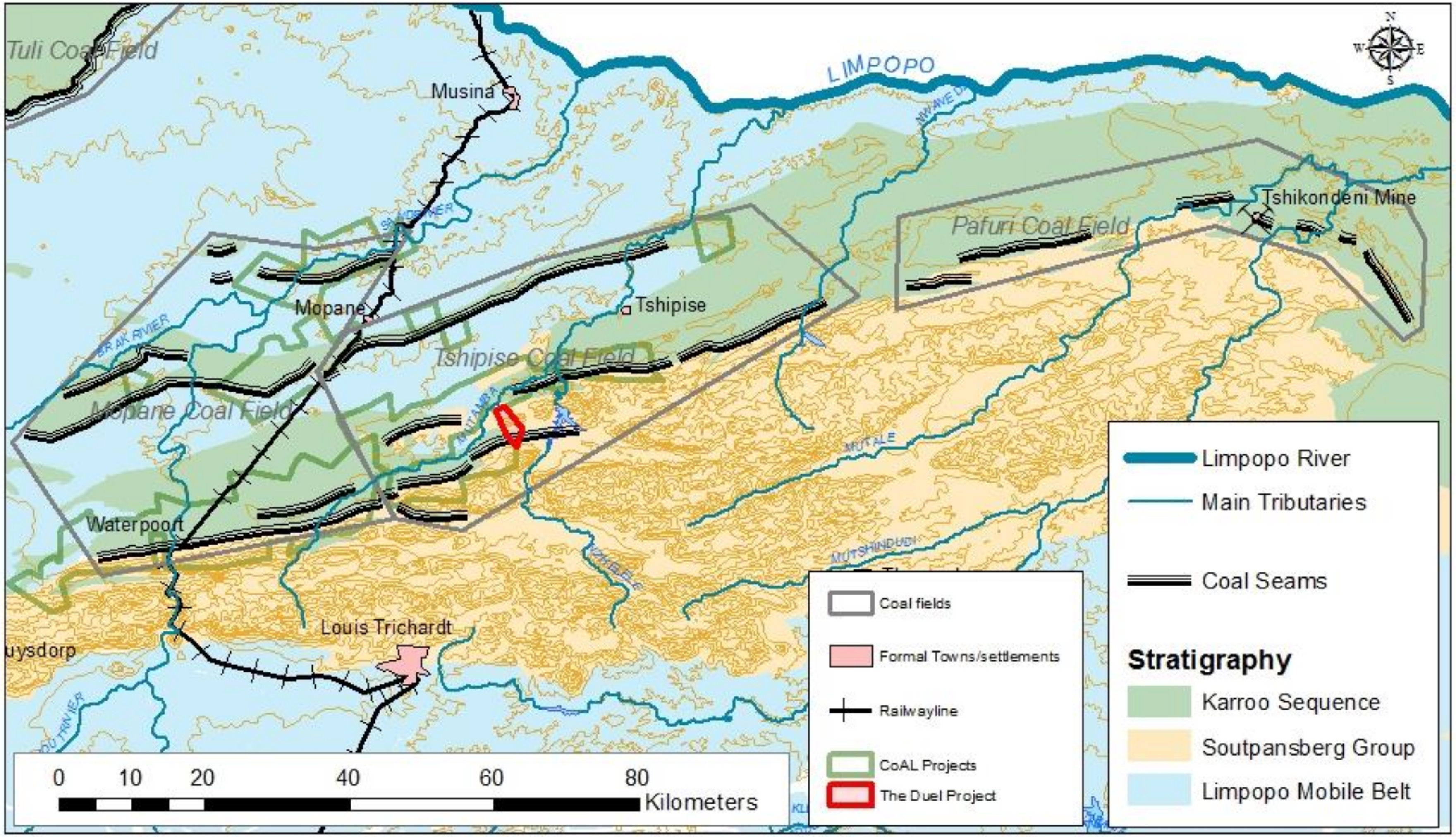

Figure 5-1 Regional geology and coal fields

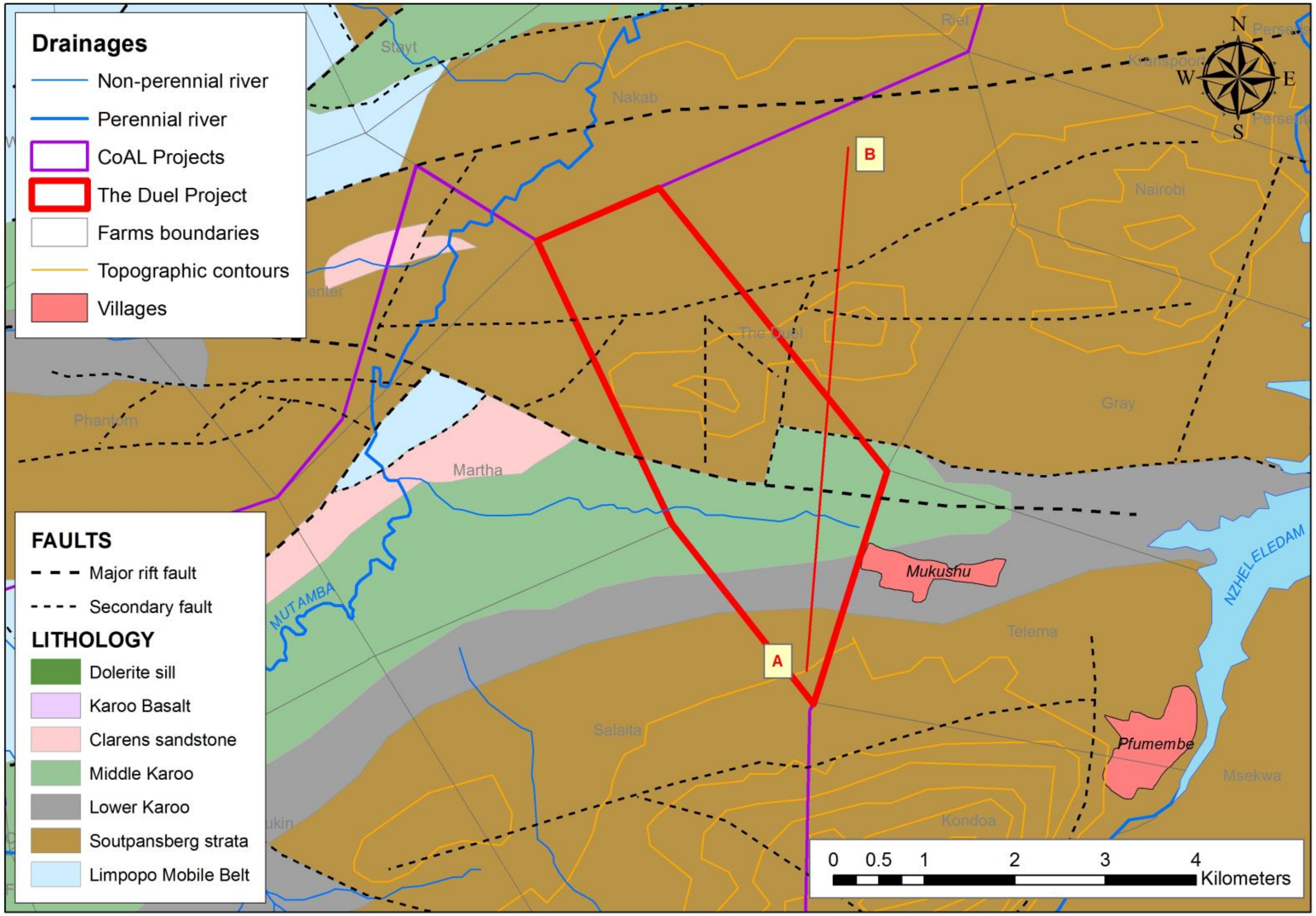

Figure 5-2 Local geological map and location of cross section

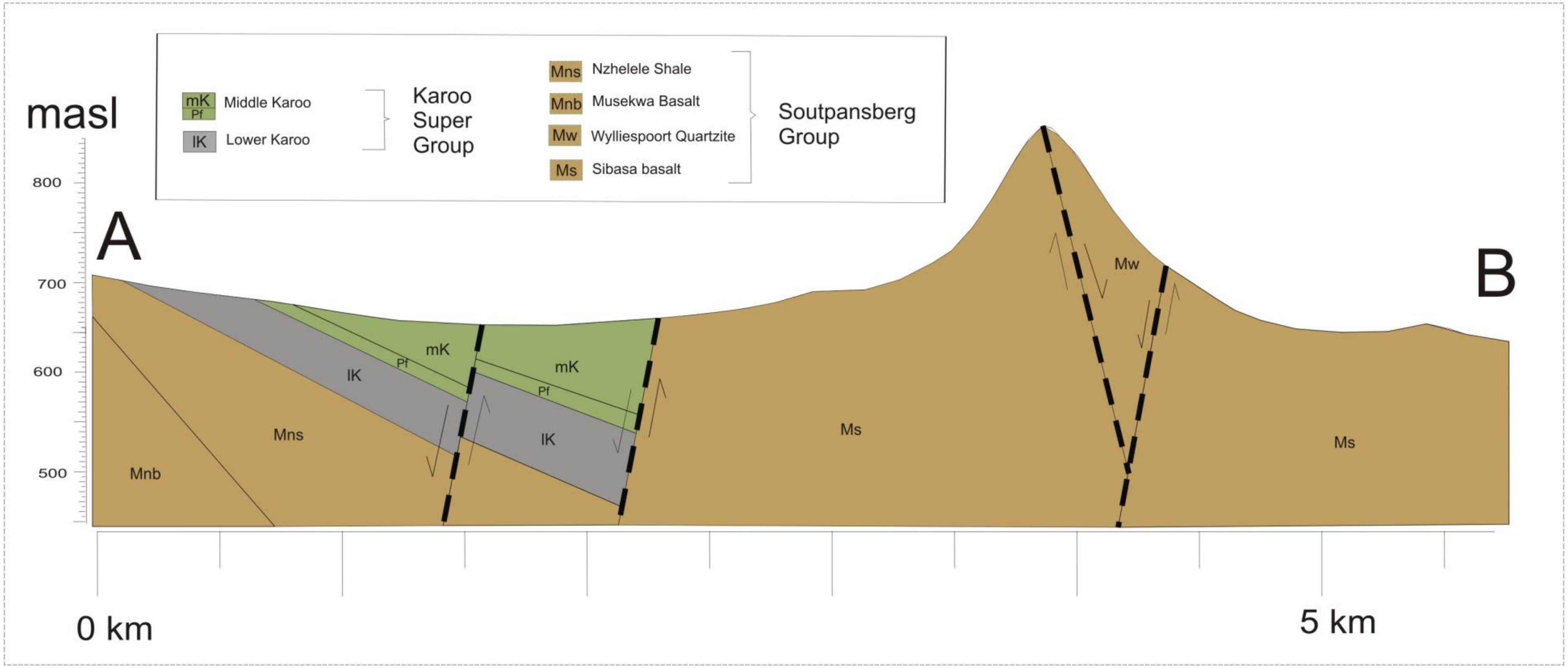

Figure 5-3 Cross section across the Duel

5.3. Structure

The study area is characterized by rift and wrench faulting, which form the regional Tshipise fault system. Rifting causes normal fault systems, resulting in horst and graben type topography, characteristic of the study area. The wrench faults are vertical shear faults caused by relative displacement of rifted blocks.

All these structural breaks' present potential groundwater targets, of which the normal faults are of greater potential.

The structure on the property consists of horst and graben features typical of a rift environment with Karoo sediments preserved in down faulted troughs. The faults trend in an east west direction causing some duplication in both Karoo and Soutpansberg strata. The faults intersected with brittle horizons such as the coal layers and the sandstone layers will host water.

5.4. Impact on Hydrogeology

The Soutpansberg Group rocks form a mountain range with shallow soil resulting in higher recharge. This is the main recharge zone of the regional aquifer. Consequently, groundwater in this aquifer is relatively fresh. Zones of high transmissivity occur where the Karoo strata rocks are down faulted against the Soutpansberg quartzite's by East – West striking fault structures. These include the brittle coal horizon, sandstone formations such as the Fripp and Klopperfontein Formations, dolerite sills and the underlying Soutpansberg quartzites and volcanics.

Groundwater derived from direct recharge within the Karoo strata is generally more saline and as it flows northward, it becomes progressively more saline. The structural link between with the Karoo strata and the Soutpansberg result in differing water levels and chemistry in boreholes in close proximity with one another.

North of the Karoo strata, across the Tshipise fault, groundwater in the Limpopo Mobile Belt gneisses is also replenished by local recharge and is less saline. Groundwater in this regional aquifer conforms to the regional topographic gradient and is drained through the E-W regional faults of the Tshipise fault system.

Groundwater is also drained by evapotranspiration and numerous springs.

6. HYDROGEOLOGY

6.1. Available Borehole Information

Available borehole information was obtained by hydrocensus and from data previously collected during the Makhado and Generaal coal projects for their Groundwater Impact Assessment Reports (CoAL 2012a and b), and recently drilled exploration holes. The springs and hydro-census borehole data are summarised in Tables 6-1 and 6-2. The springs and borehole localities in the immediate the Duel area are indicated on Figure 6-1.

Table 6-1 Summary table of springs occurring in the study area

FARM(Village)	BH No	Longitude	Lattitude	Yield (l/s)	Pump Cycle	Method	(Kl/day)	CLASS
LUKIN	LUK S-1	29.99813	-22.80328	1.0	24	Estimate	86.4	0
TELEMA	H25S0093	30.08102	-22.77180	0.1	24	Estimate	8.6	
TELEMA	H25S0098	30.10264	-22.80121	0.2	24	Estimate	17.3	
TELEMA	H25S0103	30.07204	-22.77768	1.0	24	Estimate	86.4	0
van DEVENTER	VAND-S1	29.99926	-22.74564	0.3	24	Estimate	25.9	II

Springs occur where the water table intersects the surface, usually along some structure. There are two known springs at Pfumembe (Figure 6-1), and a spring on Lukin within the Makhado project area.

Subsequent to the original census and submission of this report in 2016, three boreholes on The Duel farm were revisited in March 2019 and the data updated. The boreholes are Mon-11, Mon-13 (present water levels and resampled) and Nak-2 (sampled).

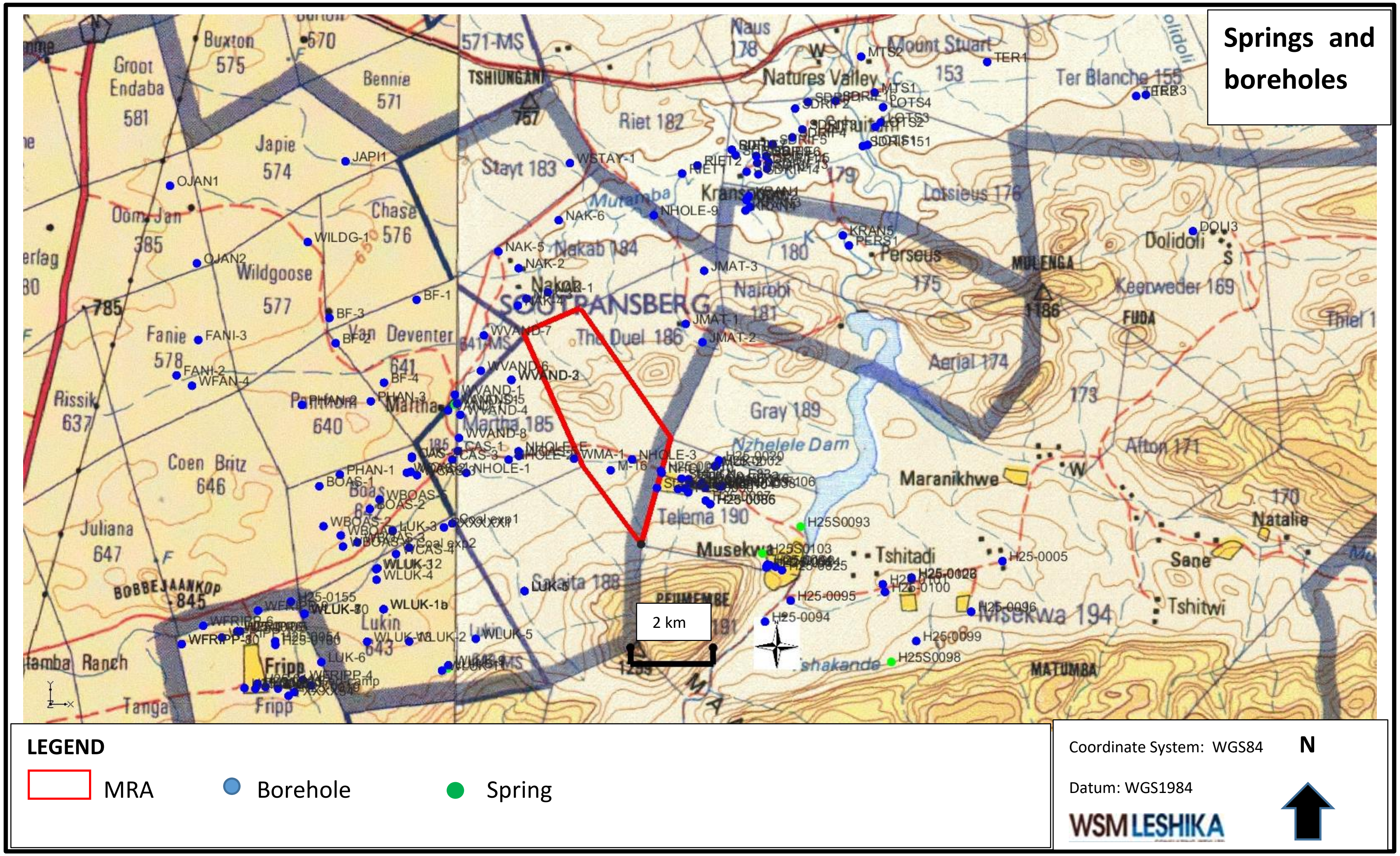

Figure 6-1 Location of springs and boreholes from the hydrocensus

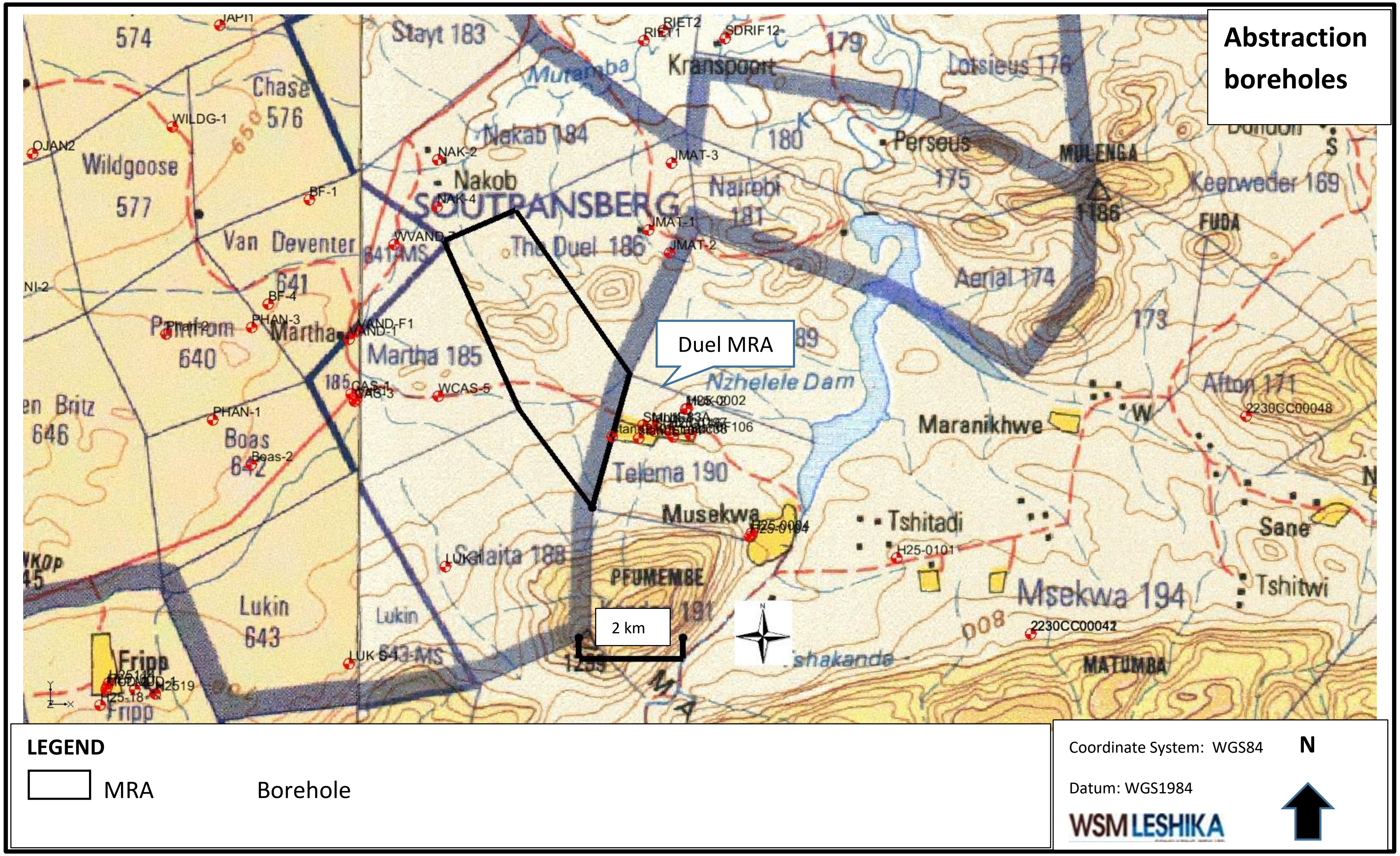

Figure 6-2 Location of groundwater abstraction boreholes

Table 6-2 Hydrocensus borehole data

Equipment*: N-none,S-submersible,M-mono,W-windpump,H-handpump,P-piezometer,E-Coal exploration
USER**: PP-Private production,VP-Community production ,MP-Mine production,MM-Mine monitor,N-not used
Status***:IU-in use, NIU-not in use

FARM/Village	BH No	Longitude	Lattitude	Equipment*	USER**	Depth	SWL (mbgl)	Date	Data Source	CLASS	Kl/day	Status***	Comment
MSEKWA	H25-0004	30.07325	-22.78014	M	VP		-	2009	census			IU	TO TEST
MSEKWA	H25-0005	30.12867	-22.779	N	N	72	19.0	2009	census	IV		NIU	TESTED
MSEKWA	H25-0026	30.10724	-22.783	H	VP		-	2009	census			IU	TO TEST
MSEKWA	H25-0095	30.0788	-22.78796	H	N	6	3.6	2009	census			NIU	BLOCKED
MSEKWA	H25-0096	30.12138	-22.7901	N	N		-	2009	census			NIU	DESTROYED
MSEKWA	H25-0099	30.10847	-22.79661	N	N	107	26.5	2009	census	II	7	NIU	TESTED
MSEKWA	H25-0100	30.10102	-22.78592	N	N		-	2009	census			NIU	TO TEST
MSEKWA	H25-0101	30.1005	-22.78425	H	VP		-	2009	census			IU	TO TEST
MSEKWA	H25-0102	30.10722	-22.78273	N	N	79	17.5	2009	census		4	NIU	TESTED
MUKUSHU	H25-0197	30.05765	-22.76242	N	N	81	29.1	2012	census	III	26	NIU	New unequipped hole
MUKUSHU	MUK-1	30.05457	-22.76158	M	VP		-	2012	census			IU	Village supply
MUKUSHU	MUK-2	30.06075	-22.75871	M	VP		-	2012	census			IU	Village supply
NAKAB	Mon-13	30.0459	-22.70397	P	MM	70	2.6	2019	drilling			IU	Piezometer installed
NAKAP	NAK-1	30.02105	-22.721	N	N		5.7	2011	census			NIU	
NAKAP	NAK-2	30.01414	-22.71575	S	PP		15.9	2019	census			IU	Sampled/could not access water level
NAKAP	NAK-3	30.01604	-22.7224	N	N		5.4	2019	census			NIU	
NAKAP	NAK-4	30.01402	-22.72389	S	PP		-	2011	census			IU	
NAKAP	NAK-5	30.00934	-22.71211	N	N		16.3	2011	census			NIU	
NAKAP	NAK-6	30.02349	-22.7052	N	N		16.6	2011	census			NIU	
NJELELEPOORT	H25-0094	30.0728	-22.79262	N	N	114	4.3	2008	census	II	1	NIU	PUMP SUCTION
OOM JAN	OJAN1	29.93187	-22.69823	S	PP	0	21.9	2013	census		2	IU	10m3/day
OOM JAN	OJAN2	29.93832	-22.71513	M	PP	0	0.0	2013	census		1	IU	5m3/week
PERSEUS	PERS1	30.09193	-22.71027	N		0	-	2013	census		0	BU	Screened pump now blocked
PHANTOM	PHAN-1	29.97235	-22.76112	S	PP	71	35.8	2011	census			IU	solar powered submersible
PHANTOM	PHAN-2	29.96329	-22.74594	S	PP	116	13.2	2011	census			IU	solar powered submersible
PHANTOM	PHAN-3	29.97952	-22.74504	S	PP	42	22.9	2011	census			IU	generator powered submersible
RIET	RIET1	30.0525	-22.6948	S	PP	0	-	2013	census		3	IU	Working under sand
RIET	RIET2	30.0561	-22.693	M	PP	0	-	2013	census		3	IU	Working
RIET	RIET7	30.06418	-22.68953	N		0	-	2013	census		0	NIU	
SCHUITDRIFT	SDRIF1	30.08202	-22.679	M	PP	0	-	2013	census		0	NIU	Strong hole - river bed
SCHUITDRIFT	SDRIF12	30.0677	-22.6943	S		0	7.5	2013	census		3	IU	
SCHUITDRIFT	SDRIF13	30.07252	-22.69362	M	PP	0	-	2013	census		0	NIU	Cable stolen - strong hole
SCHUITDRIFT	SDRIF14	30.07048	-22.69483	M	PP	0	-	2013	census		0	NIU	Cable stolen - strong hole
SCHUITDRIFT	SDRIF15	30.07285	-22.69223	M		0	-	2013	census		0	NIU	Open hole now set up
SCHUITDRIFT	SDRIF151	30.095	-22.68852	S	PP	0	-	2013	census		30	IU	Water supply to farm community
SCHUITDRIFT	SDRIF16	30.08852	-22.67868	N		0	-	2013	census		0	NIU	
SCHUITDRIFT	SDRIF2	30.07902	-22.68043	M	PP	0	-	2013	census		0	NIU	Strong hole - river bed
SCHUITDRIFT	SDRIF3	30.08077	-22.68498	M	PP	0	-	2013	census		0	NIU	Strong hole - hard rock
SCHUITDRIFT	SDRIF4	30.07842	-22.68672	M	PP	0	-	2013	census		0	NIU	Strong hole on river bank
SCHUITDRIFT	SDRIF5	30.07377	-22.68825	N		0	2.6	2013	census		0	NIU	Strong hole
SCHUITDRIFT	SDRIF6	30.07227	-22.6909	M	PP	0	4.5	2013	census		0	NIU	Very strong hole
SCHUITDRIFT	SDRIF7	30.06419	-22.68954	M	PP	0	-	2013	census		0	NIU	Silted up
SCHUITDRIFT	SDRIF8	30.06508	-22.69072	M	PP	0	-	2013	census		0	NIU	Very strong
SCHUITDRIFT	SDRIF9	30.06995	-22.69085	M	PP	0	-	2013	census		0	NIU	Two holes
SCHUITDRIFT	SDRIFT11	30.07018	-22.69237	M	PP	0	-	2013	census		0	NIU	Strong hole
STAYT	WSTAY-1	30.02608	-22.6927	N	MM	72	18.9	2012	drilling			IU	
TELEMA	H25-0002	30.0611	-22.75857	M	VP	101	41.1	2012	census	I		IU	PUMP SUCTION
TELEMA	H25-0020	30.06165	-22.75746	H	N	105	39.3	2012	census	II		NIU	PUMP SUCTION
TELEMA	H25-0024	30.07517	-22.78058	H	N	103	9.4	2012	census	II	13	NIU	TESTED
TELEMA	H25-0025	30.07672	-22.78134	H	N		-	2012	census			NIU	TO TEST
TELEMA	H25-0041	30.05727	-22.76287	H	N	89	35.8	2012	census	III	17	NIU	TESTED
TELEMA	H25-0085	30.05971	-22.76701	N	N		-	2012	census			NIU	TO TEST
TELEMA	H25-0086	30.05967	-22.76703	N	N		-	2012	census			NIU	TO TEST
TELEMA	H25-0087	30.0586	-22.76624	N	N		-	2012	census			NIU	TO TEST
TELEMA	H25-0088	30.06244	-22.76307	N	N		-	2012	census			NIU	TO TEST
TELEMA	H25-0089	30.05363	-22.7636	N	N		-	2012	census			NIU	TO TEST
TELEMA	H25-0090	30.05447	-22.76442	N	N		-	2012	census			NIU	TO TEST
TELEMA	H25-0091	30.04803	-22.7598	N	N		-	2012	census			NIU	DRY-INFO
TELEMA	H25-0104	30.07297	-22.78073	M	VP	34	14.2	2012	census	0	22	IU	PUMP SUCTION
TELEMA	H25-0190	30.07372	-22.78025	N	N	78	4.9	2012	census		35	NIU	TESTED
TELEMA	NHOLE-10	30.04819	-22.76027	P	MM	79	29.4	2012	drilling			IU	Piezometer installed
TER BLANCHE	TER1	30.12417	-22.66993	M	PP	0	-	2013	census		1	IU	
TER BLANCHE	TER2	30.15932	-22.67712	N		0	35.3	2013	census		0	NIU	Old Iscor holes
TER BLANCHE	TER3	30.1616	-22.67683	S	PP	0	35.3	2013	census		1	IU	4 holes in this locality. 2 water holes.
THE DUEL	JMAT-1	30.05362	-22.72765	S	PP		-	2011	census			IU	submersible
THE DUEL	JMAT-2	30.05758	-22.73163	S	PP		-	2011	census			IU	submersible
THE DUEL	JMAT-3	30.05785	-22.71602	W	PP		-	2011	census			IU	Windpump
THE DUEL	M-16	30.03615	-22.75976	E	N	150+	28.2	2014	census	II		NIU	Exploration borehole with strong water strike
THE DUEL	Mon-11	30.0412	-22.75736	P	MM	97	28.0	2019	census			IU	Piezometer installed
van DEVENTER	BF-1	29.99015	-22.72278	N	N		24.9	2011	census	I		IU	Testing at time of survey. Game use
van DEVENTER	BF-2	29.97116	-22.73239	N	N		18.8	2011	census	IV		NIU	Not equipped
van DEVENTER	BF-4	29.9826	-22.74096	S	PP		?	2011	census	I		IU	Lodge supply
van DEVENTER	VAND-1	29.99776	-22.74692	S	PP	30	4.1	2009	census	III	86	IU	Domestic supply to T. Smith
van DEVENTER	WVAND-1	29.99934	-22.74346	N	N	79	-	2009	drilling			NIU	
van DEVENTER	WVAND-2	30.01263	-22.7402	N	N	36	-	2009	drilling			NIU	
van DEVENTER	WVAND-3	30.01261	-22.74012	N	N	39	-	2009	drilling			NIU	
van DEVENTER	WVAND-4	30.00064	-22.74785	N	N	79	-	2009	drilling			NIU	
van DEVENTER	WVAND-5	29.99982	-22.74544	N	N	61	-	2009	drilling			NIU	
van DEVENTER	WVAND-6	30.00541	-22.73821	N	N	73	-	2009	drilling			NIU	
van DEVENTER	WVAND-7	30.00607	-22.73047	S	PP	105	6.2	2010	drilling	III	14	IU	Submersible installed
van DEVENTER	WVAND-8	30.00036	-22.75293	N	MP	60	8.0	2010	drilling	IV	346	NIU	
WILDGOOSE	WILDG-1	29.96442	-22.71032	S	PP	127	22.1	2011	census			IU	solar powered submersible

6.2. Groundwater Use

Land ownership in immediate surroundings consists of private owners and government. The government land consists of two farms occupied by 3 villages. Property ownership is summarized in figure 6-3 with production boreholes and colour coded yield ranges. Water use information to the north east of the study area including the Nzhelele Irrigation Scheme area which stretches from Tshipise/Alicedale Estates to Maswiri Boerdery is included. Although their main water supply comes from surface water (Nzhelele Irrigation Scheme) boreholes are used to supplement the water usage during drought.

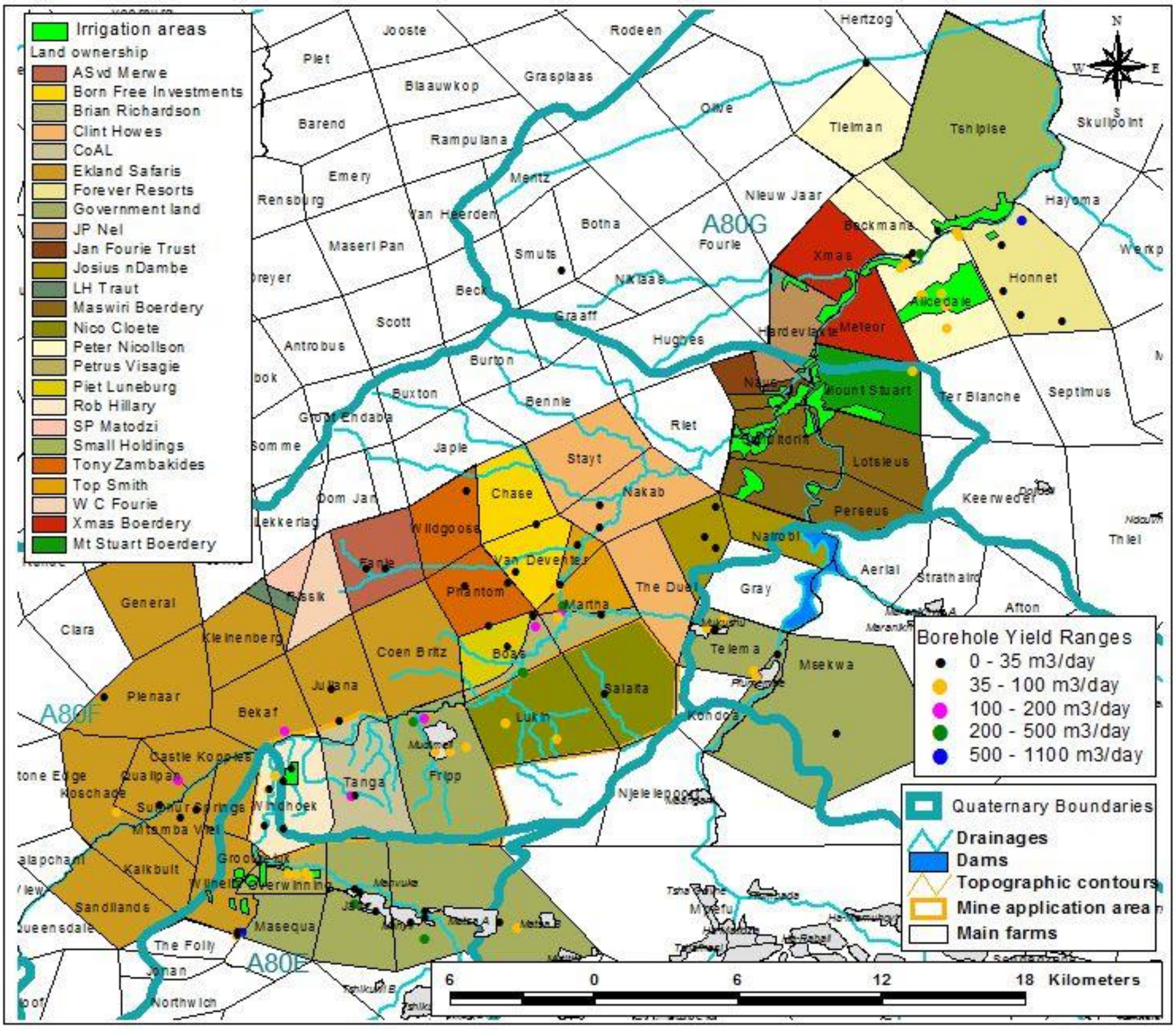

Figure 6-3 Landowner ship in the surrounding area

Groundwater use for the properties within a two-farm margin around the MRA area was considered. These include the following farms: Telema, Gray, Nairobi, Kranspoort, Riet, Stayt, Nakab, Chase, Wildgoose, Phantom, van Deventer, Martha, Lukin, Salaita and Kondoa. Groundwater use is mainly for farmsteads, hunting and game lodges, game and stock watering. The closest irrigation occurs on the farms Skuitdrift and Mount Stuart, but these are outside the area of consideration and obtain water from the Nzhelele irrigation scheme. Boreholes are used as backup in drought when the surface water is not available.

The estimated existing groundwater abstraction for the above listed farms, mainly from the secondary hard rock aquifer is summarised in table 6-3.

Approximately 57 ML/annum is abstracted from groundwater currently from the area making up the two-farm buffer zone around the MRA area.

6.3. Piezometry and Groundwater Flow

6.3.1. *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 the Makhado and Generaal Projects and the present study. These data were converted to absolute water levels by determining borehole elevation from Google Earth. The MODFLOW model (section 7), was utilised to generate current water levels as a piezometric map (Figure 6-4). The Model was also utilised to generate a map of water level under virgin conditions (Figure 6-5).

Regional groundwater flow is oriented northeast towards the Limpopo River (Figure 6-4). 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 results in minimal 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.

Table 6-3 Estimated Groundwater use

			Estimated Groundwater Use					
Quaternary	Owner/Business	Farms	House hold and Lodges (m3/day)	Game and stock watering (m3/day)	Cleared Land (Ha)	Irrigated Land (Ha)	Total Estimated groundwater use ML /annum	Comments
A80F	CoAL	Lukin	0	1	-	-	4	Water use for domestic and game
		Salaita	1	1	-	-		
		van Deventer (rem	1	1	-	-		
		Boas	2	1	-	-		
		Martha	1	1	-	-		
	Joshua nDambe	The Duel(Rem Ptn)	0	20	-	-	7	Cattle watering
		Nairobi	0	0	-	-		
	Tony Zambakides	Wildgoose 577 MS	3	3	-	-	2	Water use for domestic and game
		Phantom 640 MS						
	Born Free Investments	Chase 576 MS	3	3	-	-	2	Water use for lodge, domestic and game
		Van Deventer 641 MS						
	Clint Howes	Stayt 183 MT	1	2	-	-	1	Water use for lodge, domestic and game
		The Duel(Ptn 1)						
		Nakab 184 MT						
	Maswiri Boerdery	Riet 182 MT	3	3	-	-	2	Water use for lodge, domestic and game. Irrigation from Nzhelele scheme 830 000m^3/annum
		Kranspoort	0	0	-	-		
A80C	Mukushu	Telema 190 MT	55	8	-	-	23	Village water supply and private boreholes
	Phumembe		36	7	-	-	16	
		TOTAL	157				57	

The Mufungudzi River entering Nzhelele Dam, the Kandanama River a tributary of the Mutamba River, entering the catchment in the south-west along the N1 highway, and the upper reaches of the Mutamba River 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 River, 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 confirmed this.

6.3.2. *Local Groundwater Flow*

The localised static water level under present and natural conditions is shown in figures 6-6 and 6-7. The Duel sits on a groundwater divide between groundwater drainage to the east and west. The depth to groundwater is shown in figure 6-8.

The available data allows for the following general observations:

- The piezometric surface forms a subdued sub-surface expression of the topography.
- Some localized dewatering is evident and groundwater levels in these areas have dropped 20 m from natural conditions. This is due to pumping around Makushu village, where low yielding boreholes are being dewatered. The areas of dewatering around these boreholes are of limited extent.
- Groundwater in the Duel MRA where mining will occur is 25-40 mbgl

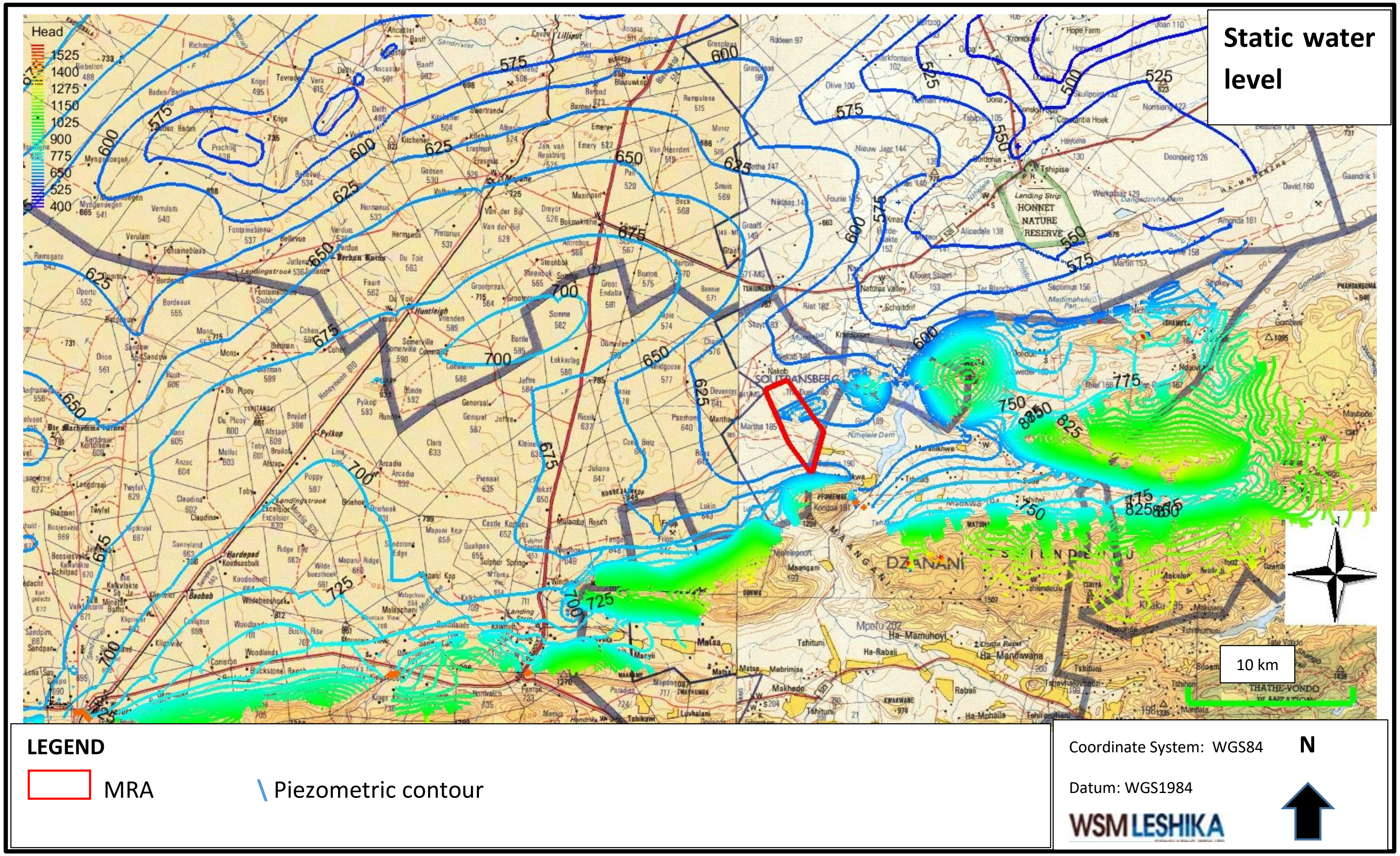

Figure 6-4 Static water level under present conditions (mamsl)

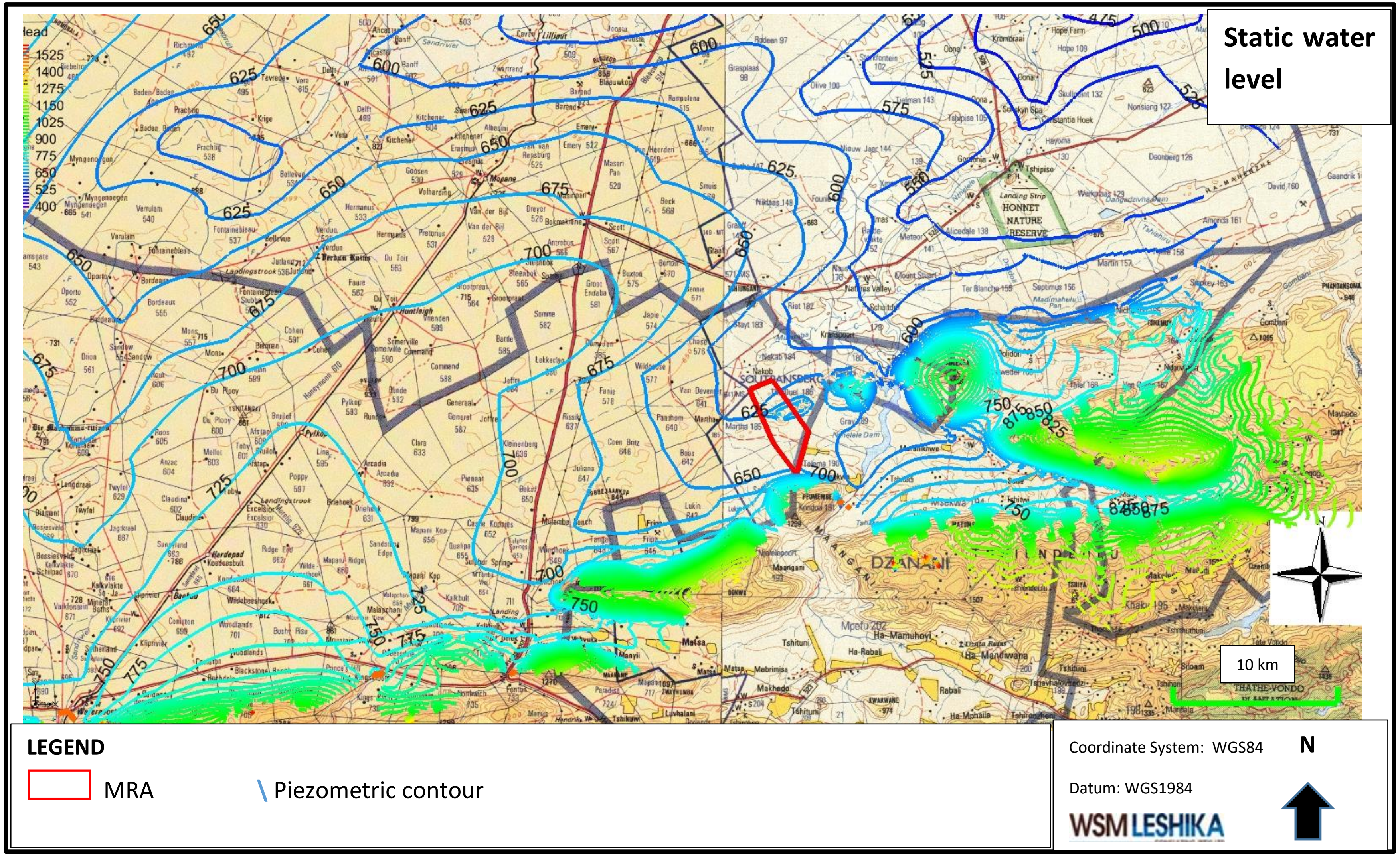

Figure 6-5 Static water level under natural conditions (mamsl)

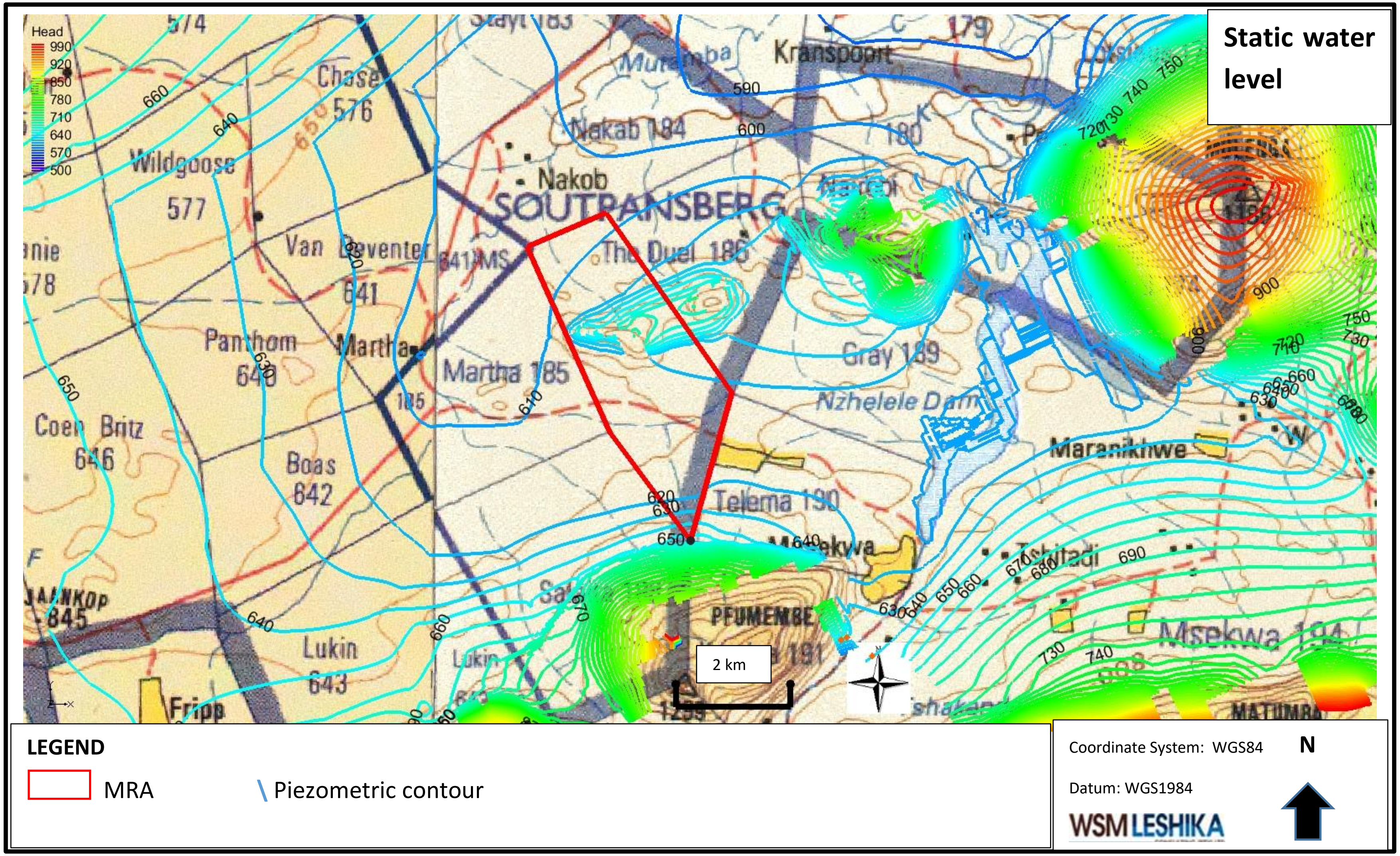

Figure 6-6 Local groundwater level under present conditions (mamsl)

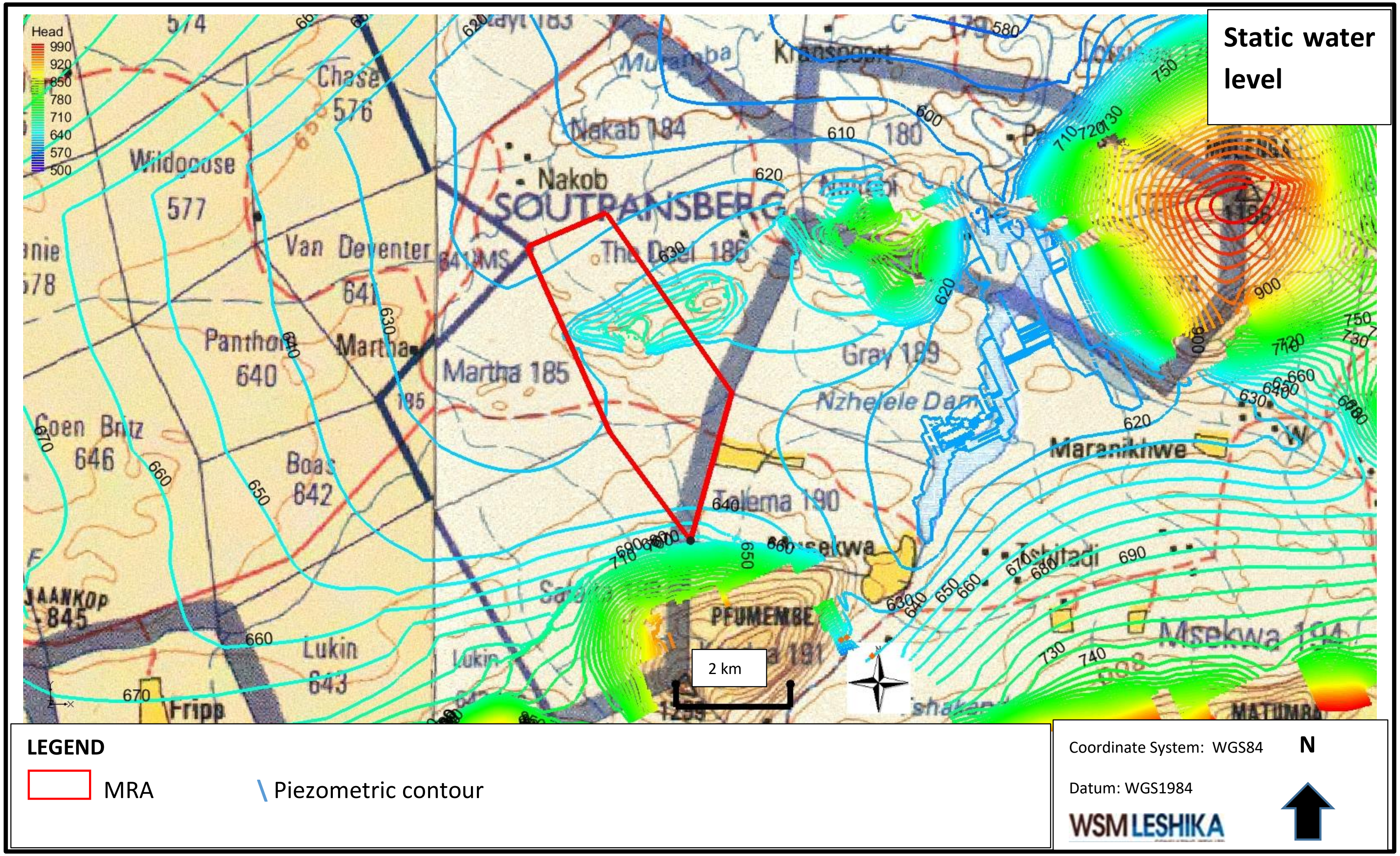

Figure 6-7 Local groundwater level under natural (mamsl)

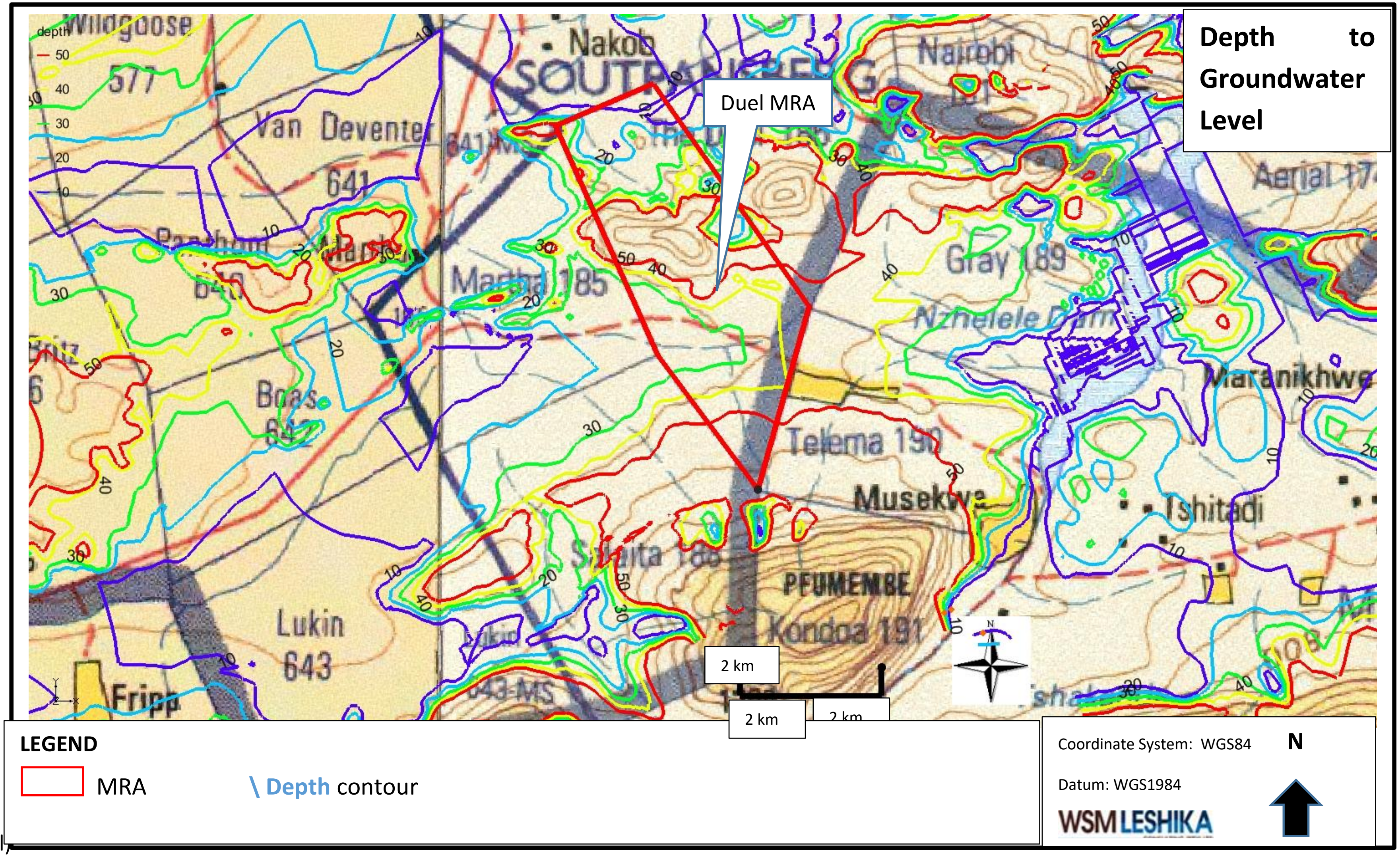

Figure 6-8 Depth to groundwater (mbgl)

6.4. Regional Water Quality

6.4.1. *Regional geochemical environment*

Groundwater quality is dependent on the concentrations of soluble salts and the residence time of water within the host rock. The water quality derived from secondary aquifers in the area can vary considerably. Consequently, lithology and topography play a significant role in observed groundwater quality

Good quality groundwater can be found in the quartzites and lavas of the Soutpansberg strata where active recharge is higher due to higher rainfall, thinner and sandier soils, and rock geochemistry that is relatively inert.

Moderate to brackish water can be found in the marine Nzhelele shale and lower Karoo strata, where inflows of good quality groundwater from the Soutpansberg strata dilute the brackish Karoo groundwater. The Fripp Formation marks a return to a continental sedimentation environment, with marine salts trapped in the pore water. The Bosbokpoort Formation of the Karoo marks a climatic change of sediment deposition to one of increasing aridity, hence salts accumulated in the rock and were trapped in the pore water. The sediments of the Bosbokpoort Formation to Red Rocks Member reflect the changing climate, with a concurrent increase in salinity up the Karoo Sequence. The climate of deposition culminates in the aeolian sands of the Tshipise Member of the Clarens Formation, where continental without marine inundation resulted in relatively fresh pore water in the sediments, hence resulting in good quality groundwater,

In figure 6-9 the TDS contours reflect the geological setting, with the most saline groundwater found in the Middle Karoo, and much fresher groundwater in the Soutpansberg.

6.4.2. *Macro chemistry*

Samples were taken from exploration borehole M-16 and 2 private boreholes in Makushu. Many of the boreholes in the vicinity of the Duel were previously sampled during the hydrocensus for Makhado and Generaal projects, hence this chemistry data was also included. The chemistry data is presented with reference to the Water Quality Threshold (WQT) according to DWS-SA Water Quality Guidelines for Rivers and Streams for the following water uses;

1. Drinking water
2. Agriculture-irrigation
3. Agriculture-livestock

The DWS thresholds for water quality macro constituents are given in table 6-4.

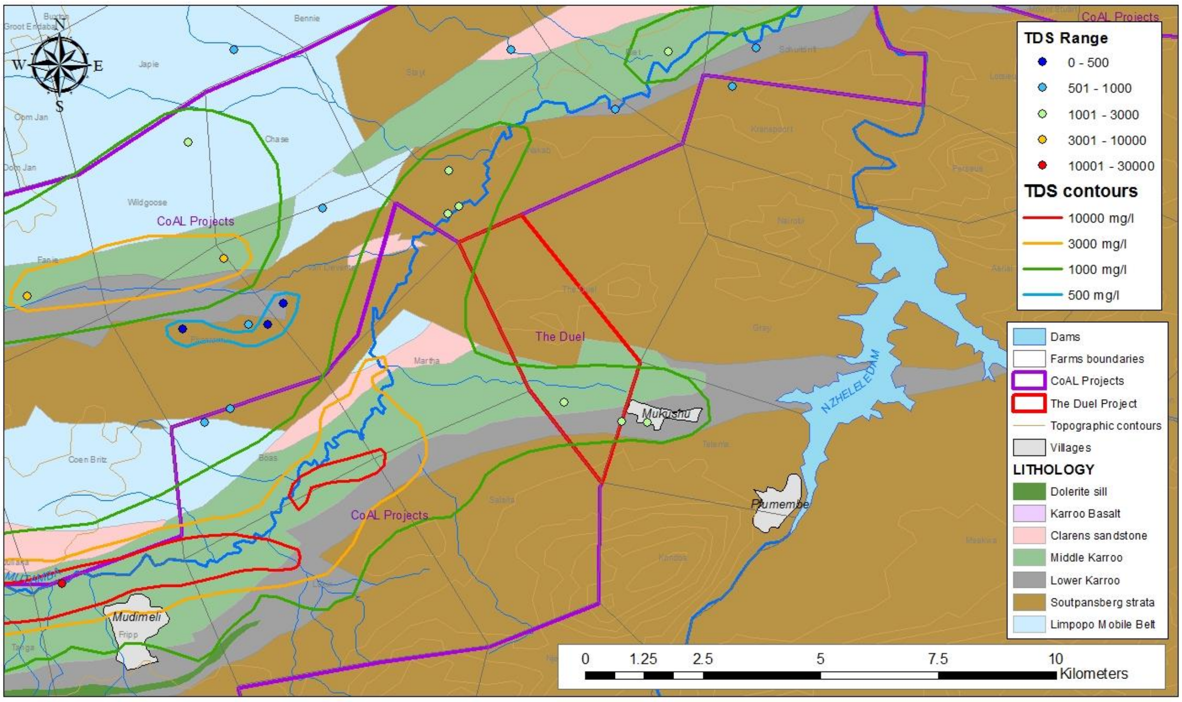

Figure 6-9 TDS contour map

Table 6-4 DWS 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		5	2		100			70
Agriculture (livestock)			1000	100	2	1000	1500	1000	500	2000

The data collected during the hydrocensus is tabulated in table 6-5 according to the DWS Domestic Water Quality Guidelines for domestic water, and in table 6-6 according to the irrigation water Guidelines.

Table 6-5 Water quality according to the DWS Water Quality Guidelines for domestic water

Borehole	E.C	TDS	pH	Hardness	NO3	F	Fe	Mn	Ca	Mg	Na	Cl	SO4
Number	mS/m	mg/l		mg/l	mg/l-NO3	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
M-16	210	1191	7.5	178	1.8	0.9	2.89	0.07	25	28	299	527	14
Mukp-1	295	1997	7.1	989	0.9	0.8	0.26	0.02	124	165	204	588	122
Mukp-2	271	1829	7.2	956	2.2	0.9	0.24	0.13	142	146	165	536	138
BF-1	139	881	7.5	358	3.1	3.1	8.04	0.05	56	53	159	181	157
BF-2	773	5191	6.9	2124	3.5	0.8	12.00	1.54	237	372	778	?	185
BF-4	72	478	7.3	282	2.2	0.4	0.57	0.27	42	43	44	62	28
BOAS -1	135	1394	6.7	853	0.0	0.5	0.03	0.14	165	107	110	186	62
EKL-15	142	733	7.8	272	13.3	0.5	0.89	0.6	33	46	143	151	11
EKL-16	85	421	7.4	180	2.7	0.2	2.79	0.04	36	22	74	121	27
FANI-1	201	1146	7.7	57	0.9	3.7	0.04	0.03	8	9	390	380	5
FANI-2	525	3564	7.2	1272	13.3	0.5	0.06	0.03	122	235	614	?	157
H18-0006	294	1591	7.9	151	0.9	0.4	0.01	0.01	34	16	511	552	110
H25-0010	246	1472	7.3	997	282.9	0.3	0.01	0.01	161	144	150	333	127
H29-0011	179	1172	7.2	641	131.7	0.2	0.01	0.2	141	70	154	224	50
Jap-1	143	1109	7.1	603	40.7	1.8	0.01	0.01	77	100	121	63	46
Kran-1	104	706	7.9	113	7.1	2.8	0.13	0.07	25	12	194	111	105
Mon-11	138	814	7.2	514	5.2	0.2	0.01	0.2	77	79	79	83	23
Mon-13	108	849	7.8	422	2.2	1.8	0.09	0.34	65	63	115	141	49
Mon-13	110	604	7.4	330	0.1	1.0	0.01	0.05	54	48	106	88	50
Mon-18	150	750	8.6	230	24.8	0.6	0.05	0.03	26	40	174	196	41
Mon-18	140	1085	8.7	378	0.9	0.6	2.38	1.4	54	59	212	184	39
PHAN-3	81	578	7.4	365	25.6	0.2	0.07	0.42	95	54	42	120	10
Mon-24	150	1105	7.9	641	35.8	1.0	13.00	0.05	28	98	109	241	57
MTS-1	154	990	7.2	222	6.2	2.8	0.02	0.03	91	37	256	346	18
Nak-2	236	1421	7.4	698	6.9	2.1	0.01	0.01	97	111	269	342	135
Nak-3	331	2376	7.5	718	0.9	3.0	2.16	0.03	61	124	529	442	170
Nak-4	276	1830	7.6	544	15.0	3.7	0.05	0.01	75	95	421	236	159
Ojan-1	232	1628	7.6	642	81.8	2.4	0.01	0.03	117	110	301	53	98
PHAN-1	93	761	7.6	543	57.5	0.5	0.03	0.03	66	61	31	35	48
PHAN-2	80	592	7.4	367	19.0	0.2	0.04	0.03	57	49	43	36	6
PHAN-3	90	671	7.2	410	23.4	0.2	0.17	0.03	62	62	53	40	10
Riet-2	298	1894	7.5	573	14.1	1.7	0.01	0.02	68	98	440	525	317
Sdrif-15	124	807	7.7	254	15.0	4.2	0.01	0.01	53	30	175	146	147
Ter-1	191	1346	7.7	460	36.2	1.4	0.01	0.3	60	75	273	218	79
Ter-3	116	861	7.9	476	6.2	0.6	0.01	0.01	73	71	90	90	45
WILDG-1	198	1397	7.4	752	44.2	1.3	0.03	0.03	118	111	167	195	113
M-16	210	958	7.5	178	1.8	0.9	0.00	0.07	25	28	299	527	14
Stand No 210	295	1677	7.1	989	0.9	0.8	0.00	0.02	124	165	204	588	122
Stand No E104	271	1539	7.2	956	2.2	0.9	0.00	0.13	142	146	165	536	138

(light blue)	Class 0	Ideal
(green)	Class 1	Good
(yellow)	Class 2	Marginal
(red)	Class 3	Poor
(purple)	Class 4	Dangerous

Table 6-6 Water Quality according to the DWS guidelines for irrigation

Borehole	E.C	TDS	Hardness	NO3	F	Fe	Mn	Mg	Na	Cl	SO4	SAR
Number	mS/m	mg/l	mg/l	mg/l-NO3	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
M-16	210.00	1190.60	177.73	0.40	0.90	2.89	0.07	28.00	298.53	527.00	14.00	9.75
Mukp-1	295.00	1997.37	989.10	0.20	0.80	0.26	0.02	165.00	204.24	588.00	122.00	2.83
Mukp-2	271.00	1828.85	955.80	2.21	0.90	0.24	0.13	146.00	165.47	536.00	138.00	2.33
BF-1	139.00	881.12	358.09	3.09	3.10	8.04	0.05	53.00	159.00	181.00	157.00	3.66
BF-2	773.00	5191.47	2123.69	3.54	0.80	12.00	1.54	372.00	778.00	0.00	185.00	7.35
BF-4	72.00	477.62	281.95	2.21	0.40	0.57	0.27	43.00	44.00	62.00	28.00	1.14
BOAS -1	135.00	1393.50	852.63	0.00	0.48	0.03	0.14	107.00	110.00	186.00	62.00	1.64
EKL-15	142.00	733.42	271.83	13.26	0.50	0.89	0.60	46.00	143.00	151.00	11.00	3.78
EKL-16	85.00	420.57	180.49	2.65	0.20	2.79	0.04	22.00	74.00	121.00	27.00	2.40
FANI-1	201.00	1146.27	57.04	0.88	3.70	0.04	0.03	9.00	390.00	380.00	5.00	22.48
FANI-2	525.00	3563.77	1272.36	13.26	0.50	0.06	0.03	235.00	614.00	0.00	157.00	7.49
H18-0006	294.00	1590.96	150.79	0.88	0.40	0.01	0.01	16.00	511.00	552.00	110.00	18.11
H25-0010	246.30	1471.99	996.91	282.88	0.25	0.01	0.01	144.25	150.30	333.20	126.88	2.07
H29-0011	179.20	1171.82	641.28	131.72	0.17	0.01	0.20	70.41	154.47	223.50	50.24	2.65
Jap-1	142.90	1109.06	602.93	40.66	1.80	0.01	0.01	99.88	121.46	62.70	45.72	2.15
Kran-1	104.00	705.67	113.42	7.07	2.80	0.13	0.07	12.42	194.02	110.80	105.16	7.93
Mon-13	108.00	848.87	421.74	2.21	1.80	0.09	0.34	63.00	115.00	141.00	49.00	2.44
Mon-13	110	604	330	0.1	1.0	0.01	0.05	48	106.00	88.00	50.00	2.38
Mon-18	150.00	750.02	229.64	24.75	0.60	0.05	0.03	40.00	174.00	196.00	41.00	5.00
Mon-18	140.00	1084.76	377.80	0.88	0.60	2.38	1.40	59.00	212.00	184.00	39.00	4.75
PHAN-3	80.90	578.33	364.70	25.64	0.20	0.07	0.42	54.00	42.00	36.00	10.00	1.87
Mon-24	150.00	1104.62	640.78	35.80	1.00	13.00	0.05	98.00	109.00	120.00	57.00	7.48
MTS-1	153.50	990.41	222.34	6.19	2.80	0.02	0.03	36.88	256.20	241.10	17.50	4.60
Nak-2	236.00	1421	698	6.9	2.1	0.01	0.01	111.00	269.00	342.00	135.00	8.59
Nak-3	331.00	2376.20	717.88	0.88	3.00	2.16	0.03	124.00	529.00	519.00	170.00	7.86
Nak-4	276.00	1829.86	543.53	15.03	3.70	0.05	0.01	95.00	421.00	442.00	159.00	5.17
Ojan-1	231.80	1628.06	642.11	81.77	2.40	0.01	0.03	110.16	300.84	236.20	98.02	0.58
PHAN-1	93.00	761.12	543.35	57.46	0.50	0.03	0.03	61.00	31.00	53.00	48.00	0.98
PHAN-2	79.90	591.84	366.58	19.01	0.20	0.04	0.03	49.00	43.00	35.00	6.00	0.96
PHAN-3	89.50	671.33	410.13	23.43	0.20	0.17	0.03	62.00	53.00	40.00	10.00	1.14
Riet-2	297.80	1893.64	573.33	14.14	1.70	0.01	0.02	97.75	439.55	525.30	316.96	7.99
Sdrif-15	123.70	807.41	253.90	15.03	4.20	0.01	0.01	29.70	175.38	146.00	146.56	4.79
Ter-1	191.20	1345.82	459.86	36.24	1.40	0.01	0.30	75.27	273.36	217.60	79.18	5.55
Ter-3	116.40	861.07	475.52	6.19	0.56	0.01	0.01	71.04	89.80	89.80	45.00	1.79
WILDG-1	198.00	1396.95	751.74	44.20	1.30	0.03	0.03	111.00	167.00	195.00	113.00	2.65
M-16	210.00	958.35	177.73	1.77	0.90	0.00	0.07	28.00	298.53	527.00	14.00	9.75
Stand No 210	295.00	1677.02	989.10	0.88	0.80	0.00	0.02	165.00	204.24	588.00	122.00	2.83
Stand No E104	271.00	1539.30	955.80	2.21	0.90	0.00	0.13	146.00	165.47	536.00	138.00	2.33

The study area is characterised by poor groundwater quality typical of arid environments and of upper Karoo strata with elevated salts. Constituents of concern are:

- High Total Dissolved Solids; which is largely geological by origin
- Hardness; which is largely geological by origin and mimics TDS patterns

- Nitrates: which are related to settlement due to sanitation and overgrazing. The Soutpansberg is more prone to nitrate contamination as soils are thinner and sandier
- Fluoride; which is geological in origin and is related to the presence of volcanics and dolerite dykes
- Iron; which is related to aridity and the formation of ferricrete in the drier upper Karoo and LMB, located to the north

Table 6-7 shows the average water quality for each major geological grouping. The highest salinities are found in the upper Karoo, except for the Clarens Formation. The freshest groundwater is found in the Limpopo Mobile Belt.

Table 6-7 Groundwater quality by geology

	Lower Karoo				
	EC (mg/l)	Nitrate	Fluoride	Sulphate	Iron
Average	252	2.3	1.2	99	0.15
Median	271	1.2	0.7	122	0.09
maximum	498	8.2	4.2	147	0.57
	Soutpansberg				
Average	182	14.4	1.5	90	0.27
Median	179	5.3	0.5	105	0.03
maximum	331	64.0	3.7	170	2.16
	Upper Karoo				
Average	678	2.9	1.0	424	2.22
Median	210	2.9	0.8	79	0.31
maximum	4020	8.2	3.7	4103	13.00
	Limpopo Mobile Belt				
Average	166	6.6	2.0	79	1.16
Median	143	6.3	2.1	64	0.01
maximum	154	18.5	3.1	157	8.04

The DWS thresholds for water quality micro constituents are given in table 6-8. The data collected during the hydrocensus is tabulated in table 6-9. Concentrations exceeding the WQT for any of the above uses are marked in red.

These were determined by ICP-scan trace metal analysis. Due to the sensitivity of Aquatic organisms, the threshold limits are very low and are below the ICP method detection limit of certain trace metals i.e. Al, Cd, Cr, Cu, Hg, Mo, Pb, Se and Zn. For the remaining uses the trace elements content is for most samples below the threshold level.

Table 6-8 DWS Water Quality Threshold Classification – Micro chemistry

Element	Al	As	B	Cd	Co	Cr	Cu	Fe	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	0.50	0.05		0.005		0.050	1.3		0.4			0.010	0.05	0.100	5.000
Agriculture(irrigation)	5.00	0.1	0.5	0.010	0.05	0.100	0.2		0.02	0.010	0.200	0.200	0.02	0.100	1.000
Agriculture(livestock)	5.00	1	5	0.010	1	1.000	0.5		10	0.010	1.000	0.100	0.05	1.000	20.000

The table indicates slightly elevated boron in boreholes adjacent to the Mutamba River on the farms Nakab, Fanie and Van Deventer (figure 6-10). There are 2 possible sources for boron in groundwater: rocks of primary basic volcanic origin such as basalt or leaching from such rocks. Leached boron is relatively abundant in marine sediments, such as the lower Karoo shales and mudstones. This boron can be mobilised by hydrothermal activity resulting from igneous intrusions or upwelling thermal water in faults. The boreholes where such sediments are located are adjacent to faults associated with hydrothermal activity, such as the Tshipise fault.

Table 6-9 Micro-chemistry from historical data with DWS-WQT Classification.

Element	Al	As	B	Cd	Co	Cr	Cu	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
BF-1	0.10	0.01	0.35	0.005	0.025	0.025	0.025	0.05	0.025	0.025	0.020	0.020	0.025	0.025
BF-2	1.65	0.01	0.64	0.005	0.025	0.025	0.037	1.54	0.025	0.025	0.020	0.020	0.025	0.319
BF-4	0.10	0.01	0.19	0.005	0.025	0.025	0.025	0.27	0.044	0.025	0.020	0.020	0.025	0.025
EKL-15	0.10	0.13	0.25	0.005	0.025	0.025	0.025	0.14	0.025	0.025	0.020	0.020	0.036	0.025
EKL-16	0.14	0.01	0.16	0.005	0.025	0.025	0.083	0.60	0.025	0.025	0.020	0.020	0.025	0.196
FANI-1	0.20	0.01	0.78	0.005	0.025	0.025	0.025	0.04	0.025	0.025	0.020	0.020	0.025	0.102
FANI-2	0.10	0.01	0.74	0.005	0.025	0.025	0.025	0.03	0.025	0.025	0.020	0.020	0.037	0.025
H18-0006	0.10	0.01	0.96	0.005	0.025	0.025	0.025	0.03	0.025	0.025	0.020	0.020	0.025	0.157
H25-0010	<0,01	<0,03	0.25	<0,01	<0,01	<0,01	<0,01	<0,01	<0,05	<0,01	<0,09	0.02	0.05	0.06
H29-0011	<0,01	<0,03	0.31	<0,01	<0,01	<0,01	<0,01	<0,01	<0,05	<0,01	<0,09	0.03	0.02	0.08
Jap-1	<0,01	<0,03	0.21	<0,01	<0,01	<0,01	<0,01	0.20	<0,05	<0,01	<0,09	<0,02	0.03	1.00
Kran-1	<0,01	<0,03	0.28	<0,01	<0,01	<0,01	<0,01	<0,01	<0,05	<0,01	<0,09	<0,02	<0,01	<0,01
Mon-13	0.59	0.01	0.37	0.005	0.025	0.025	0.025	0.07	0.060	0.025	0.020	0.020	0.025	0.025
Mon-13	0.10	0.01	0.41	0.005	0.025	0.025	0.025	0.34	0.025	0.025	0.020	0.020	0.025	0.025
Mon-18	0.10	0.01	0.22	0.005	0.025	0.025	0.025	0.03	0.025	0.025	0.020	0.020	0.050	0.025
Mon-18	0.13	0.01	0.36	0.005	0.025	0.025	0.025	0.03	0.025	0.025	0.020	0.020	0.030	0.025
Mon-2	0.13	0.01	0.98	0.005	0.025	0.025	0.025	1.40	0.025	0.025	0.020	0.020	0.025	0.025
Mon-24	2.81	0.03	0.29	0.005	0.025	0.025	0.025	0.42	0.025	0.025	0.020	0.020	0.025	2.210
MTS-1	<0,01	<0,03	0.33	<0,01	<0,01	<0,01	<0,01	0.05	<0,05	<0,01	<0,09	0.03	<0,01	0.01
Nak-2	0.10	0.01	0.50	0.005	0.025	0.025	0.025	0.03	0.025	0.025	0.020	0.020	0.025	0.025
Nak-3	0.49	0.01	0.97	0.005	0.025	0.025	0.025	0.91	0.025	0.071	0.047	0.034	0.177	1.550
Nak-4	0.12	0.01	0.69	0.005	0.025	0.025	0.025	0.03	0.025	0.025	0.020	0.020	0.032	0.036
Ojan-1	<0,01	<0,03	0.71	<0,01	<0,01	<0,01	0.02	<0,01	<0,05	<0,01	<0,09	<0,02	0.03	0.02
PHAN-1	0.10	0.01	0.10	0.005	0.025	0.025	0.025	0.03	0.025	0.025	0.020	0.020	0.032	0.025
PHAN-2	0.10	0.01	0.16	0.005	0.025	0.025	0.025	0.03	0.025	0.025	0.020	0.020	0.026	0.025
PHAN-3	0.11	0.02	0.17	0.005	0.025	0.025	0.025	0.03	0.025	0.025	0.020	0.020	0.025	0.027
PHAN-3	0.10	0.01	0.16	0.005	0.025	0.025	0.092	0.03	0.025	0.025	0.020	0.020	0.040	0.096
Riet-2	<0,01	<0,03	0.75	<0,01	<0,01	<0,01	<0,01	0.02	<0,05	<0,01	<0,09	<0,02	0.02	0.03
Sdrif-15	<0,01	<0,03	0.24	<0,01	<0,01	<0,01	<0,01	<0,01	<0,05	<0,01	<0,09	<0,02	0.01	0.01
Ter-1	<0,01	<0,03	0.39	<0,01	<0,01	<0,01	<0,01	0.30	<0,05	<0,01	<0,09	<0,02	0.03	0.35
Ter-3	<0,01	<0,03	0.22	<0,01	<0,01	<0,01	<0,01	<0,01	<0,05	<0,01	<0,09	0.02	<0,01	0.01
WILDG-1	0.10	0.01	0.35	0.005	0.025	0.025	0.027	0.03	0.035	0.025	0.020	0.020	0.025	0.073
M-16	0.436	0.002	0.065	0.000	0.001	0.001	0.006	0.069	0.004	0.024	0.005	0.006	0.006	1.090
Stand No 210	0.013	0.001	0.073	0.000	0.000	0.000	0.001	0.018	0.000	0.003	0.000	0.005	0.000	0.102
Stand No E104	0.009	0.002	0.062	0.000	0.000	0.000	0.003	0.133	0.000	0.003	0.000	0.003	0.000	0.465

Elevated manganese is also observed in some boreholes. Manganese is an abundant element distributed mainly in manganese oxides of which pyrolusite (MnO_2) is the most common. Manganese also occurs as an impurity in iron oxides, which are abundant in the coal bearing layers and iron rich sediments common in sandstones. The principal controls on manganese concentration in groundwater are pH and the redox (oxidation-reduction) condition. Manganese is mobilised under acidic conditions, but as the groundwater in the area is neutral to alkaline (table 6-5), the mobility of manganese is determined by ambient redox conditions. Under anaerobic conditions, manganese is reduced to the more soluble form, Mn(II), which is released from minerals. As dissolved oxygen concentrations in groundwater tend to decrease with borehole depth, anaerobic conditions and hence high manganese concentrations tend to occur more commonly in deep boreholes. As groundwaters flow through an aquifer, their compositions typically evolve from aerobic to anaerobic, the rates of change depending on the rates of diffusion of oxygen and other oxidants in the system. Reduction reactions in aquifers and soils follow a sequence as the conditions become progressively more reducing. Typically, the first compound to be removed from the system is oxygen, followed by nitrate and thereafter manganese. Progressively more reducing conditions lead to reduction of iron followed by sulphate. Hence groundwaters further down a flow path often have iron and manganese.

6.5. Local Water Quality

Figure 6-10 shows the location of boreholes where groundwater quality was sampled. Figure 6-11 shows the Piper Plot of geochemistry. Due to the processes of geological origin, aridity, land use, and mixing of waters from the Soutpansberg into the Karoo, no pattern of water groups can be distinguished.

Figure 6-12 shows a Durov diagram of water chemistry. The chemical analysis of ground water can be categorised into 9 different classes based on the concentrations and proportions of major ion constituents. The water occurring in the study area plots within 5 of the Durov class divisions.

- Class 2: Mg/bicarbonate water (BF-2, Phan-2, Phan-3, Boas-1, BF-4, Mon-24, WildG-1, Mon-13): Primary waters of low salt concentration (100 – 1000g/l): usually close to the recharge source.
- Class 5 and 6: Mg, Na, K/sulphate water (BF-1, Nak-2, Nak-4, SDRIF-15, Nak-3, Kran-1): Secondary waters resulting from waters of the bicarbonate class enriched by soluble sulphate and chloride salts.
- Class 8 and 9: Mg, Na, K/Chloride water (Stand E104 and 210, M-16, Riet-2): – complex waters (> 1000mg/l) derived from secondary water types and can indicate old or stagnant water, aggravating natural causes or pollution. These are located near settlements.

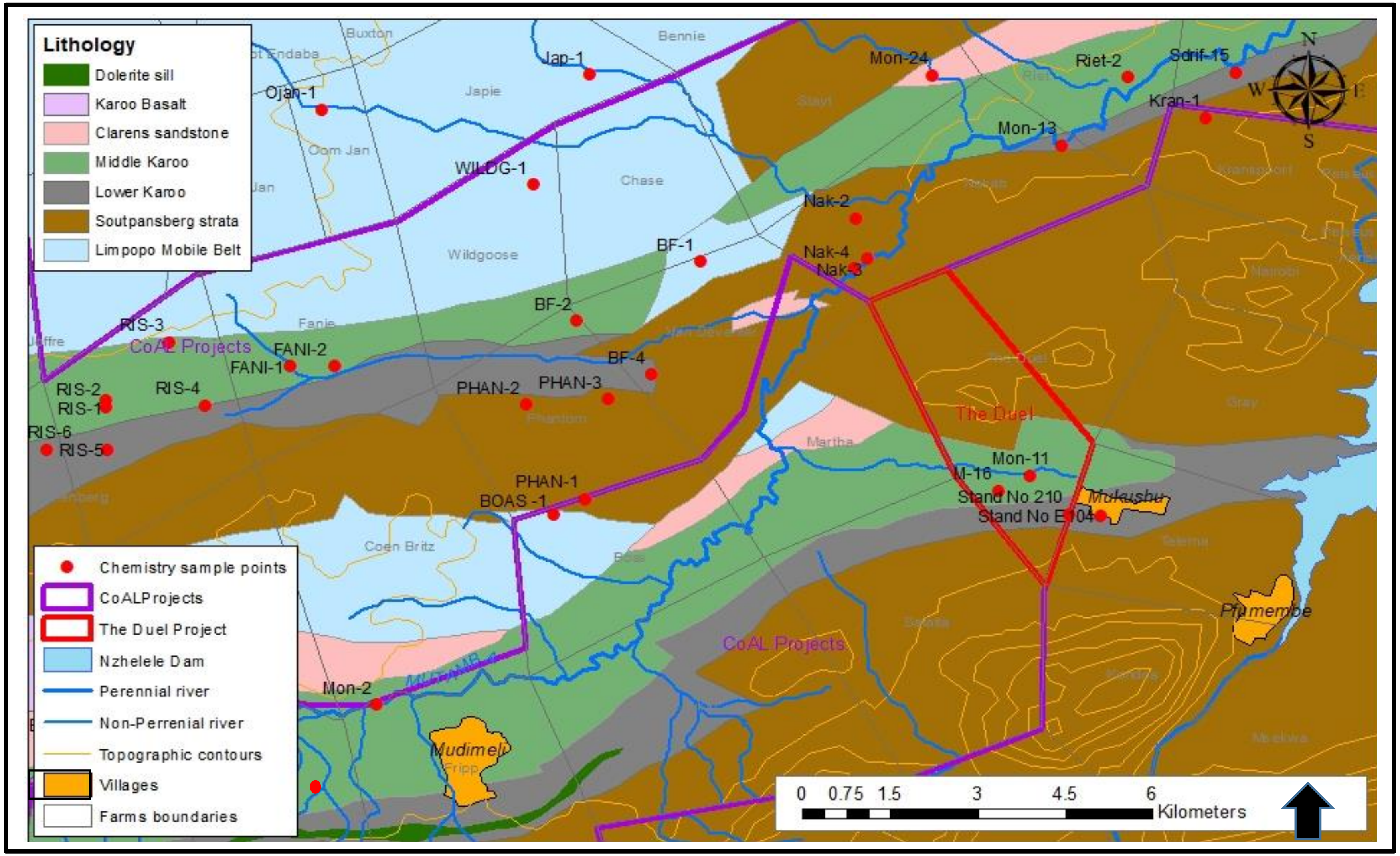

Figure 6-10 Location of water quality sampling in the vicinity of the Duel

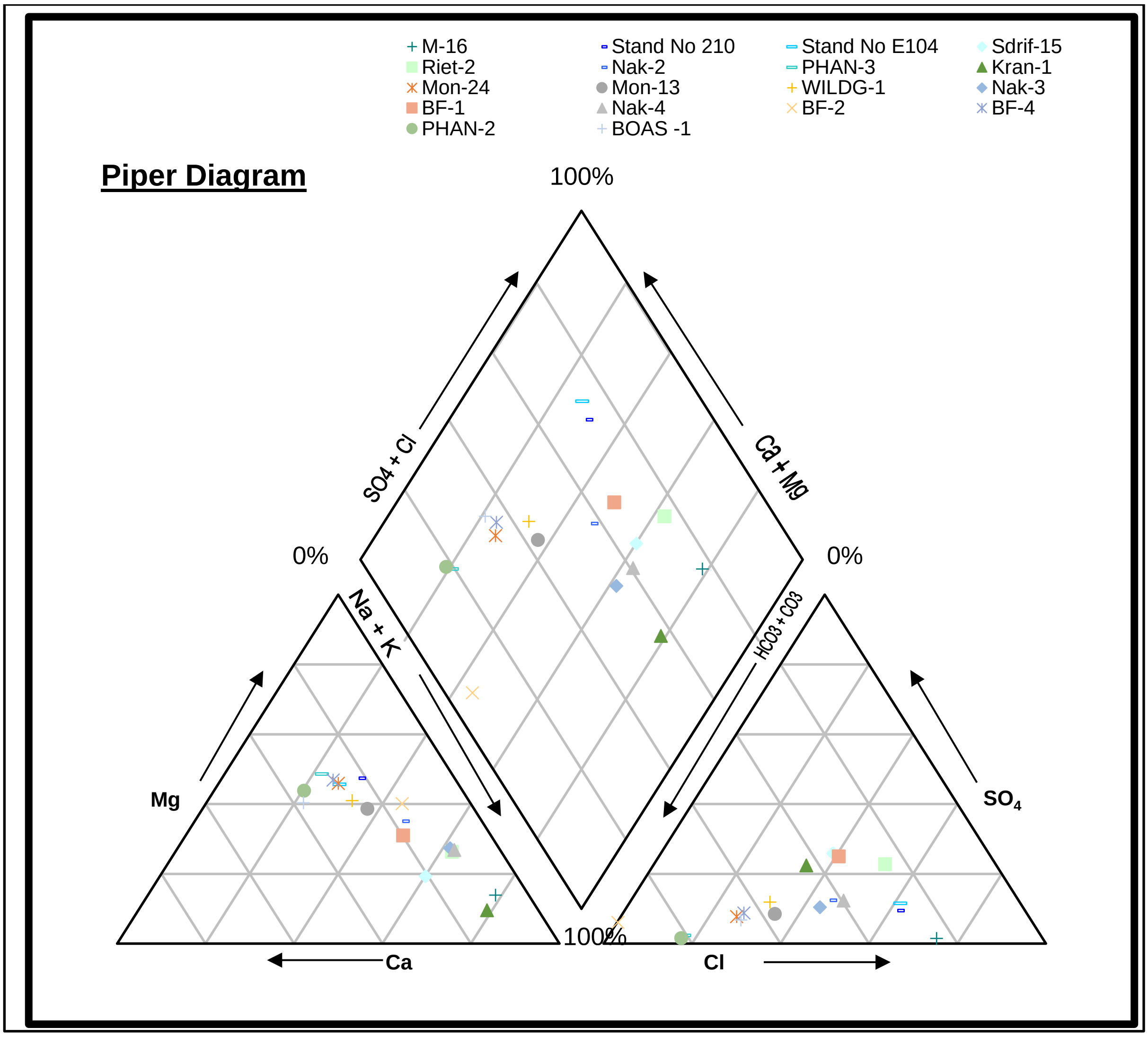

Figure 6-11 Piper diagram of water quality

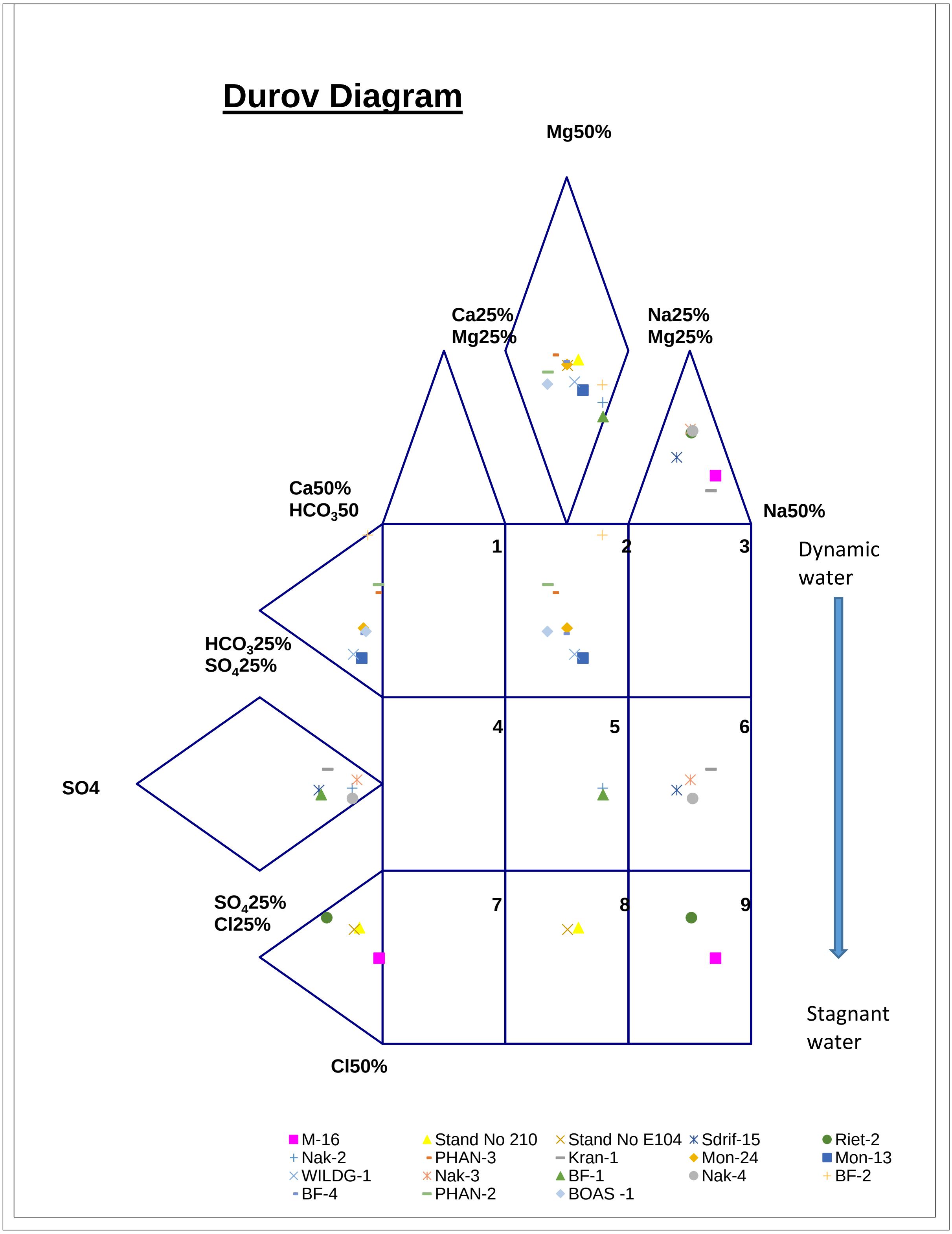

Figure 6-12 Durov diagram of water quality

6.6. Aquifers

Aquifers in the study area consist mainly of confined secondary aquifers in consolidated rocks consisting of crystalline basement rocks of the LMB, stratified Soutpansberg and Karoo sediments and lavas. In the unfractured state these rocks are impermeable and of low groundwater potential. Groundwater is associated with weathering, faults, shear zones and dyke intrusions in these rocks.

Limpopo Mobile Belt: The weathered zone is generally poorly developed and not more than 20 m deep. Most drill targets encounter early strikes between 20 and 30 m, hence the weathered zone is not typically an aquifer. Storage is limited as it is restricted to fractures. Although the potential to intersect water diminishes with depth the heterogeneous nature of the LMB does produce water in fractures at deeper levels in some boreholes.

The Soutpansberg Group: These rocks form the hills and mountains to the north and south of the coal beds because of the weather resistant quartzites of the Soutpansberg Group. These hills and mountains form a zone of higher recharge which feed into aquifer systems lying down gradient.

Karoo strata: Groundwater capacity within the sedimentary layers can be enhanced along brittle horizons such as sandstone or coal layers brecciated by fault/shear displacement. Dolerite sills and dykes are also zones of enhanced groundwater occurrence.

7. GROUNDWATER FLOW MODEL

The establishment of a numerical groundwater model was considered necessary in order to derive a water balance, to determine flow direction, to quantify potential inflow into the open pit over time, and to identify water users at risk from the proposed project.

7.1. Description of the Model

The USGS MODFLOW2000 Finite Difference groundwater model was utilised in the US Department of Defence GMS 10.0.11 (Groundwater Modelling System) interface to simulate and plot groundwater flow. MODFLOW numerically solves the three-dimensional partial differential equation which defines groundwater flow in a porous medium by using a finite-difference mathematical solution method. MODFLOW allows definition of the environment using parameter values, each of which can be applied to each specific grid cell and is assumed to be uniform over that cell.

MODFLOW in the GMS package has the relevant capabilities to simulate flow and contaminant transport in a heterogeneous environment. MODFLOW simulates steady and non-steady state flow in an irregularly shaped flow system in which aquifer layers can be set as confined, unconfined, or a combination of confined and unconfined. It allows flow to and from external stresses such as boreholes, recharge, evapotranspiration, discharge to springs/drains, seepage to and from river beds, and the effect of barrier dykes to be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (be different in one direction than the other). The storage coefficient/specific yield may be heterogeneous.

MODFLOW is currently the most internationally used numerical model for groundwater flow problems and can simulate a wide variety of systems. It is used to simulate systems for water supply, containment remediation and mine dewatering. MODFLOW has extensive publicly available documentation, and it is reviewed by the United States Geological Survey. When properly applied, MODFLOW is the recognised standard model accepted by courts, regulatory agencies, universities, consultants and industry in the United States and elsewhere.

MODFLOW solves the equations for the three-dimensional movement of groundwater in a network of defined cells for defined time steps. Using defined parameters of transmissivity and storativity, together with specifications of flow and/or head conditions at the boundaries of an aquifer system (such as recharge, abstraction, evapotranspiration flow to and from rivers and drains etc.), MODFLOW solves for the value of head (water level) for each grid cell at each defined moment in time.

7.2. 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 inputs, outputs and stresses on the groundwater environment. The development of a conceptual model includes identifying hydrogeological layers, boundary conditions, and zones of similar or differing properties that need to be differentiated.

Based on the conceptual model, 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 mathematical 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;
- The history of groundwater abstraction which modifies water levels and the water balance;
- The spatial and vertical 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 or shallow water table areas, abstraction from boreholes, dykes and faults and permeability boundaries, springs and baseflow to streams and rivers.

7.2.1. *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 Mufungudzi Rivers, hence recharge rates are highly variable between catchments and within catchments, 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 serving as aquicludes 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 of equal recharge 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.

7.2.2. *Discharge*

Based on the observed hydraulic gradient, the aquifer was considered to discharge naturally towards the Nzhelele River, the Sand, Mufungudzi and Kandanama Rivers as baseflow. A perennial flow and a water level approximately equal to the river in these channels, even with boreholes pumping large volumes in their proximity, suggests these rivers can lose water to the aquifer. This was confirmed during the Makhado study (CoAL, 2012a) which found groundwater with an isotopic signature similar to surface water in boreholes abstracting groundwater near the river prior to the confluence with the Mutamba River.

Consequently, these portions of river were treated as river, or head dependent boundaries. 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 flow over significant volumes of alluvium. Some of these alluvial compartments are utilised by irrigators via abstraction from well points. These rivers were considered as drains, as river losses to the alluvium remains in the alluvium and is utilised by riverine vegetation and irrigators. River losses do not recharge the regional aquifer since hydraulic gradients are oriented towards the channels.

Pans and springs were also considered as drains.

7.2.3. *Evaporation*

It was considered necessary to include evapotranspiration to drain groundwater and prevent baseflow. Evaporation allows the drainage of groundwater without generating excessive 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 DWS), groundwater baseflow to surface water courses only exists along the Kandanama and Mufungudzi, hence, natural recharge must be lost through riverine vegetation and spring discharge which is equal to at least the volume of recharge.

7.2.4. *Boundary Conditions*

Modelling results are 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. For this reason, it is generally best to extend a model to no-flow boundaries, such as watersheds, or impermeable dykes, or rivers across which no groundwater flow takes place, except into the river.

To avoid boundary condition problems and to incorporate the cumulative impacts of all the potential mining projects in the Soutpansberg region, the model domain covered several Quaternary catchments in which mines are proposed, or in which mining may impact on the water balance (figure 7-1). It is most probable that all the mines will have a cumulative effect if mining occurs.

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. 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 River, 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 proposed Duel Coal Project 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 (figure 7-2).
- The Nzhelele Dam was also treated as a constant head boundary.
- Discharge to springs and pans were simulated using drains (figure 7-2), 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 0.05-0.1 m^2/day/m.
- The perennial Sand, Nzhelele, Kandanama and Mufungudzi Rivers were treated as a head dependent river boundary (figure 7-2), capable of discharging water to the aquifer, or receiving water, depending on the piezometric head in the aquifer in that cell. The Limpopo River 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 0.05-2 m^2/day/m.

- The ephemeral 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 0.001-0.005, with smaller values along small tributaries.
- The entire surface of model domain was treated as an evaporation boundary, where water is removed from aquifer cells at the specified flow rate if the water level is at ground surface, declining linearly to zero when groundwater drops to 6 m below ground surface. A significantly higher evapotranspiration rate was used along channel margins, and the foot of Soutpansberg where significant green belts can be observed.
- Dykes with observed water level elevations across the dyke were treated as barrier boundaries. This type of boundary restricts flow across the barrier depending on the set barrier conductance.
- Groundwater abstraction via boreholes was treated as a specified flow boundary, which removes water from the aquifer cell in which the borehole is located according to the specified discharge.
- Open pit workings were treated as drain cells for all model layers where mining was taking place during the mining interval.
- The elevation of linear and areal boundaries, such as perennial and ephemeral drainages and evaporation surface depth were assumed to be equal to surface elevation as obtained from a DTM (figure 7-3).

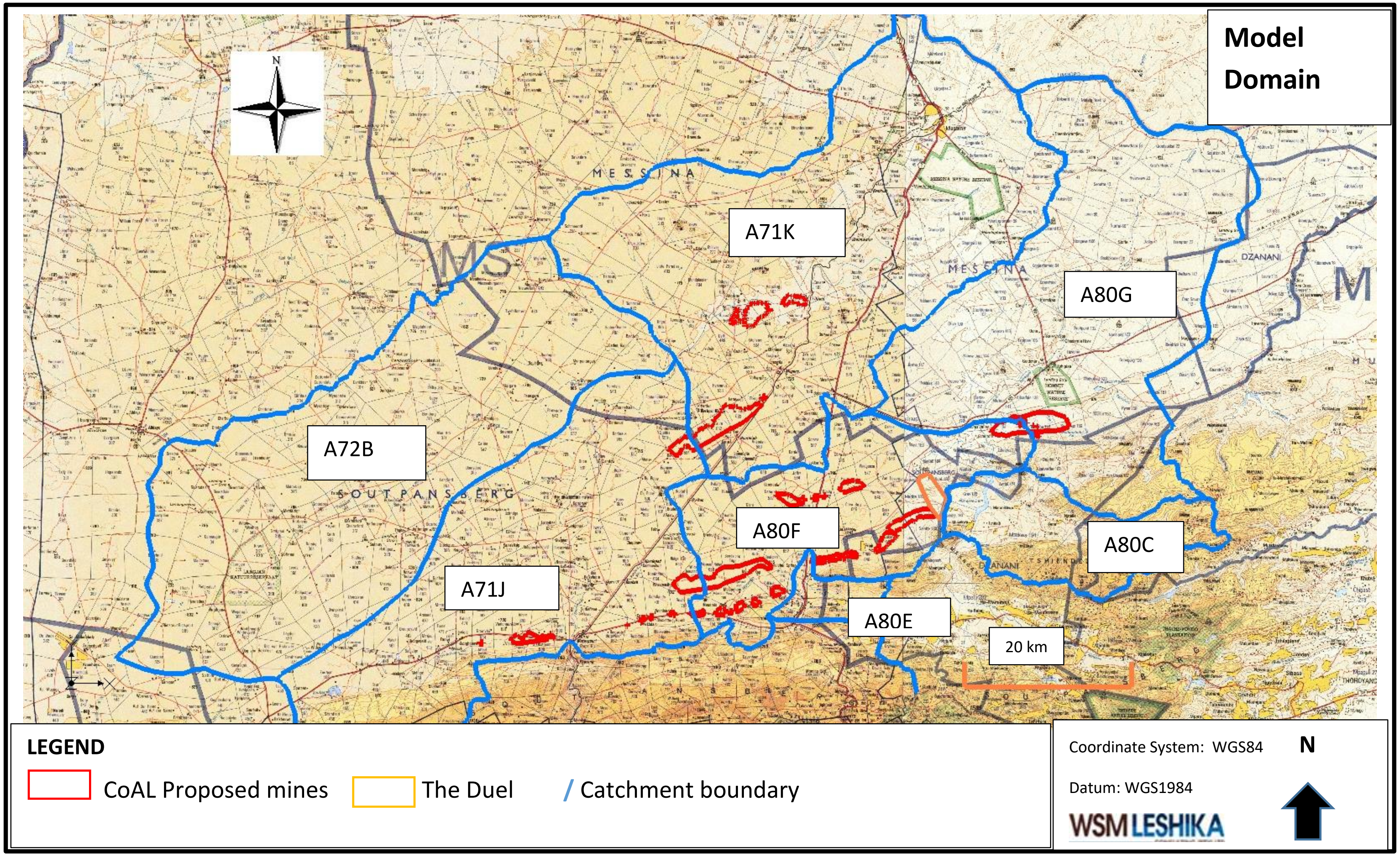

Figure 7-1 Model domain

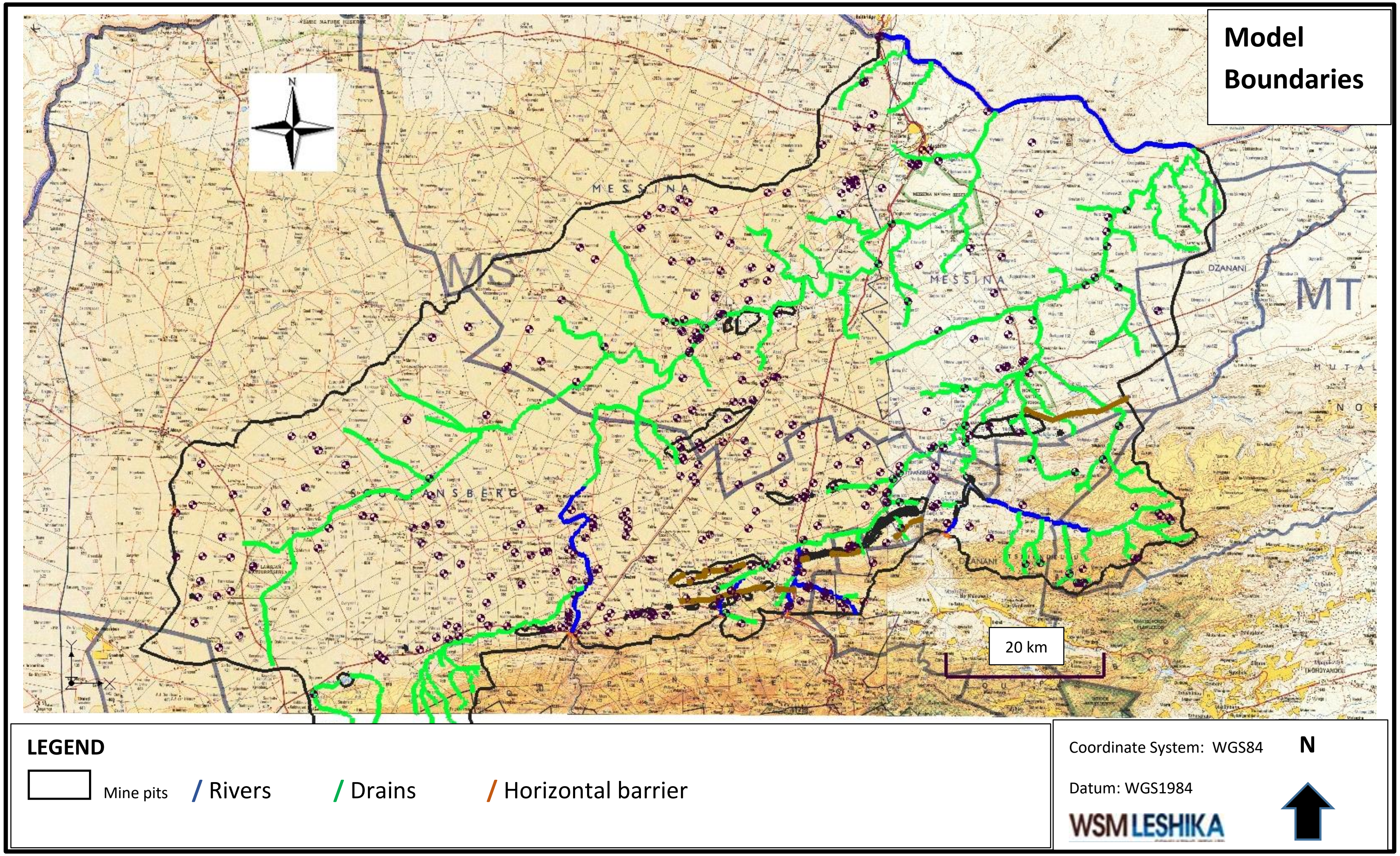

Figure 7-2 Model boundary conditions

7.3. Horizontal and Vertical Spatial Definition

To define the horizontal extent, the model domain considered was the surface area between the Limpopo River and the watershed defined by the Soutpansberg (figure 7-1). For use in the model, the watershed and ground surface were defined by a DTM. The DTM was interpolated to a fine meshed TIN (figure 7-3) then interpolated to the MODFLOW grid.

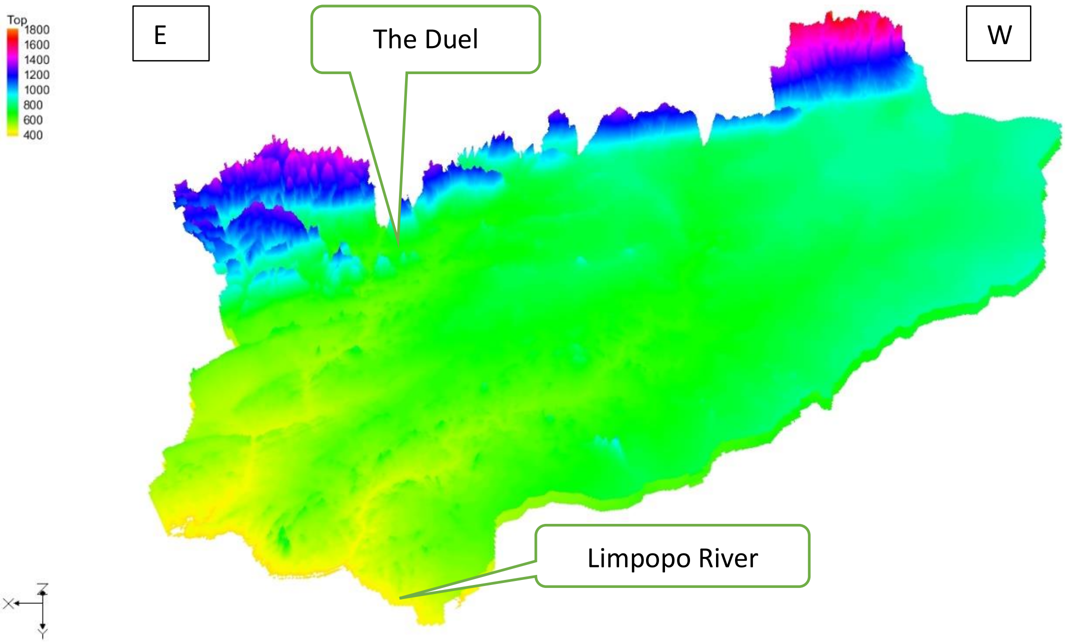

Figure 7-3 DTM of model domain

In a finite difference model, the aquifer is represented by rectangular cell blocks in each model layer. Each cell is assigned a permeability, specific yield, specific storage, thickness and recharge parameter. Hydraulic head in each cell of each layer and the exchange of water between cells and across boundaries are 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 model grid was set to 100m x100m cells in the vicinity of the various mining sites and springs, expanding outwards to a maximum cell size of 500 m x 500 m, at a maximum multiplier of 1.3 for each cell away from the mines. 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 130 x 130 m, once outside the pit. The fine modelling interval allows the steep hydraulic gradients generated by dewatering to be represented.

The resulting grid was 790x1056 cells, oriented at east to the North, along the orientation of major faults. 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.

Due to such complexities and the large area covered by the Greater Soutpansberg mining area and the number of mines in operation during the lifespan of mining, a regional 2-layer model was developed to determine the cumulative impact of all the mines, from which local multi-layer models for each mine can later be developed once mining plans have been finalised.

To define the vertical extent of the model, the depth of mining, the depth of weathering, and the depth of water strikes were considered. Based on the surface DTM, a depth of 400 m depth was considered to be the bottom edge of the model to accommodate underground mining. Based on the depth of water strikes region, high yielding water strikes and the depth of weathering, 120 m was considered the depth of the permeable weathered and fractured aquifer (layer 1), and 280 m was considered the depth of a less permeable fractured aquifer (layer 2).

Each geological formation was assigned its own permeability and storage parameters. From layer 1, these were considered to decrease with depth due to reduced weathering and fracturing, hence the use of 2 layers. Clastic sedimentary formations like quartzite were assumed to have a more gradual decline in permeability with depth than layered shales and sandstones, and a lower ratio of vertical to horizontal permeability due to the lack of layering found in clay rich formations.

7.4. Rivers

The level of the river channel was determined from the DTM. The river conductance was calibrated so that simulated water levels in boreholes next to the river matched observed water levels. A conductance of 0.05-2 m^2/d/m was calibrated (table 7-1).

Table 7-1 Drain conductance

River	Conductance (m^2/d/m)
Sand	0.1-0.2
Nzhelele	0.2-0.3
Kandanama	0.05-0.1
Mufugundzi	0.1
Mutamba and tributaries	0.1-2

7.5. Drains

Ephemeral water courses and springs were considered as drains. These can potentially drain the aquifer but not recharge it. The levels of these drains were obtained from the DTM. Drain conductance was calibrated to 0.001 for small channels in higher mountain regions to 1 for major perennial springs (table 7-2). Drain discharge was calibrated so that total baseflow from rivers and ephemeral channels matched observed volumes in GRAII in each Quaternary catchment.

Table 7-2 Drain conductance

Drain	Conductance ($m^2/d/m$)
Ephemeral channels	0.001-0.005
Pans	0.05-0.1
Springs	0.1-1

7.6. Evaporation

Evapotranspiration was assumed to occur from groundwater at a maximum rate of 1.8-36.5mm/a, with the higher rates being where alluvium occurs along channels. The maximum rate occurs if the water level was at surface, dropping linearly to zero if the water level dropped to 6 m below surface. The evapotranspiration rate was calibrated to ensure that no baseflow occurs in rivers known to be ephemeral.

Evaporation was calibrated to keep groundwater levels below surface and to reduce baseflow so that ephemeral channels do not produce baseflow.

7.7. 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, implying a flow barrier. This was simulated as a horizontal flow barrier boundary across both layers. The barrier has a conductance value to restrict the flow of water across the barrier. The conductance value was calibrated to 5-8 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. Near the proposed mines, drilling data allowed the position of sills to be more accurately established.

7.8. Permeability

Each geological formation was assigned its own permeability and storage parameters, differentiated by lithology and topography. These were considered to decrease with depth due to reduced weathering and fracturing, hence the use of 2 layers. Clastic sedimentary formations such as sandstones were assumed to have a more gradual decline in permeability with depth than non-clastic formations 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.

Permeabilities in m/day for geological formations are listed in table 7-3.

Table 7-3 Model permeabilities

Layer	Permeability (m/d)	Transmissivity (m2/d)	Vertical anisotropy	Specific yield	Specific storage
Limpopo mobile Belt					
Layer 1	0.004-0.05	1-9	10	0.001	$8.3X10^{-6}$
Layer 2	0.0005-0.001	0.1-2	10	$1.7X10^{-6}$	$1.7X10^{-8}$
Soutpansberg					
Layer 1	0.003-0.06	0.5-11	10	0.001	$8.3X10^{-6}$
Layer 2	0.001	0.2	10	$1.7X10^{-6}$	$1.7X10^{-8}$
Soutpansberg Range					
Layer 1	0.0015-0.008	0.3-1.5	10	0.001	$8.3X10^{-6}$
Layer 2	0.0001-0.0005	0.02-0.1	10	$1.7X10^{-6}$	$1.7X10^{-8}$
Karoo					
Layer 1	0.06-0.1	11-18	10	0.002	$1.7X10^{-5}$
Layer 2	0.005	1	10	$1.7X10^{-6}$	$1.7X10^{-8}$
Clarens Formation					
Layer 1	0.01-0.22	2-40	10	0.002	$1.7X10^{-5}$
Layer 2	0.005	1	10	$1.7X10^{-6}$	$1.7X10^{-8}$
Basalt					
Layer 1	0.1-0.25	18-45	10	0.002	$1.7X10^{-5}$
Layer 2	0.005	1	10	$1.7X10^{-6}$	$1.7X10^{-8}$
Rivers					
Layer 1	0.03-0.25	5-45	10	0.002	$1.7X10^{-5}$
Layer 2	0.005	1	10	$1.7X10^{-6}$	$1.7X10^{-8}$
Faults					
Layer 1	0.7	126	10	0.002	$1.7X10^{-5}$
Layer 2			10	$1.7X10^{-6}$	$1.7X10^{-8}$
Mine fill					
Layer 1	1	180	1	0.1	0.0016

The vertical conductivity between layers was set to 0.1 times horizontal permeability, which means the horizontal permeability is 10 times the vertical.

The specific yield value was calibrated from abstraction data collected during the bulk sample excavation of the Makhado Project. 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 at Makhado. The specific yield was calibrated so that similar pit inflows were derived for the Makhado Project mine pits in this study as in the Makhado Project modelling study.

7.9. Rainfall Recharge

Recharge applied to the various lithologies is shown in table 7-4. Mine pits were considered to have a high recharge of 255 mm/a (70% of rainfall) post mining after being filled and top soiled and before vegetation is established. It was assumed that, except for some surface runoff, most rainwater would infiltrate as recharge. After 3 years recharge was assumed to decline to 73 mm/a (20% of rainfall), then to 36 mm/a (10% of rainfall) after 6 years when rehabilitation is complete.

Table 7-4 Recharge in mm/a

	Recharge	**Post mining**	
		3 years	**6 years**
Mine pits	0	255	73
Soutpansberg, steep slopes, shallow soil	11-55		
Soutpansberg, deeper soils	1-20		
Karoo mudstones	2.2-7.3		
Karoo Clarens Formation	3.6-5.8		
Basalt	3.7-7.4		
Limpopo Mobile Belt	1.8-4.8		

Recharge was simulated using a constant inflow into defined parameter zones and calibrated against borehole water levels in the steady state model. The weighted recharge to the entire model domain was 13.2 mm/a.

7.10. Abstraction

Groundwater abstraction was simulated by discharge boundaries in cells containing production boreholes. Groundwater abstraction was estimated from the DWS WARMS database of registered water use, and from a hydrocensus, however, it was found that the registered use of 46 Mm^3/a (CoAL 2012a, 2012b and2012c) over the model domain is much higher than recharge and that irrigated lands could not be observed on Google Earth to account for the high registered water use. The following was concluded:

- The registered water use was not utilised every year
- Farmers along the Nzhelele scheme register a groundwater use but 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 abstracted 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. Based on crop water demand given in SAPWAT, 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 are assumed to utilise only alluvial water
- Lands along the Nzhelele had only a fraction of their estimated use met from boreholes
- Irrigation groundwater demand was only turned on in the model during the calibration run if observed water levels in the NGA were post 1985, as the irrigation was assumed to be post 1985. The irrigation was subsequently turned on to derive present day water levels.

Based on the above assumptions, actual present water use was calculated as 6 Mm^3/a. In addition, the MODFLOW NWT package was utilised in the CoAL studies (2012a, 2012b and2012c), which reduces borehole abstraction proportionally to keep water levels above a selected level. A maximum water level of 100 metres below ground level was selected. The subsequent current groundwater abstraction that could be met was simulated as 5.5 Mm^3/a.

7.11. 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 with current groundwater abstraction 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 YEAR 1 once mining begins and water levels begin to be affected.

7.12. Model Simulations

The simulations undertaken are shown in table 7-5 based on the available mining plans (figure 7-4).

Table 7-5 Model simulations performed

Simulation	State	Number of Model Time steps	Years simulated	Purpose of simulation	Impacts
1	Steady			Model calibration	Abstraction only on farms with recent water levels
2	Steady	`		Present day water levels Initial head for transient state model	Addition of all abstraction
3	Transient	16	16	Impact of mining	Makhado life of mine, The Duel, Voorburg, Wildebeesthoek, Mount Stuart mine start ups
4	Transient	22	22	Impact of mining	Makhado closure and water level recovery, Voorburg, Wildebeesthoek, Mount Stuart, The Duel life of mine, Generaal, Jutland, Chapudi start up
5	Transient	11	11	Impact of Mining	Jutland and Generaal up to the closure of Generaal
6	Transient	17	17	Impact of Mining	Closure of all mines

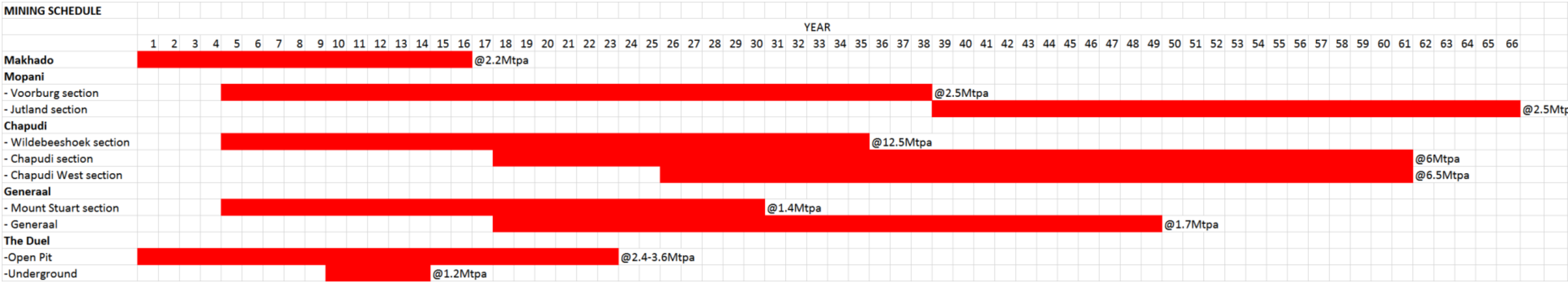

Figure 7-4 Mining Schedule

7.13. Mining Levels and Inflows

Where detailed mining plans are not available, 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. Detailed mining plans are available for Makhado and The Duel, and these mining plans were used to establish the drain extent and depth per annual time interval, with the drain declining linearly in depth over the time interval (figure 7-5).

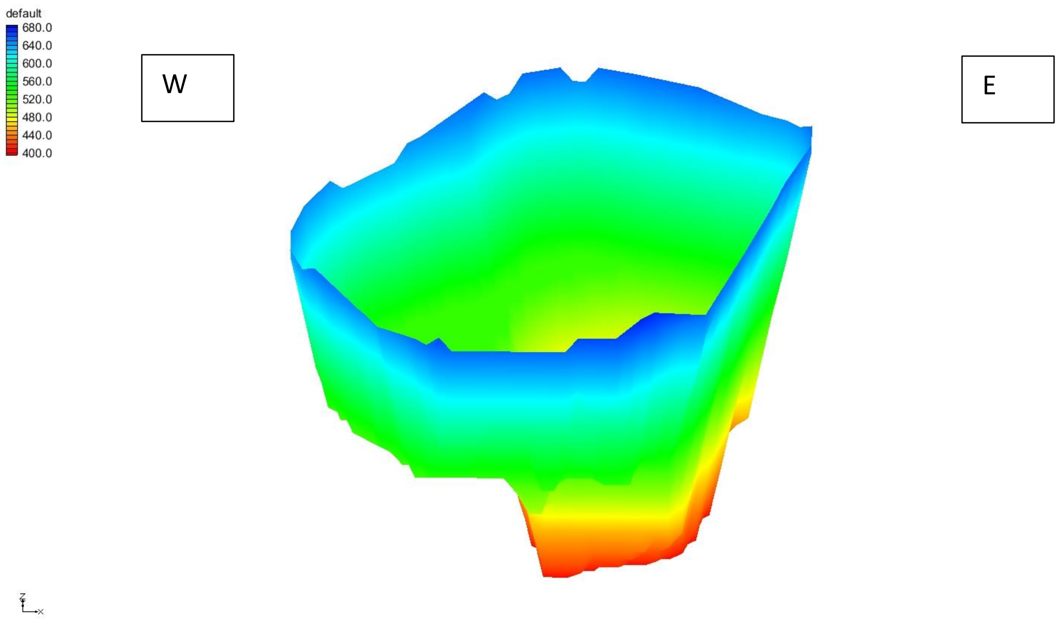

Figure 7-5 Profile of The Duel open pit drain configuration in Year 16 in mamsl

The planned underground mine at Mount Stuart and The Duel were treated as a drain in layer 2, progressing from surface to a depth of 400 m, and the underground workings at The Duel Coal Project were assumed to descend to 400 m. This assumes inflows only take place at depth, and the upper layer can remain saturated, being dewatered by water seeping down from surface to the lower layer. The drain conductance is equal to the coal conductivity, 0.05 $m^2/d/m$ for open cast mines, and to 0.002 $m^2/d/m$ for the underground workings. After mining stops, the drains in the cells forming the pit were turned off, allowing water levels in the pit to recover.

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 7-3).

7.14. 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 across boundaries match observed field measurements to within an acceptable error margin. Calibration under known conditions against observed data is critical if the model is to be used to forecast scenarios for which no observed data is available.

The model inputs that need to be estimated are often distributed spatially and (or) temporally, so that the number of parameter values could be infinite. The number of observations, however, generally is limited. Model calibration is the process of demonstrating that the model can successfully simulate observed aquifer behaviour. Calibration is a process whereby certain parameters of the model such as recharge and hydraulic conductivity are altered in a systematic fashion and the model is repeatedly run until the computed solution matches field-observed values within an acceptable level of accuracy.

Calibration of the model was based on water levels in 965 observation boreholes identified in the original and subsequent hydrocensus, in the NGA, in the GRIP database, and newly drilled boreholes. 657 boreholes were historic water levels from the NGA, 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 NGA, 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, since the NGA records water levels at the time of drilling. The water levels in the vicinity of these boreholes should therefore be calibrated with abstraction excluded.

The trial and error manual calibration method was utilised.

Measured water levels below ground surface had to be converted to absolute water levels in terms of metres above mean sea level. 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 NGA 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 calibration protocol followed was based on the following considerations:

a. **Simplicity.** The model was kept simple while still accounting for all the lithology and boundary conditions identified. The model domain was divided into sub regions based on geological formations, each which had an original estimated hydraulic conductivity. All the cells in each sub-region were calibrated together so that each sub-region has an equal parameter value for hydraulic conductivity. Additional complexity, such as calibrating conductance values for leakage to drains, and varying recharge and evaporation, was included subsequently when it was seen that the model had an inability to reproduce observed water levels and fit the regional water balance.

b. **Existing information.** Existing information on recharge, baseflow and borehole yields, and abstraction was utilised to constrain the problem so that the water balance fit regional estimates.

c. **Conceptual model**. The conceptual model (7.2) was utilised to quantify parameters based upon their need to represent existing knowledge about the system and to impose constraints.

d. **Data types considered.** The overall water balance of the study had to match estimates of the water balance in GRAII, as well as water levels matching observed water levels in boreholes. Water levels were compared to ground surface to ensure water levels are below surface.

e. **Calibration target.** Seasonal water levels may vary by about 5 m and pumping rates may fluctuate daily. An effort was taken to use water levels taken in the same monthly period of each year where multiple records exist in order to minimise this variation. This was not possible if only 1 water level at one moment in time is available for a borehole. In addition, the surface elevations of boreholes can be 2 m out. Consequently, an observation interval of 5 m was selected as being an acceptable calibration target for NGA boreholes with poor coordinate accuracy and historical variation, and 2 m for hydrocensus boreholes. Calibration was continued until boreholes within the study area where within this calibration interval.

f. **Model Convergence.** A stringent model convergence to within 0.5 m and 50 m^3/d over the entire model domain was selected to minimise errors in the water balance, resulting in a water balance error of only 0.24%.

g. **Evaluate model fit using Residuals.** A residual of 50 m was selected with no linear trend across the range of observed values to indicate no systematic error in over or under simulating water levels in areas of high and low water level.

The Statistics of fit are:

Mean Residual (Head)	-9.34 m
Mean Absolute Residual (Head)	15.06 m
Root Mean Squared Residual (Head)	20.29 m
R^2	0.98

The observed vs simulated water level plot is shown in figures 7-6. No trend of over or under simulation exists as the slope of the best fit line is almost 1 (figure 7-6). The residual error plot (figure 7-7) shows no trending or systematic error in heads across the range of water levels, with some water levels over or under simulated. This suggests no systematic error of over or under simulation. The location of the observation boreholes is shown in figure 7-8.

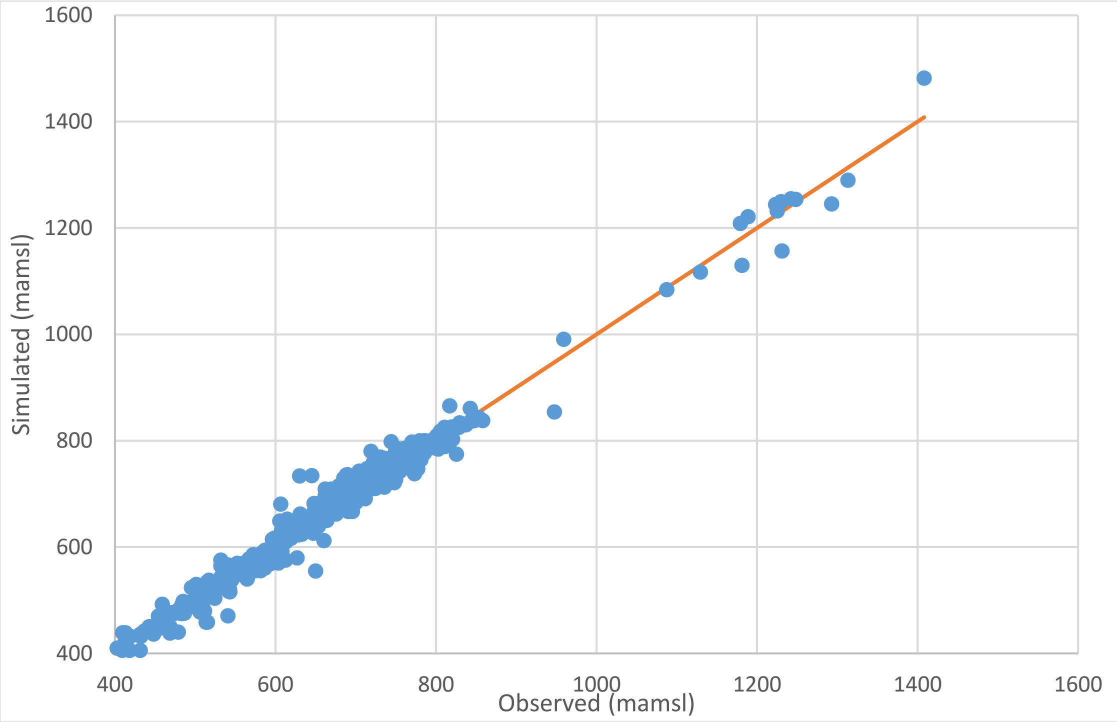

Figure 7-6 Observed vs simulated water level

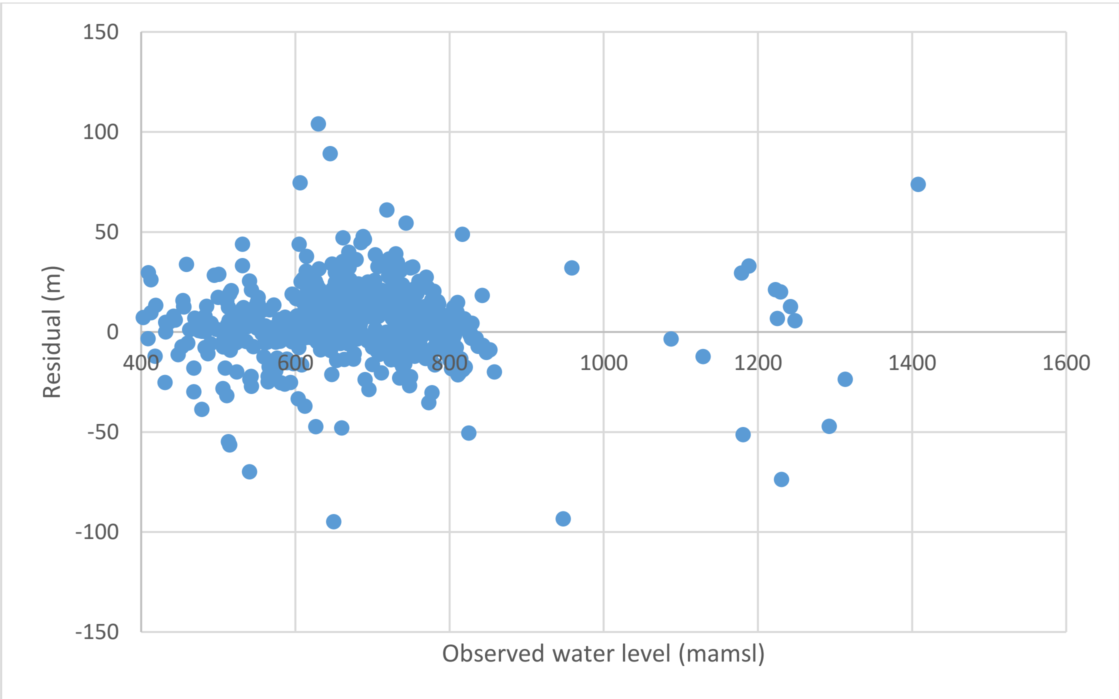

Figure 7-7 Residual error in simulated water levels

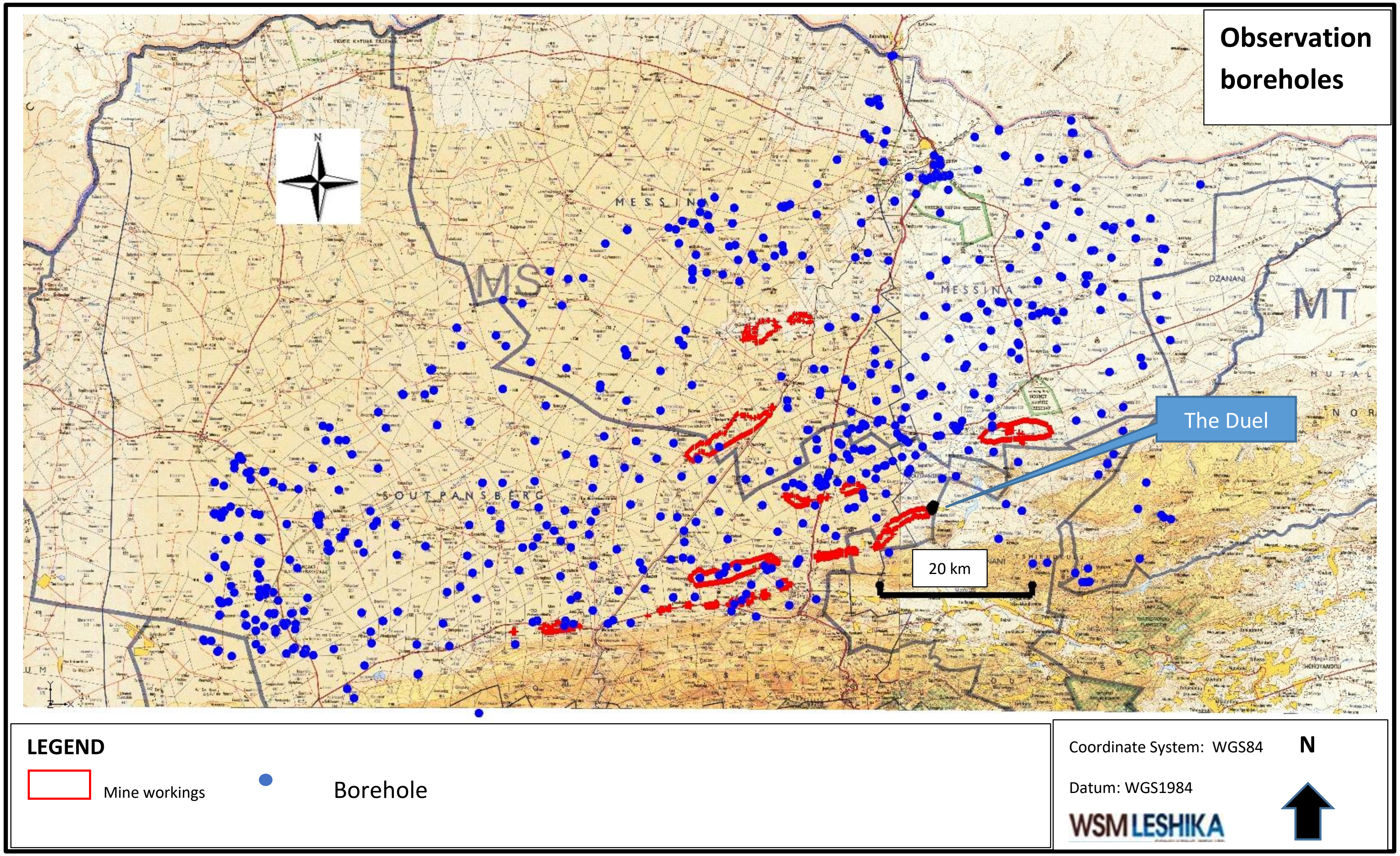

Figure 7-8 Location of observation boreholes

Table 7-6 Simulated and observed water balance for each Quaternary catchment

Catchment	Area	MAP	GRAII Recharge	GRAII Recharge	GRAII Baseflow	Simulated Recharge		Drain baseflow	River baseflow	River Losses	Total Baseflow	
	Km^2	mm/a	mm/a	M^3/d	mm/a	mm/a	M^3/d	M^3/d	M^3/d	M^3/d	M^3/d	mm/a
A71J	1162	396	8.7	27696.99	0	6.59	20965	3927	2849	1067	5709	1.79
A71K	1668	305	6.05	27647.67	0	3.48	15917	1458	410	354	1514	0.33
A72B	1554	344	7.9	33634.52	0	4.12	17556	152	0	0	152	0.04
A80E	67	622	24	4405.48	15.74	20.54	3770	310	3578	1147	2741	14.93
A80C	294	576	21	16915.07	10.97	17.53	14119	5963	4705	250	10418	12.93
A80F	630	388	4.5	7767.12	0	5.05	8711	1138	148	244	1042	0.60
A80G	1230	333	5.7	19208.22	0	4.29	14456	2424	319	442	2301	0.68
Total				137275.07			95494	15372	12009	3504	23877	

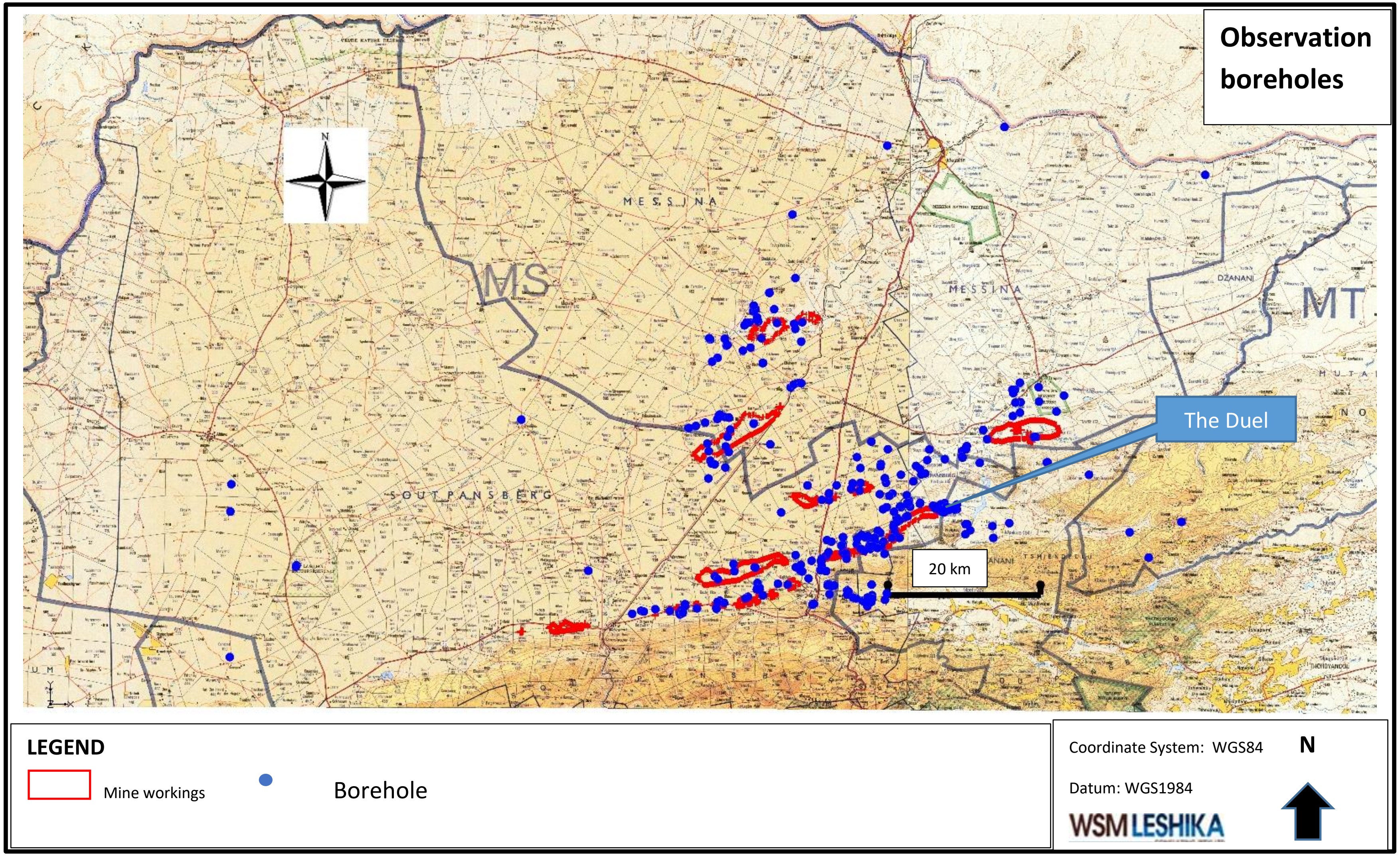

Figure 7-9 Location of observation boreholes used in calibration under abstraction conditions

Model calibration was also undertaken via water balance per Quaternary catchment under virgin conditions, and comparison with the water balance in GRAII to ensure recharge and discharge figures approximate the water balance (table 7-6).

The results of the calibration for water levels against hydrocensus boreholes (figure 7-9), where abstraction is assumed to be occurring, are shown in figures 7-10 and 7-11.

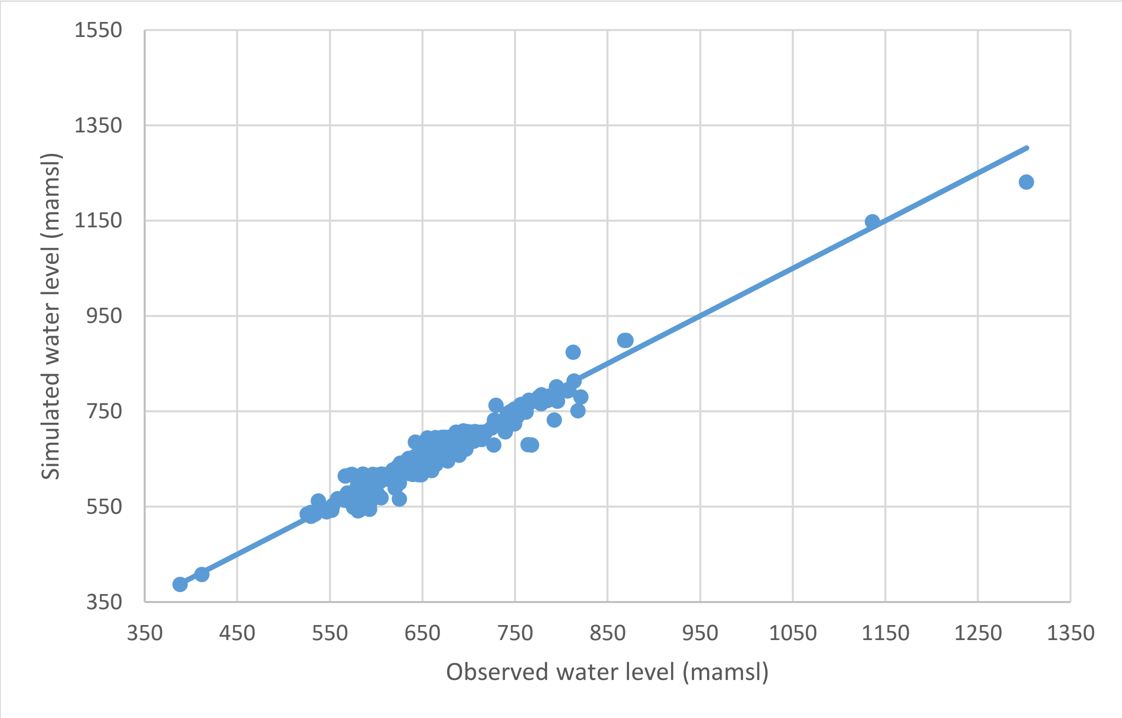

Figure 7-10 Observed vs simulated water level under abstraction conditions

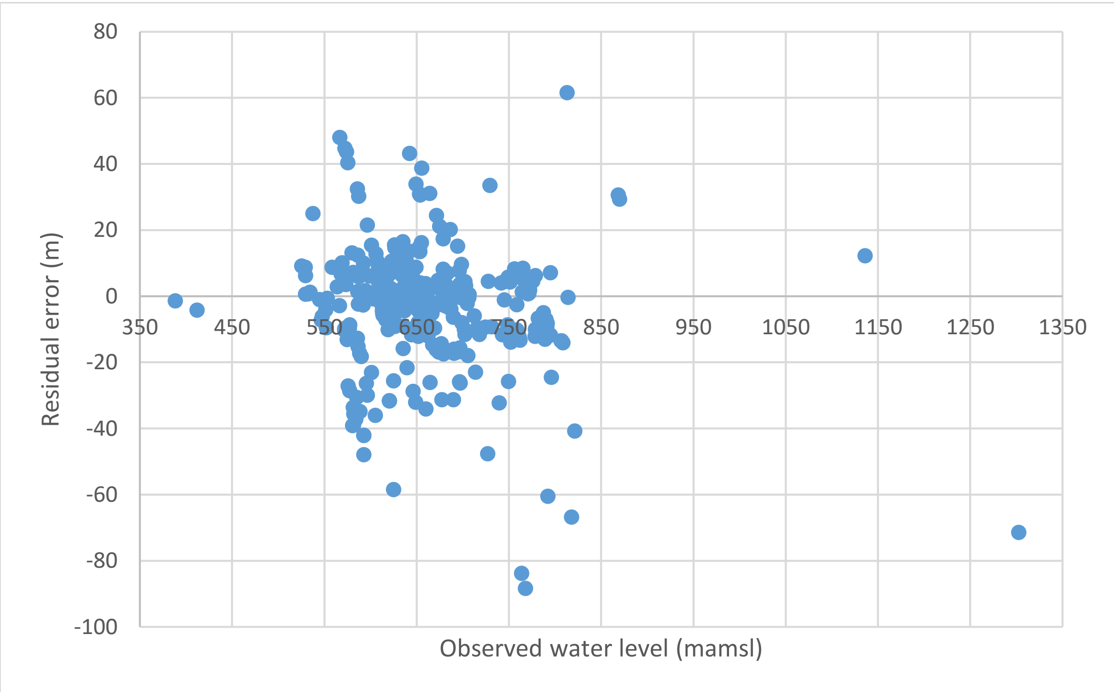

Figure 7-11 Residual error in water levels under abstraction conditions

The Statistics of fit are:

Mean Residual (Head)	16.47 m
Mean Absolute Residual (Head)	22.32 m
Root Mean Squared Residual (Head)	30.85 m
R^2	0.96

8. MODEL RESULTS

Modelling results are expressed as water level maps, drawdown maps 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.

8.1. Water Balance

8.1.1. *Steady state - Pre-Mining Conditions*

The water balance of catchment A80F in which The Duel is located under natural and present conditions is shown in Table 8-1. Inflows from rivers to the aquifer occur at 340 m^3/d from the perennial tributary flowing northward to the Mutamba River from the Soutpansberg under current conditions due to abstraction near the river. In addition, baseflow has been depleted. This tributary loses water to the aquifer due to pumping on Windhoek, Eckland and Overwinning, and flow disappears before it reaches the Mutamba River. Inflows of 576 m^3/d also occur along the Tshipise fault and another fault entering the catchment area from the south at Masekwapoort, and across the western catchment boundary with A71J. Outflows from the aquifer occur largely as evapotranspiration, and eastward groundwater flow towards the Nzhelele River. Outflow also occurs to numerous springs and water courses as springflow.

Abstraction results in a nett reduction in outflow across the eastern boundary, increased losses from the river, a reduction in discharge from springs, and reduced evapotranspiration.

Table 8-1 Water balance under present and pre-mining conditions

Flow Component	Inflow (m^3/d)	Outflow (m^3/d)
Virgin Conditions		
Faults and inflow across boundary (nett)		296
Rivers	240	148
Evapotranspiration		7117
Springs and ephemeral channels		1127
Recharge	8448	
Abstraction		0
Total	8688	8688
Current Conditions		
Faults and inflow across boundary (nett)	576	208
Rivers	370	0
Evapotranspiration		6990
Springs and ephemeral channels		370
Recharge	8487	
Abstraction	0	1794
Total	9364	9364

8.1.2. *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 8-2 for the following years:

Year 4: prior to the start of Wildebeesthoek, with Makhado and The Duel 4 years in operation

Year 14: Makhado in operation, final year of The Duel underground, Voorburg, Mount Stuart and Wildebeesthoek in operation

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

Year 17: Closure of Makhado

Year 24: Voorburg, Jutland, Wildebeesthoek, Mount Stuart, Chapudi and Chapudi west, Generaal in operation. Last year of the Duel in operation

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.

Table 8-2 Simulated water balance of A80F at various stages of mining

Flow Component	Inflow (m^3/d)	Outflow (m^3/d)
Year 4		
Storage	1607	7
Faults and flow across catchment boundary	995	276
Rivers	311	
Evapotranspiration		7214
Springs and ephemeral channels		360
Recharge	8645	
Abstraction		1803
The Duel		1059
Makhado		839
Total	11558	11558
Year 14		
Storage	3979	14

Faults and flow across boundary	1599	272
Rivers	311	
Evapotranspiration		6932
Springs and ephemeral channels		246
Recharge	8645	
Abstraction		1564
Makhado		3632
Wildebeesthoek		0
Mount Stuart		1182
The Duel		693
Total	14534	14534
Year 16		
Storage	3936	7
Faults and flow across boundary	1656	271
Rivers	311	
Evapotranspiration		6783
Springs and ephemeral channels		236
Recharge	8645	
Abstraction		1424
Makhado		3953
Wildebeesthoek		4
Mount Stuart		1349
The Duel		521
Total	14548	14548
Year 17		
Storage	6640	12095
Faults and flow across boundary	1562	
Rivers	318	
Evapotranspiration		7082
Springs and ephemeral channels		260
Recharge	15150	

Abstraction		1569
Wildebeesthoek		68
Mount Stuart		1468
The Duel		859
Total	23670	23670
Year 24		
Storage	4472	2191
Faults and flow across boundaries	1476	
Rivers	318	
Evapotranspiration		7033
Springs and ephemeral channels		240
Recharge	9695	
Abstraction		1350
Wildebeesthoek		1580
Mount Stuart		1243
Other mines		1378
The Duel		702
Total	15961	15961

The impacts of mining on the water balance of A80F are shown in table 8-2 and figure 8-1.

- Abstraction of groundwater for existing users is reduced from 1794 Kl/d to 1350 Kl/d due to the lowering of the water table as a result of the cumulative impact of mining.
- The total dewatering volume from mines rises to a peak of 5823 Ml/d in year 16.
- The bulk of these inflows are into Makhado, which is at LOM. In this time period aquifer storage losses are 3929 Ml/d, hence they form the bulk of inflows into the pits. This volume represents the volume lost from aquifer storage. The remainder of inflows represent groundwater flow intercepted by the pits, which would have discharge elsewhere, or flow across aquifer boundaries due to a flow reversal caused by the cone of depression of the water table around the mines.
- Inflows across the catchment boundary increase from 575 Ml/d to 1656 Ml/d.
- By year 17 aquifer storage shows a nett gain of 5455 Ml/d due to the refilling of the Makhado pits.

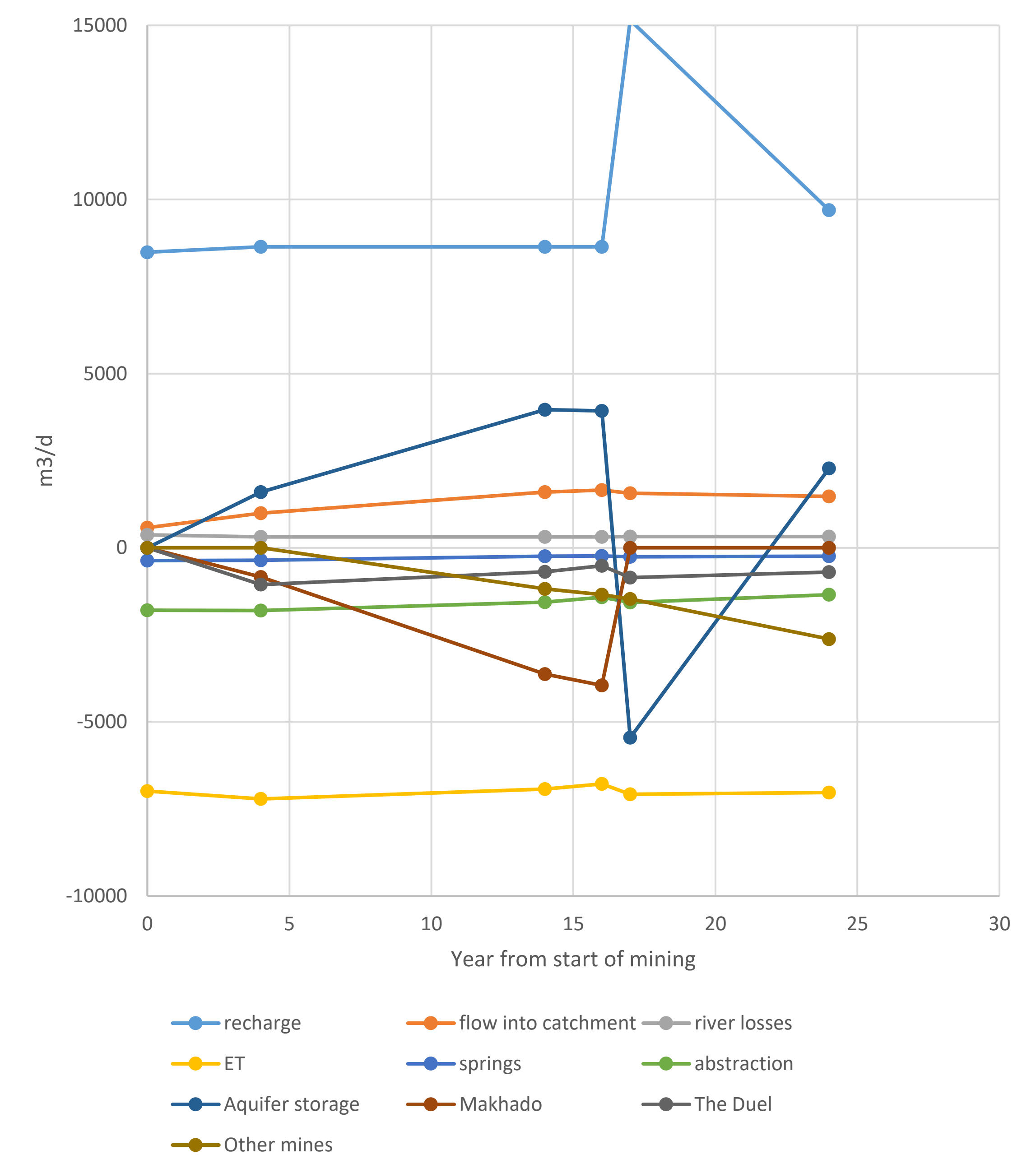

Figure 8-1 Cumulative Impacts on catchment A80F from mining

8.2. Inflows into the Duel

Inflows into The Duel were assumed to occur based on the mining plan showing the extent and depth of mining in each year.

Inflows into the pit reflect the progression of mining to greater depths, combined with mining activities at Makhado. Whichever operation is at greater depth will receive proportionally greater inflow.

Inflows at The Duel rise to 1958 m^3/d by year 3, the decline to below 1000 m^3/d after year 6 when the pit floor stabilises at 490 mamsl (figure 8-2). Inflows increase slightly after Makhado shuts down in year 17.

Significant advantage is gained by simultaneous mining at Makhado and the Duel due to dewatering volumes being shared across both mines.

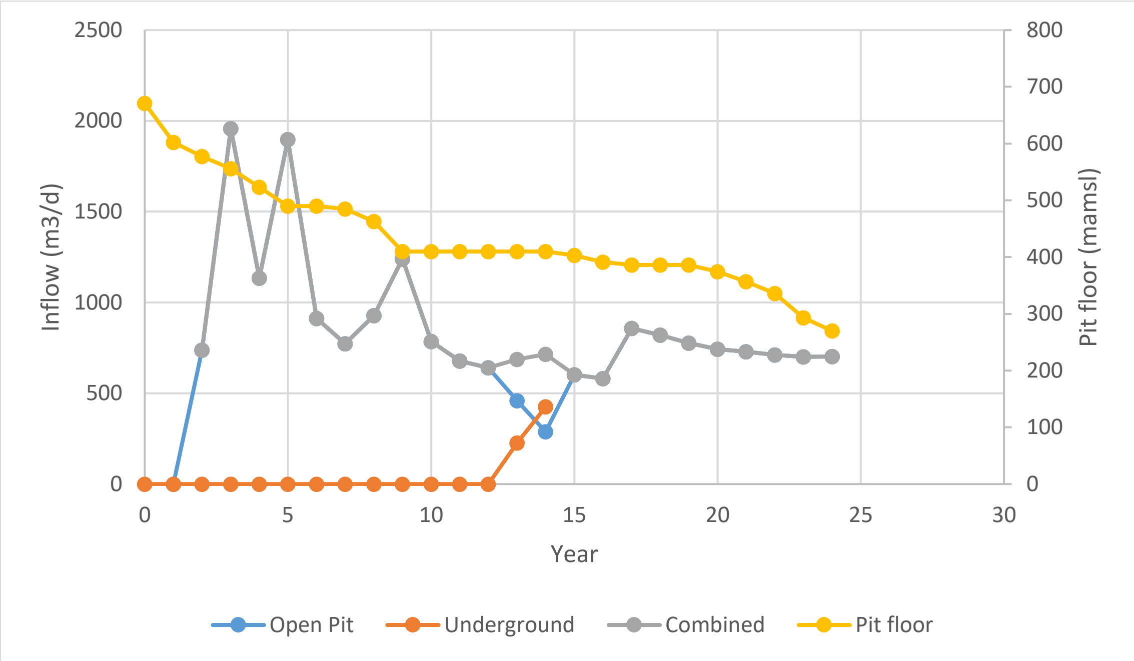

Figure 8-2 Inflow into the Duel

8.3. Impacts of Mining

The impacts of mining on the water balance are shown in figure 8-1 and table 8-2. Baseflow reduction (as springflow) is reduced from 370 m^3/d to 240 m^3/d over the life of The Duel. This is a cumulative impact of all mining impacting on catchment A80F.

Abstraction of groundwater for existing users is reduced from 1794 m^3/d to 1350 m^3/d by the end of the life of mine. This reduction occurs largely at Fripp and Windhoek, where significant dewatering due to mining occurs from Makhado. The boreholes at Musekwa and Makushu can still meet demand as they are located across a groundwater divide from The Duel.

The reduction in inflows to Nzhelele dam are shown in figure 8-3. This reduction is caused by a lowering of aquifer water levels and the cutting off of eastward natural groundwater flow by the cone of depression caused by pit dewatering and abstraction.

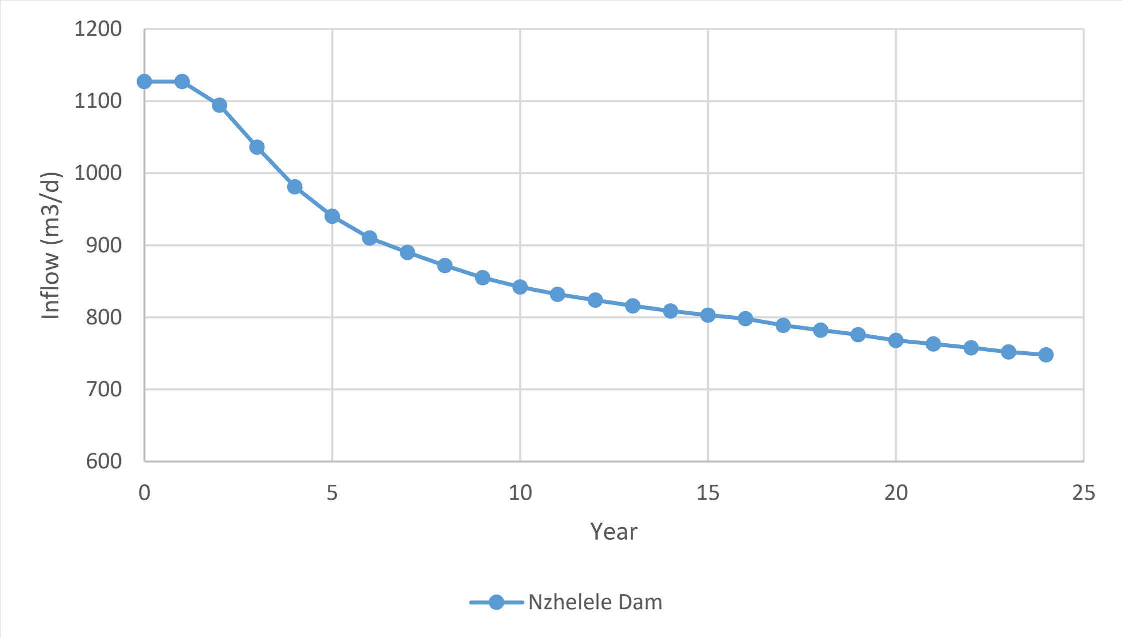

Figure 8-3 Inflows to Nzhelele dam from groundwater

8.4. Water Level Drawdown

Drawdown is the measure of water level decline taken from a bases point, in this case prior to commencement of mining. Due to the number of mines in operation, drawdown is a cumulative impact of all the mines, especially the Makhado Project, directly adjacent to The Duel Coal project. Drawdown of the water level after mining commences is shown for various periods of time in Figures 8-4 to 8-9.

By year 16, the last year of operation at the Makhado Project, drawdown at The Duel Coal Project exceeds 50 m in Makushu, and significant drawdown of 5 to 50 m exists in the entire valley to the Nzhelele Dam from year 5. Significant impacts of over 5 occur on the farms Gray and Martha. The presence of Nzhelele Dam limits further drawdown, as the head provided by the Dam maintains aquifer levels adjacent to the dam. Drawdown of over 20 m persists to year 34, 10 years after the closure.

Figure 8-10 shows that by year 16 after start of mine a flow reversal exists and groundwater gradients are oriented from Nzhelele Dam towards The Duel project, implying a potential loss of water from the dam towards the mine.

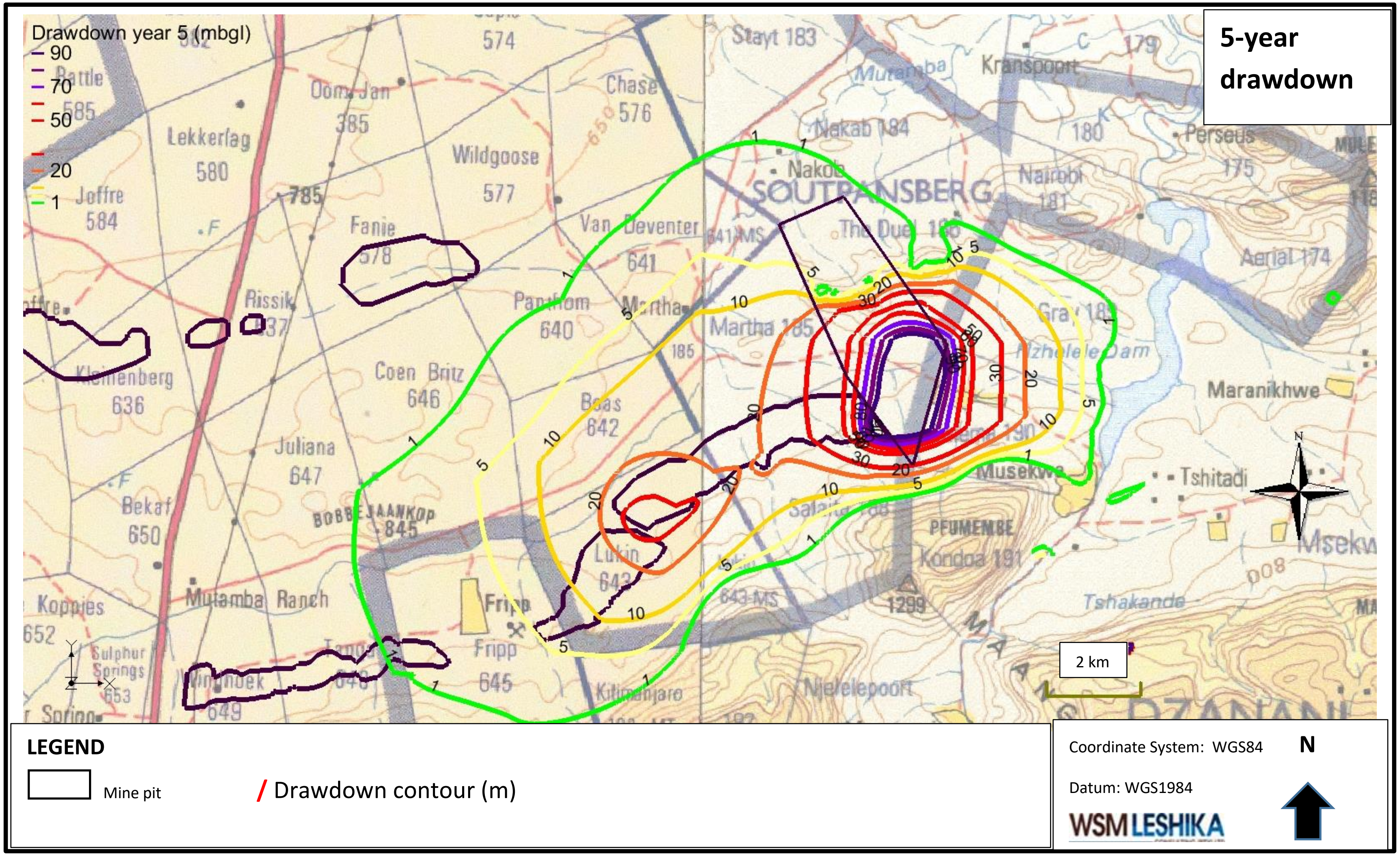

Figure 8-4 Drawdown of water level (m) after 5 years

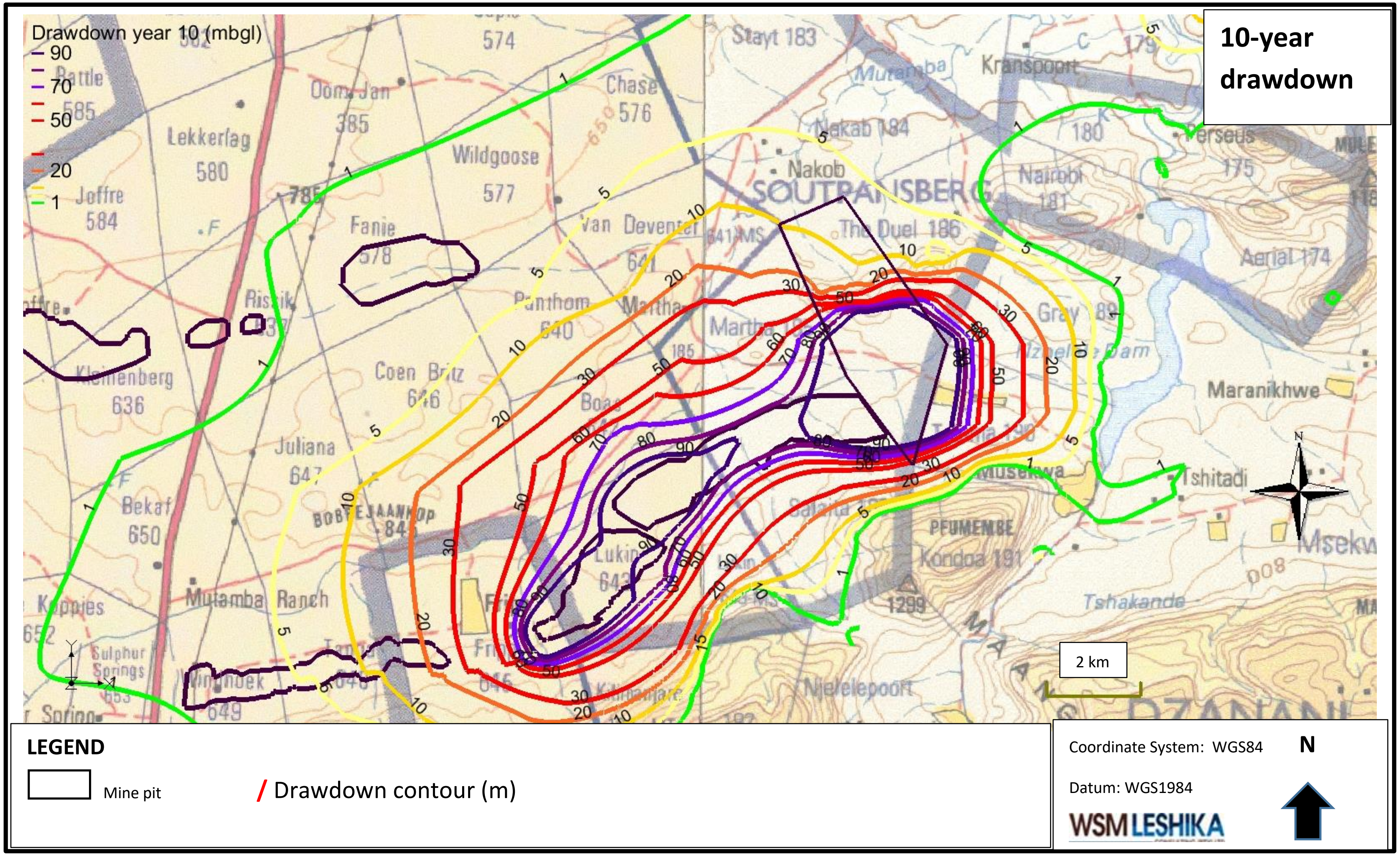

Figure 8-5 Drawdown of water level (m) after 10 years

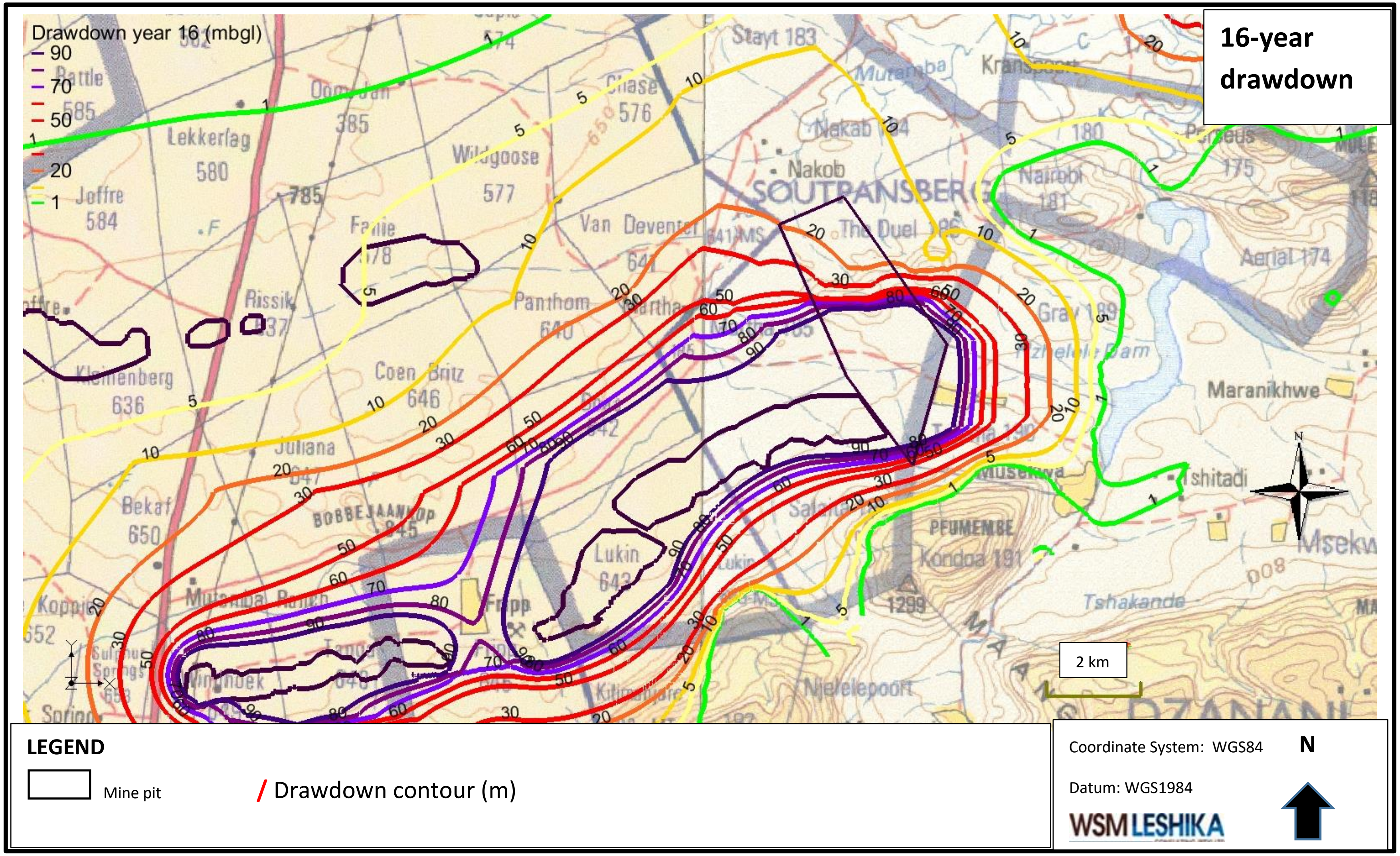

Figure 8-6 Drawdown of water level (m) after 16 years

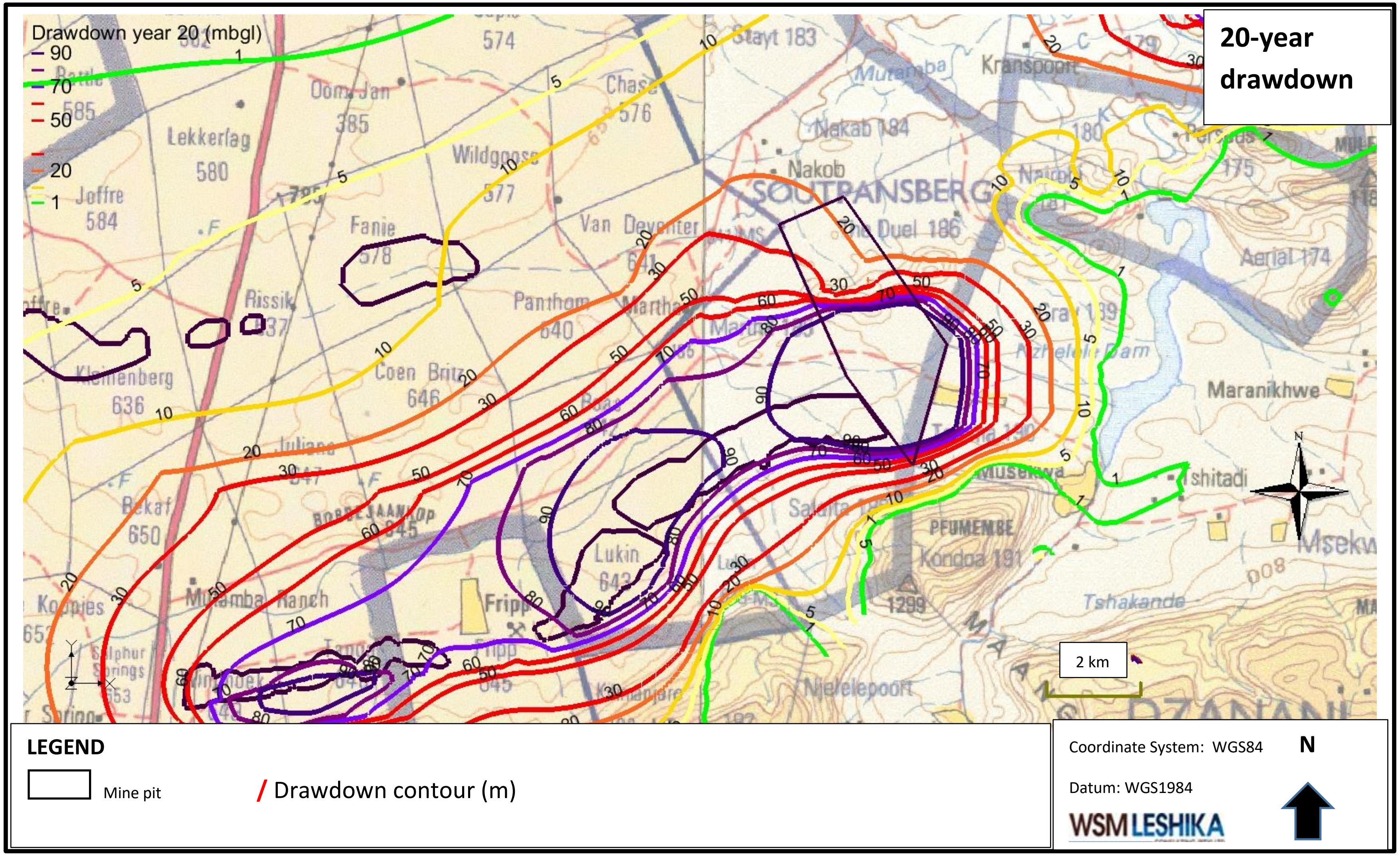

Figure 8-7 Drawdown of water level (m) after 20 years

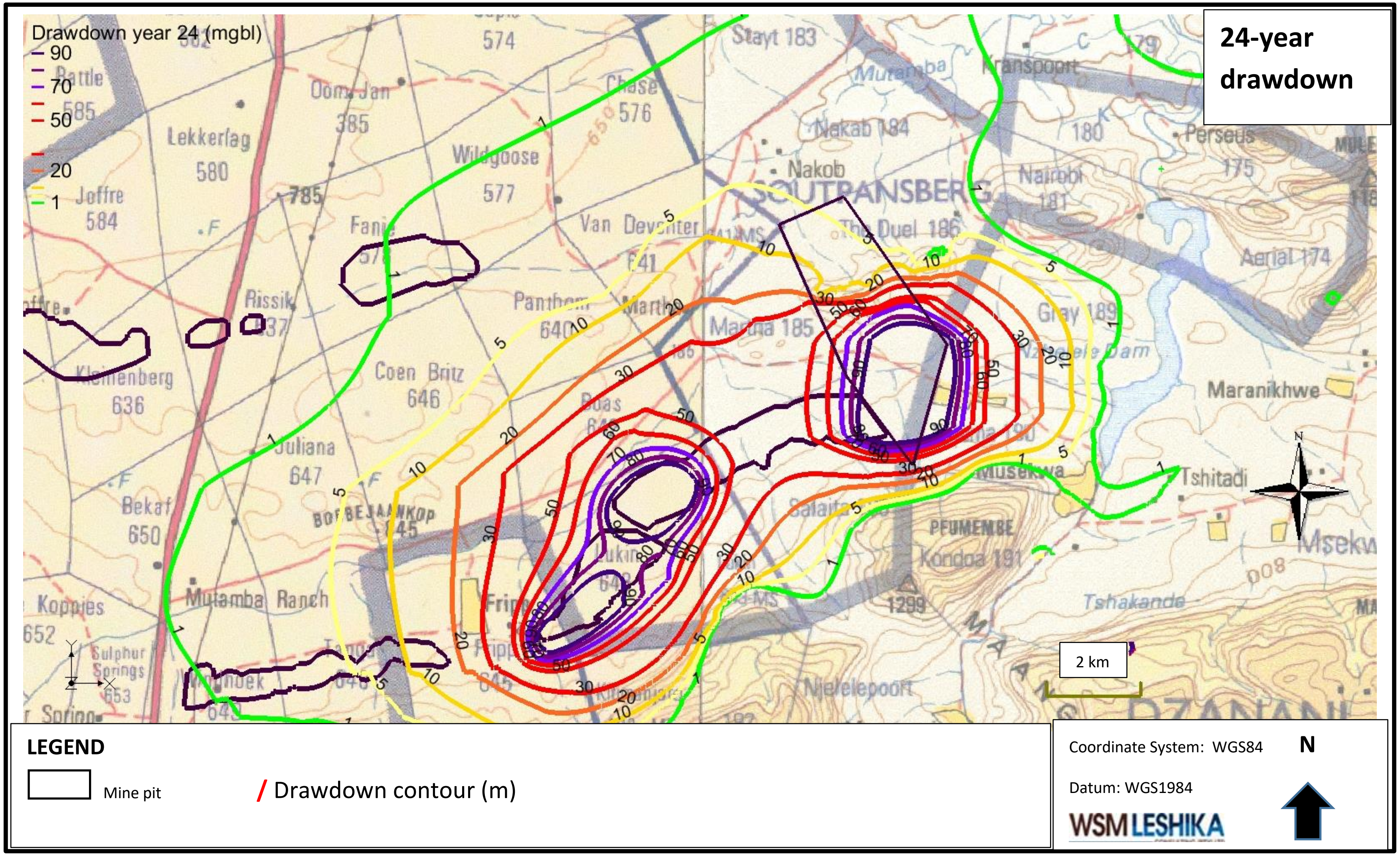

Figure 8-8 Drawdown of water level (m) after 24 years

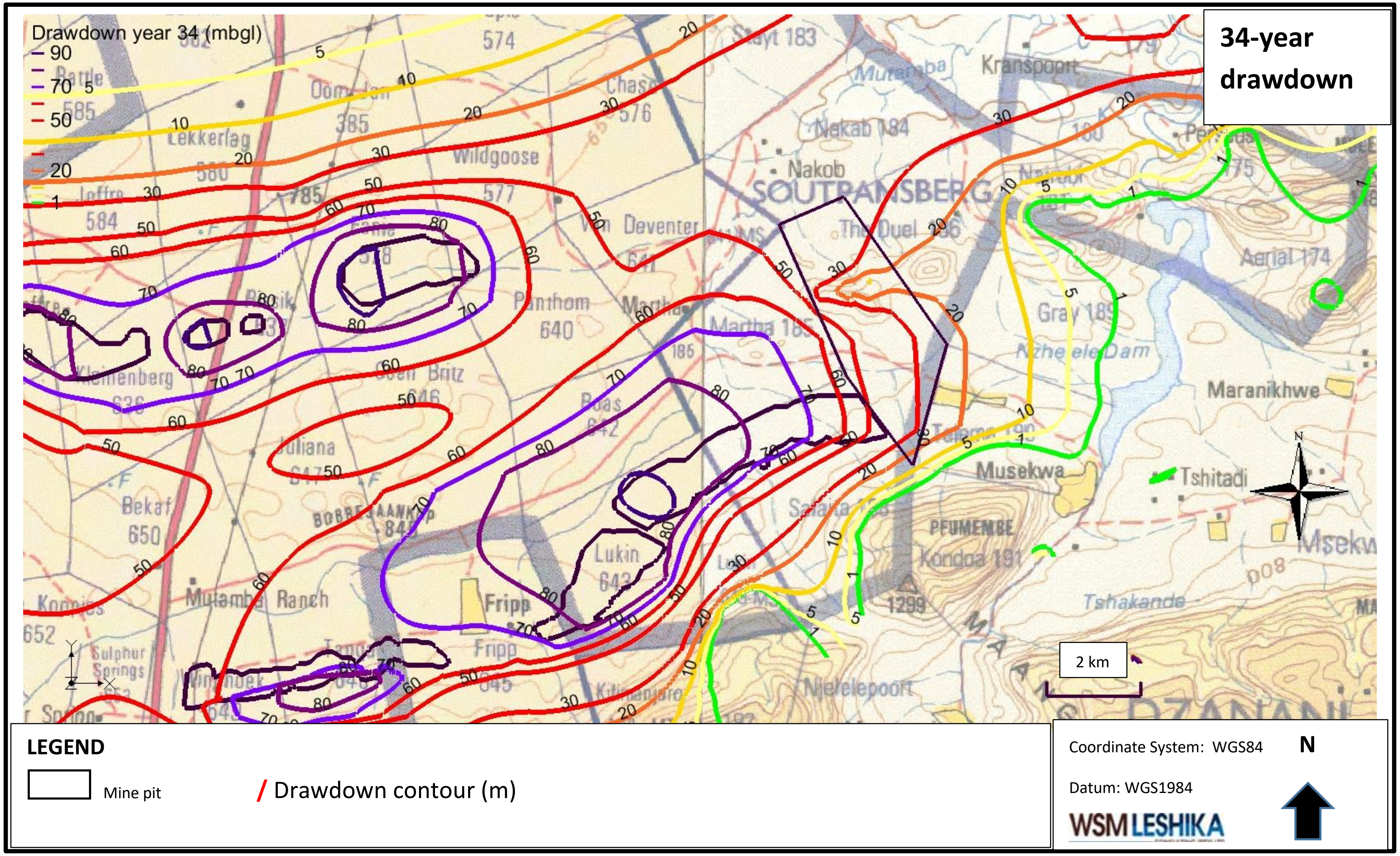

Figure 8-9 Drawdown of water level (m) after 34 years

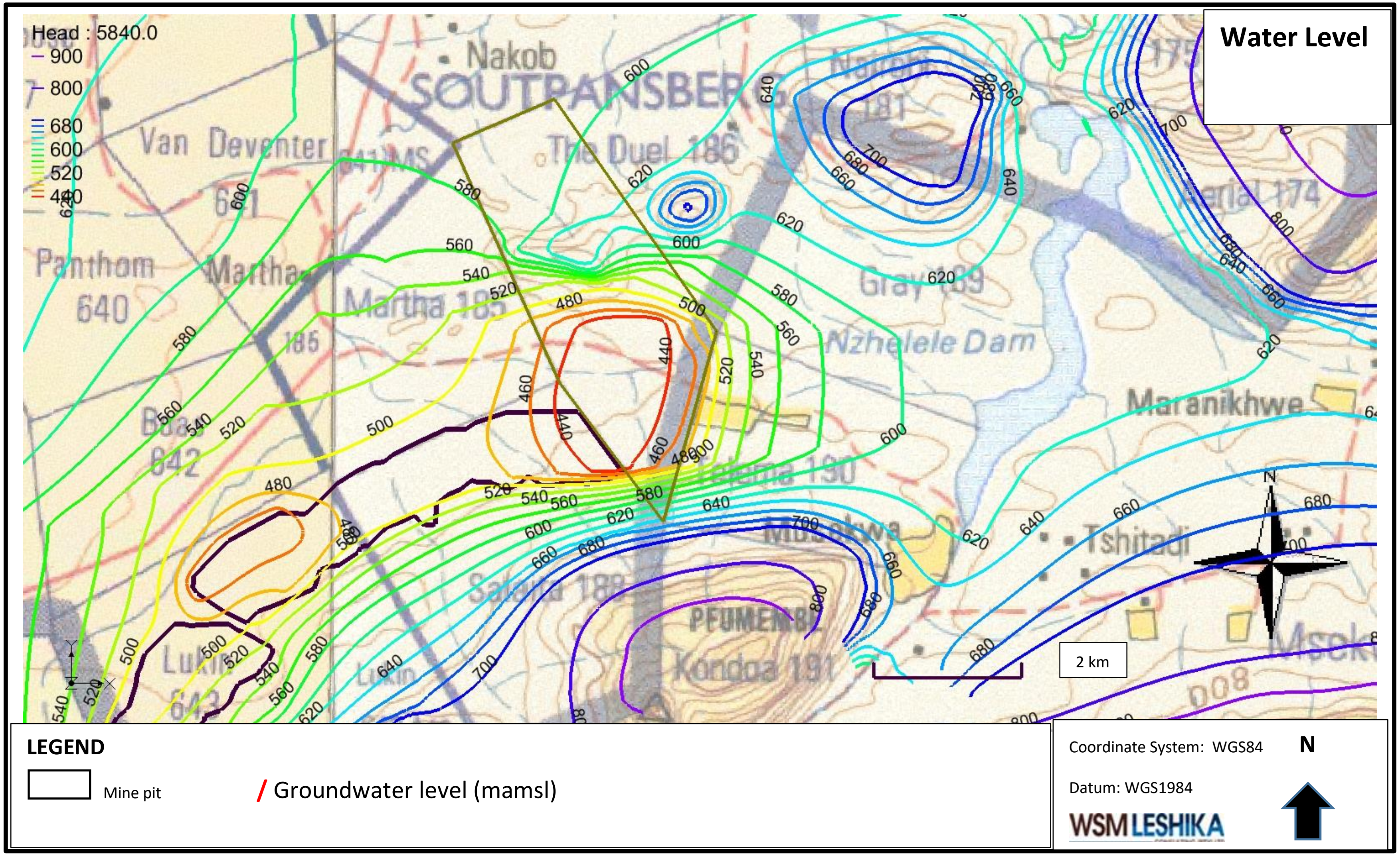

Figure 8-10 Groundwater level in year 16 in mamsl

The impact on water levels in Makushu and Mussekwa is shown in figures 8-11 and 8-12. Water levels decline rapidly, reaching 60 m of drawdown in Makushu by 10 years after start of mine, and it is exepcted the village boreholes will rapidly go dry. Water levels in Musekwa drop by up to 3 m.

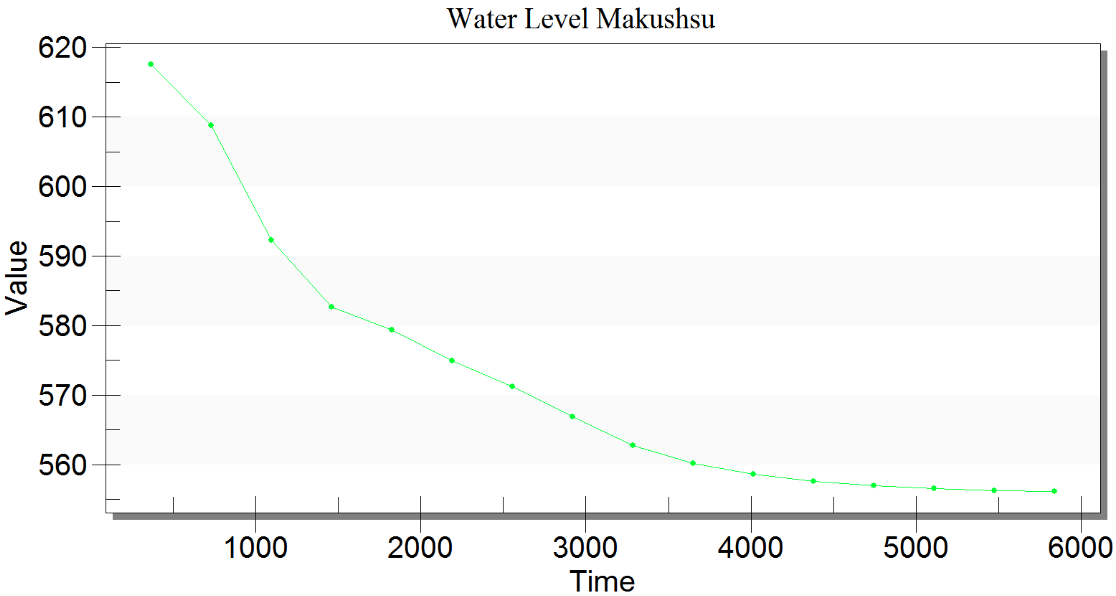

Figure 8-11 Groundwater level at Makushu in mamsl in days after start of mine

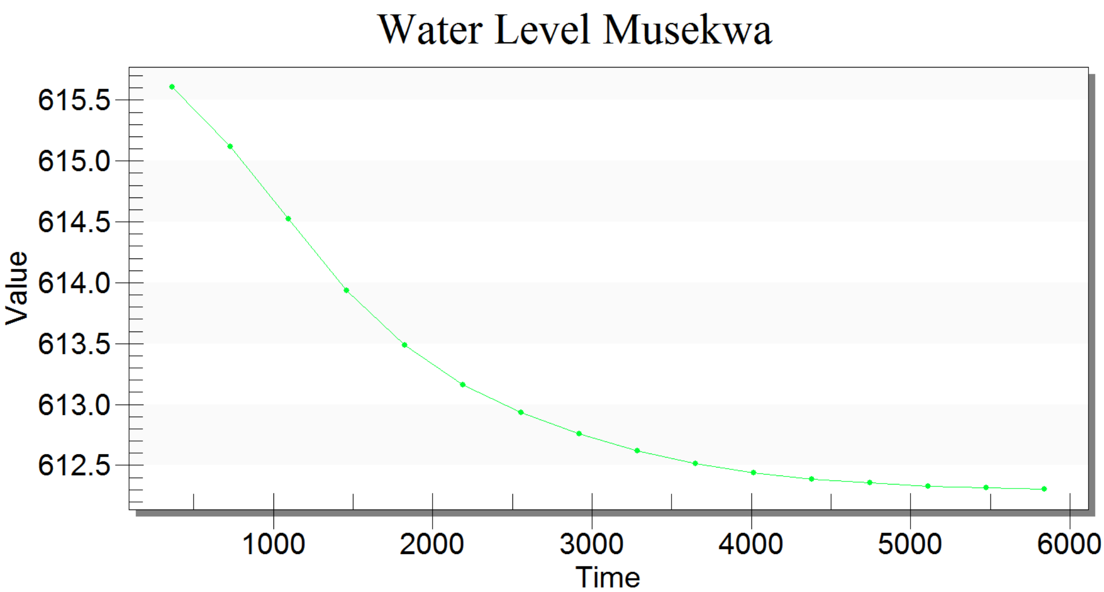

Figure 8-12 Groundwater level at Musekwa in mamsl in days after start of mine

9. GEOCHEMISTRY

9.1. Sources of Acid Rock Drainage

Groundwater contamination due to mining occurs when the rock is broken up, either by blasting or by excavation, to expose a greater surface area of mineralized rock to water and oxygen. Acid generating minerals such as pyrite are oxidised, and soluble elements enter into the groundwater system. In the case of coal, which is often sulphur rich, pyrite (FeS_2), sulphur combines with water to form sulphuric acid enhancing its ability to dissolve other elements in the rock and is commonly known as acid mine drainage (AMD) or acid rock drainage (ARD). The neutralisation of acid occurs from the dissolution of carbonates, which adds alkalinity and calcium and magnesium to the system. Sources of pollution from a coal mine include the following;

- Overburden and spoil piles
- Slurry and slimes dumps
- Return water dams, effluent and evaporation ponds
- Open cast pits

9.2. General Mineralogy

The coal bearing formation in the area is the Madzaringwe Formation and is predominantly bright coal with a high vitrinite content. The total current selection of broad coal bearing horizons is on average 30m. This coal seam will be mined by opencast and underground methods and then beneficiated in a washing plant.

Other minerals associated with the coal include carboniferous shales, mudstones, dolerite, calcrete, and traces of Anatase, Ankerite, Calcite, Diopside, Dolomite, Forsterite, Hematite, Ilmenite, Kaolinite, Lizardite, Microcline, Muscovite, Plagioclase, Pyrite, Quartz, Rutile, Siderite, Smectite, and Talc.

9.3. Sulphur Distribution

Sulphur, in the form of sulphide, is a major nuisance in coal mining operations, often producing Acid Mine Drainage (AMD) upon reaction with air and water.

For contaminant outflow prediction, the frequency distribution of concentrations of sulphur in the mining area is critical. The frequency distribution of sulphur concentration shows the probability of sulphur likely to appear as waste. The frequency distribution of sulphur in coal samples from Makhado to the Duel is shown in figure 9-1. The location of the samples is shown in figure 9-2.

Figure 9-2 shows that the highest S concentrations occur to the south west of Makhado and at The Duel the coal is less than 2% sulphur.

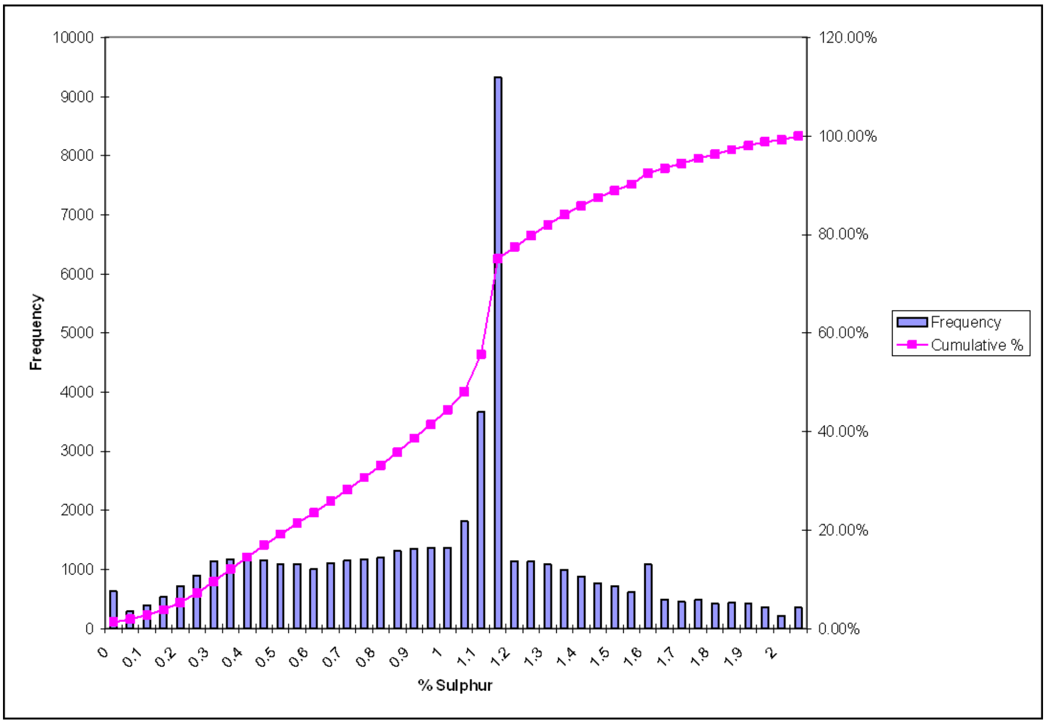

Figure 9-1 Frequency distribution of %S in coal samples

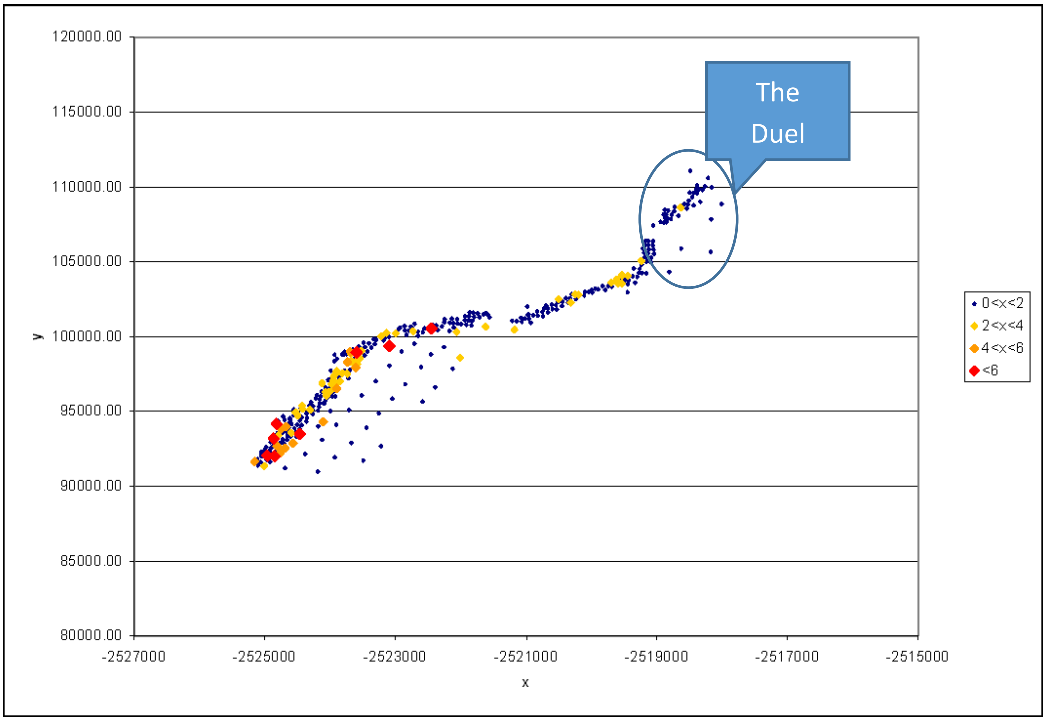

Figure 9-2 Known %S detail in mining area of Makhado to the Duel

9.4. Location of Boreholes for Geochemical Sampling

Two borehole logs were sampled for ABA, XRF and XRD analysis. The location of the boreholes is shown in figure 9-3. The borehole logs are shown in figure 9-4.

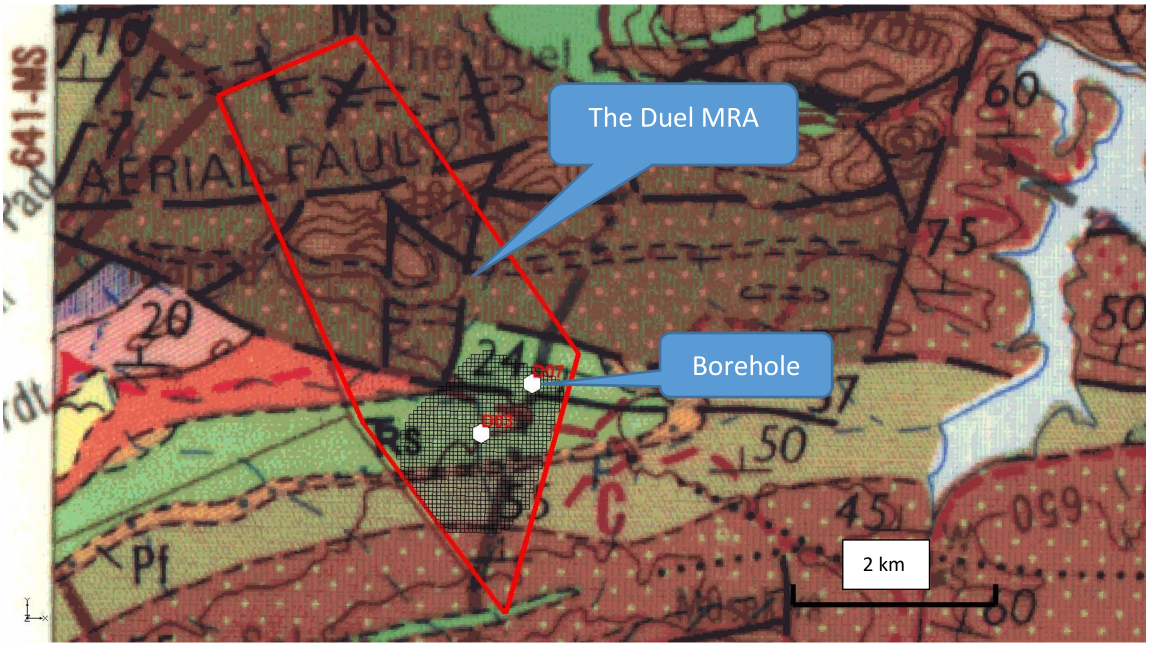

Figure 9-3 Location of boreholes for geochemical sampling

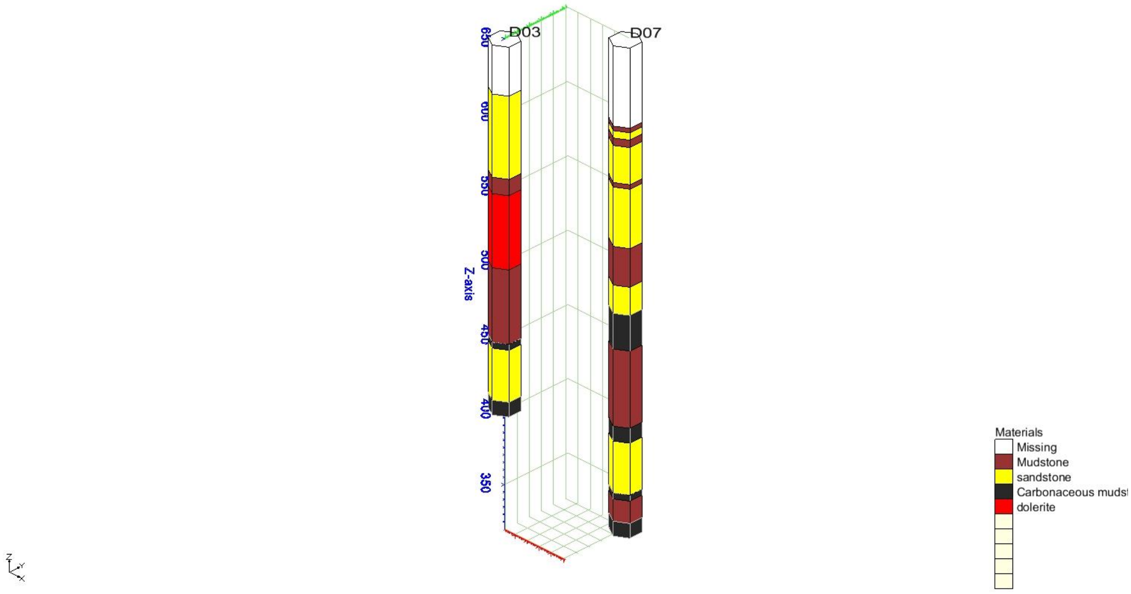

Figure 9-4 Logs of sampled boreholes

9.5. Elemental Composition of Rocks

Elemental composition of the rocks was determined by X-ray fluorescence (XRF). The XRF analysis yields major constituents as oxides and minor constituents as elements. The values of the XRF reactive Major elements are shown in figure 9-5, except for silica oxides.

The bulk of the samples are silica oxides, which are non-reactive. A major component is LOI (loss on ignition) which represents carbon burned off the samples. The LOI increases with depth, becoming abundant below 200 m. After LOI, iron predominates in all samples.

Presumably in the form of pyrite.

The values for the XRF Minor elements are shown in table 9-1. The elements of abundance greater than 100 ppm are red-shaded.

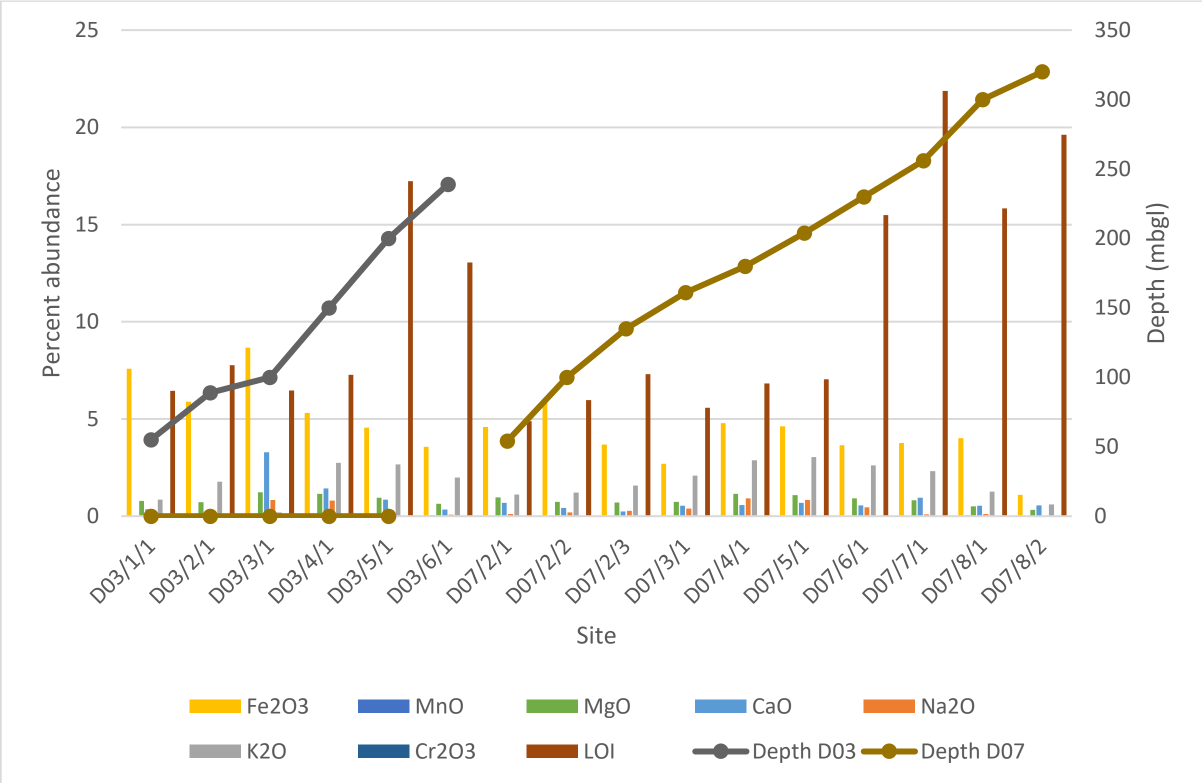

Figure 9-5 Percentage of potentially reactive major elements from XRF

Table 9-1 Minor Elements

Trace Elements	Trace Element Concentration (ppm) [s]															
	D03/1 /1	D03/2 /1	D03/3 /1	D03/4 /1	D03/5 /1	D03/6 /1	D07/2 /1	D07/2 /2	D07/2 /3	D07/3 /1	D07/4 /1	D07/5 /1	D07/6 /1	D07/7 /1	D07/8 /1	D07/8 /2
	15934	15935	15936	15937	15938	15939	15940	15941	15942	15943	15944	15945	15946	15947	15948	15949
As	<0.43	<0.43	<0.43	5.15	12.2	12.9	0.51	<0.43	5.57	3.74	6.7	8.13	7.5	19.6	26.6	33.2
Ba	266	570	175	698	509	375	153	402	466	278	622	577	557	454	503	545
Bi	1.36	1.35	0.97	1.33	1.76	1.64	1.41	1.56	1.5	1.24	1.17	1.35	1.57	1.43	1.54	1.82
Cd	4.12	4.92	8.18	6.48	8.64	4.47	4.75	4.69	6.74	4.78	5.41	4.35	4.05	6.82	7.58	<3.04
Ce	62	79	80.9	72.1	85.3	72.4	81.9	41.7	78.5	86	62.2	67.2	79.1	72.2	114	121
Cl	108	103	154	107	128	104	119	111	114	128	118	114	105	96.2	100	105
Co	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56	<0.56
Cs	2.37	4.51	5.59	2.88	3.09	2.06	3.66	4.98	5.35	6.3	3.49	2.54	5.08	8.74	2.93	8.24
Cu	53	30.6	153	34.3	47.3	54	29.9	39.7	34.2	30.4	38.9	36.7	49.9	48.8	81.9	95.3
Ga	28.9	32.3	26.3	23.6	31.5	33.6	21	29.3	29.5	20.6	24.9	25	29.4	31	41.8	61.3
Ge	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Hf	21.4	10.7	30	7.8	8.42	2.21	9.48	14.2	7.3	3.95	7.96	<0.38	0.67	12.9	10.1	4.84
Hg	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
La	47.6	38.5	57.4	9.8	47.8	46.1	56.2	30.3	51.8	57.5	14.6	3.91	41.6	45.4	64.3	85.6
Lu	3.37	3.19	3.47	3.07	3.27	2.68	2.72	3.09	2.65	2.33	2.91	2.75	2.64	3.03	2.81	2.31
Mo	2.23	2.29	2.22	2.34	2.18	2.34	2.31	2.24	2.24	2.33	2.27	2.35	2.31	2.22	2.27	2.14
Nb	30.5	33.4	33.5	22.5	33	37.7	21.2	32.1	39	21.5	24.6	24.2	28.7	36.6	49.2	73.8
Nd	<2.39	18.2	26.2	<2.39	21.3	31.7	13.6	<2.39	8.01	29.1	<2.39	40.5	24.9	20.8	28.9	54.3
Ni	45.5	29.4	20	20.2	30.3	31.2	29.8	33.1	21.5	16.3	13.1	11.1	8.36	18	49	95.4
Pb	<2.03	<2.03	<2.03	<2.03	55.1	64.8	<2.03	<2.03	<2.03	<2.03	<2.03	9.44	5.22	114	217	271
Rb	73.3	185	<0.42	242	312	188	75.4	128	158	126	289	254	344	292	144	81.8
Sb	6.4	4.81	6.02	7.5	12.8	7.83	7.3	<1.48	2.3	5.18	4.06	2.09	11.3	15.2	4.43	7.82

Sc	16.6	16.8	22.7	21.5	19	18.3	18.5	19.2	16.4	19.1	18.9	19.2	19	19.8	18.7	21.8
Se	<0.36	<0.36	<0.36	<0.36	0.74	0.86	<0.36	<0.36	<0.36	<0.36	2.93	<0.36	<0.36	0.54	0.54	1.1
Sm	30.1	20	30.7	21.8	20.4	12	17.1	19.6	12.5	15.2	21.4	17.1	14.6	14.5	12.5	<1.62
Sn	25.3	25.6	18.4	23.3	34.4	30.3	21.3	23.9	22.2	20.8	25.5	22.2	33.8	36.6	35.2	40.9
Sr	51	159	380	350	295	293	176	234	212	146	304	294	334	264	337	565
Ta	2.47	1.43	2.6	1.76	1.62	0.85	10.7	1.56	2.13	1.33	1.89	1.42	1.46	1.5	0.91	0.73
Te	0.19	<0.16	8.29	<0.16	<0.16	<0.16	80.7	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16
Th	21.9	22.3	2.96	17.8	27.3	29.5	674	22.2	22.1	16.7	22.1	20.3	27.1	29.1	44	64.5
Tl	0.43	0.91	0.52	0.38	0.59	0.82	92.3	0.27	0.58	0.45	0.24	0.28	0.28	<0.11	0.35	1.1
U	3.52	6.22	<0.74	5.1	10.6	10.4	61.2	3.46	7.18	6.02	8.96	4.53	8.24	10.4	9.33	10.3
V	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60	<7.60
W	1.92	1.41	1.97	1.52	1.32	1.08	<0.29	1.64	1.35	1.07	1.54	1.5	1.41	1.68	1.26	1.03
Y	32.8	63	57	69.7	67.1	69.3	13.2	47.9	58.3	45	46.9	46.7	53.9	73.7	86	141
Yb	19.8	11	18.8	11.5	9.32	4.85	<1.05	12.3	7.2	7.12	11.5	12.2	10.8	12.4	7.05	<1.05
Zn	72.4	85.1	136	112	173	144	<5.49	71.1	128	130	142	141	135	211	172	236
Zr	510	479	669	296	434	445	101	516	581	402	310	278	373	521	596	1 045

Table 9-2 Acid base accounting

Modified Sobek (EPA-600)	D03/1/1	D03/2/1	D03/3/1	D03/4/1	D03/5/1	D03/6/1	D07/2/1	D07/2/2	D07/2/3	D07/2/3	D07/3/1	D07/4/1	D07/5/1	D07/6/1	D07/7/1	D07/8/1	D07/8/2	D07/8/2
Paste pH	8.3	7.9	8.2	8.7	8.4	8.4	8.4	8.8	8.8	8.9	8.7	9	9	8.9	8.2	8.4	8.4	8.3
Total Sulphur (%) (LECO)	<0.01	0.29	0.07	0.15	0.38	0.08	<0.01	0.03	0.03	0.03	0.38	0.35	0.76	0.29	1.05	0.12	0.15	0.15
Acid Potential (AP) (kg/t)	0.313	9.06	2.19	4.69	12	2.5	0.313	0.938	0.938	0.938	12	11	24	9.06	33	3.75	4.69	4.69
Neutralization Potential (NP)	7.68	4.83	43	27	31	7.55	13	1.54	-3.88	-3.39	3.47	17	4.09	17	13	6.76	8.17	7.68
Nett Neutralization Potential (NNP)	7.36	-4.23	41	22	19	5.05	13	0.6	-4.82	-4.33	-8.41	6.27	-20	7.9	-20	3.01	3.48	2.99
Neutralising Potential Ratio (NPR) (NP: AP)	25	0.533	20	5.66	2.61	3.02	43	1.64	4.14	3.61	0.292	1.57	0.172	1.87	0.381	1.8	1.74	1.64
Rock Type	III	I	III	III	II	III	III	III	III	III	I	II	I	II	I	III	III	III
Lithology	SM	SM	D	M	CM	CM	M	SM	M	M	S	CM	M	CM	CM	SM	CM	CM
Top (mbgl)	30	55	90	100	150	201	19	54	100		135	161	180	204	230	256	300	
Bottom (mbgl)	55	89	100	150	200	239	54	100	135		161	180	204	230	256	300	320	

Lithology Code

SM: sandstone and mudstone

D: dolerite

M mudstone

CM carbonaceous mudstone

S sandstone

9.6. Mineralogical Characteristics

The mineralogical characteristics of the rock samples obtained were submitted to X-Ray diffraction (XRD) and the percentages of minerals determined. The percentage minerals as determined by XRD, excluding quartz, which is the bulk of most samples is shown in figure 9-6.

Predominating over the samples are Hematite and Kaolinite and Muscovite clays. Iron is present as hematite, pyrite and traces of siderite. Kaolinite concentration increases with depth and pyrite concentrations increase below 100 m.

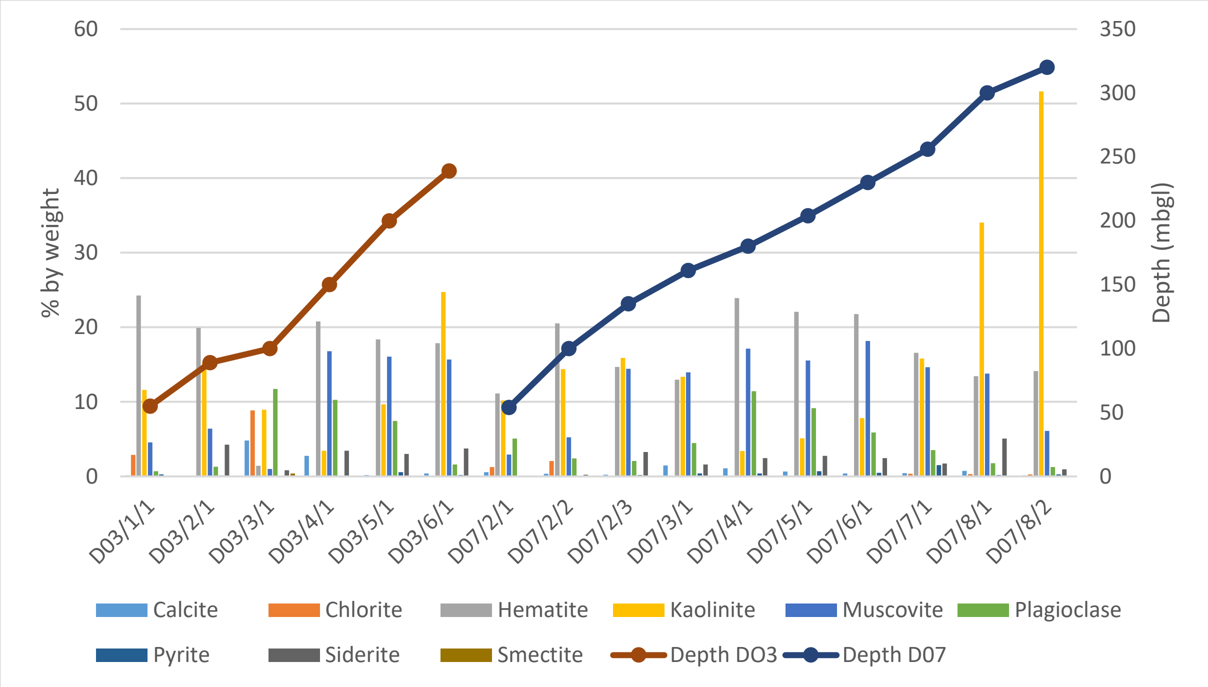

Figure 9-6 Mineralogy by XRD

9.7. Acid Base Accounting of Samples

Acid Base Accounting (ABA) is an analytical procedure that was developed to screen the acid-producing and acid-neutralising potential of overburden rocks prior to large scale excavations but is more generally used today to predict the mine drainage water quality. It is a static procedure and therefore does not provide information on the rate with which acid generation or neutralisation will proceed. These details are determined by kinetic weathering or leaching tests.

In ABA, the acid generating potential [AP = total sulphur content in % * 31.25, synonymous with maximum potential acidity (MPA)] due to the oxidation of sulphur minerals in a rock sample and the acid neutralising capacity [ANC, determined according to Sobek et al. 1978] of a rock sample (neutralising bases, mostly carbonates and exchangeable alkali and alkali earth cations) are subtracted to obtain a Net Neutralisation Potential (NNP = NP - AP).

The results are customarily reported in tons calcium carbonate per thousand tons of overburden (or parts per thousand), with negative NNP values indicating the potential to generate acid and therefore a predicted net acid drainage water quality from the rock. Positive values indicate acid-neutralising potential or a predicted net alkaline drainage water quality from a rock sample.

18 Rock samples were collected from 2 boreholes and each distinct horizon was sampled and submitted for Acid-Base Accounting. Representative coal seam samples, carbonaceous shale's and mudstones, sandstones and dolerite were sampled to characterise the waste.

The resulting values representing acidity or basicity are presented in table 9-2. Two measures are employed to characterise acid- or base-forming potential of minerals, one based on the percentage sulphur (assumed sulphide) and one based on the ratio of neutralising potential to acid-forming potential. The latter is called the NPR (neutralising potential ratio).

The rocks are classified into 3 types according to:

TYPE I	Potentially Acid Forming	Total S (%) > 0.25% and NP: AP ratio 1:1 or less
TYPE II	Intermediate	Total S (%) > 0.25% and NP: AP ratio 1:3 or less
TYPE III	Non-Acid Forming	Total S (%) < 0.25% and NP: AP ratio 1:3 or greater

And according to the NPR by:

Potential for ARD	Initial NPR Screening Criteria	Comments
Likely	**< 1:1**	Likely AMD generating
Possibly	**1:1 – 2:1**	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
Low	**2:1 – 4:1**	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	**>4:1**	No further AMD testing required unless materials are to be used as a source of alkalinity

For sustainable long-term acid generation, at least 0.3% Sulphide-S is needed. Values below this can yield acidity but it is likely to be only of short-term significance. Samples with less than 0.3% Sulphide-S are regarded as having insufficient oxidizable Sulphide-S to sustain acid generation.

NPR ratios of >4:1 are considered to have enough neutralising capacity to buffer acidity that is generated.

NPR ratios of 3:1 to 1:1 are considered inconclusive.

NPR ratios below 1:1 with Sulphide-S above 3% are potentially acid-generating.

Figure 9-7 shows that ABA with the samples with an NPR below 4 showing below the horizontal line. When NPR below 4 and the % sulphur is considered, D3/2/01, D3/5/01, and D07/03/01-D707/01 have sulphur above 0.25% and are potentially acid generating. A significant number of samples analysed by ABA showed distinct potential for acid generation.

Of interest is the relationship between paste pH and neutralising potential. Paste pH is a measure of the instantaneous reactions of surface minerals that are readily available for weathering. Neutralising potential is a measure of the maximum potential of the sample to neutralise acid in a more rigorous setting. Paste pH is the kinetic measure and NP is the thermodynamic measure. This relationship is shown in figure 9-8. The high paste pH values indicate no acid generation prior to the ABA analysis. Sample with a high AP/NR ratio are potentially acid generating, however, only D3/02/1 and D7/07/1 have a low paste pH indicative readily available acid generation.

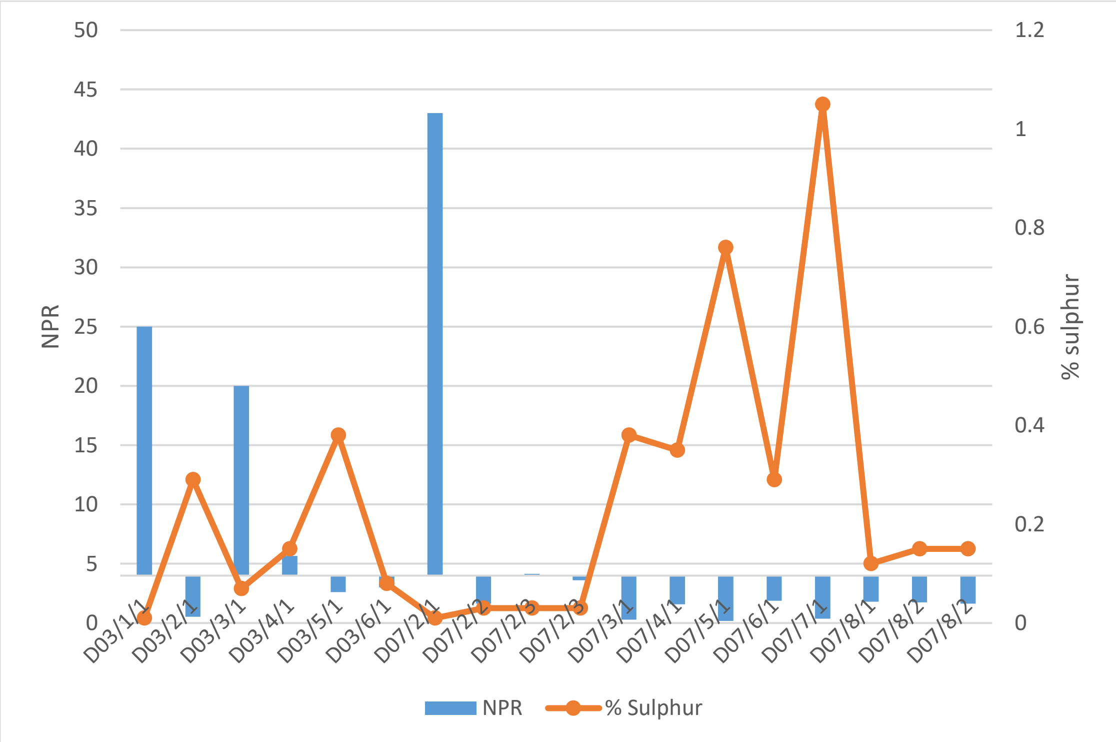

Figure 9-7 NPR and % sulphur

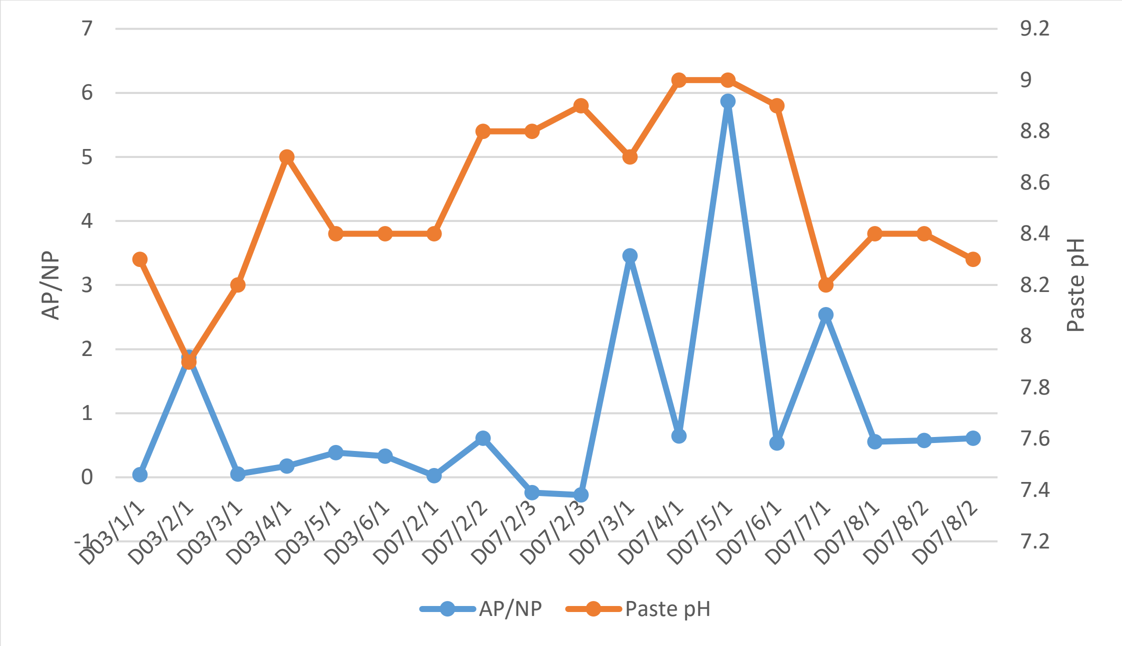

Figure 9-8 Paste pH and AP/NR

Given the low presence of calcite (figure 9-6), the high neutralising potential cannot be explained by calcite alone. It is likely that the additional neutralising potential may arise from decomposition of clays during the ABA analysis. These clays are unlikely to react quickly in an environmental setting. Thus, the measurement of neutralisation potential may overestimate potential neutralisation of acid-forming minerals under weathering.

9.8. Metal Leaching Tests

The potential leachate quality emanating from waste rock material is characterised using leaching tests with varying pH values.

The short-term metal leach tests were performed at Makhado and not undertaken on samples from The Duel. These included an Acid Rain (AR) leach test, where carbonic acid is used to react with rock material, and the Toxicity Characteristic Leach Protocol, (TCLP) which is used to simulate contact of mine waste rock material with organic acids.

9.8.1. *Acid Rain leach tests*

During the Acid Rain leach test, the only constituents of concern identified were iron and manganese in terms of Domestic Water Quality Guidelines. In terms of Aquatic Ecosystems guidelines, the leaching of zinc was identified as of concern.

9.8.2. *Toxicity Characteristic Leach Protocol (TCLP)*

The elements of concern when samples were leached by acetic acid were found to be iron and manganese in terms of domestic water quality guidelines, and Aluminium, manganese, lead and zinc, and some copper in terms of aquatic ecosystems.

In the case where the short-term leach tests did not indicate “no hazard”, laboratory kinetic tests were conducted.

9.9. Laboratory Kinetic Testing

Laboratory kinetic testing methods are used to estimate long-term weathering rates, and to estimate the potential for mine wastes and geologic materials to release discharges that may have impacts on the environment.

9.9.1. *Humidity Cell Tests*

Humidity cell tests were conducted over a period of four weeks.

The domestic use constituents of greatest concern were those pertaining to pH, iron and manganese. Regarding aquatic ecosystems, those of greatest concern relate to the concentrations of lead, zinc, aluminium, selenium and pH, in the case of the most carboniferous of the samples.

The humidity test results indicated the potential for exceedance of DWS guideline limits in some or all the samples analysed.

9.10. Saturation Indices

In order to model future scenarios, it is important to understand the origin of chemical species and the dynamics that may impact the fate of this species and its equilibrium dynamics in the groundwater environment.

To determine possible geological minerals in equilibrium with groundwater, the chemical modelling package PHREEQC was used to calculate the saturation index. If a saturation index is less than 0, then the solution is undersaturated with respect to that solid and can still be dissolved. If the saturation index is equal to 0, the solution is saturated with respect to the solid, and if the saturation index is positive, the solid is supersaturated and will precipitate over the timeframe characteristic to the solid and the solution.

Saturation indices were calculated for the 3 boreholes located on or in the immediate vicinity of The Duel (6.3). The saturation indices of the most likely solids to be present in the system are presented in table 9-3.

Table 9-3 Saturation indices for borehole chemistry

Site	si_Calcite	si_Dolomite	si_Gypsum
M-16	-0.25	-0.15	-3.01
Stand210	0.15	0.72	-1.62
standE104	0.25	0.82	-1.50
BF4	-0.21	-0.11	-2.40
PHAN-3	0.3	0.62	-1.85

Due to uncertainty in, temperature and redox conditions, it is normally taken that a solid may be in equilibrium if the absolute value of the saturation index is less than 0.9. The groundwater in the vicinity of The Duel has a strong relationship with calcite and dolomite and some with gypsum. The saturation index of close to 0 for calcite and dolomite suggests these minerals are controlling the concentrations of the calcium ion, magnesium ion and of carbonate (or bicarbonate) ion. This shows the presence of two strong acid-neutralising minerals in the likely flow-path of mine waters suggesting that potentially acidic and metal-laden mine water effluents may be attenuated naturally by minerals comprising the aquifer intersecting the Project.

9.11. Acid Rock Drainage Potential and Depth

Table 9-4 is a summary of the ABA results for each potential waste rock type. The average NP and AP for each rock type and pit was determined to characterise the waste to be backfilled into each pit.

Table 9-4 Summary of acid and neutralisation potential of mine wastes

	Total Sulphur [%]	**AP [kgCaCO$_3$/t]**	**NP [kgCaCO$_3$/t]**	**NNP = NP-AP [kgCaCO$_3$/t]**	**NPR = NP: AP**	**Type**
Sandstone/mudstone	0.11	3.52	5.21	1.69	1.45	III
Dolerite	0.07	2.19	43	40.89	1967	III
Mudstone	0.20	6.18	7.36	1.19	1.19	III
Carbonaceous mudstone	0.35	10.99	14.49	3.49	1.32	II
sandstone	0.38	12	3.47	-8.41	0.29	I

The percent sulphur increases with depth in both boreholes, and sulphur concentration and potential significant acid generation only becomes an issue from rocks from below 250 m (figure 9-9).

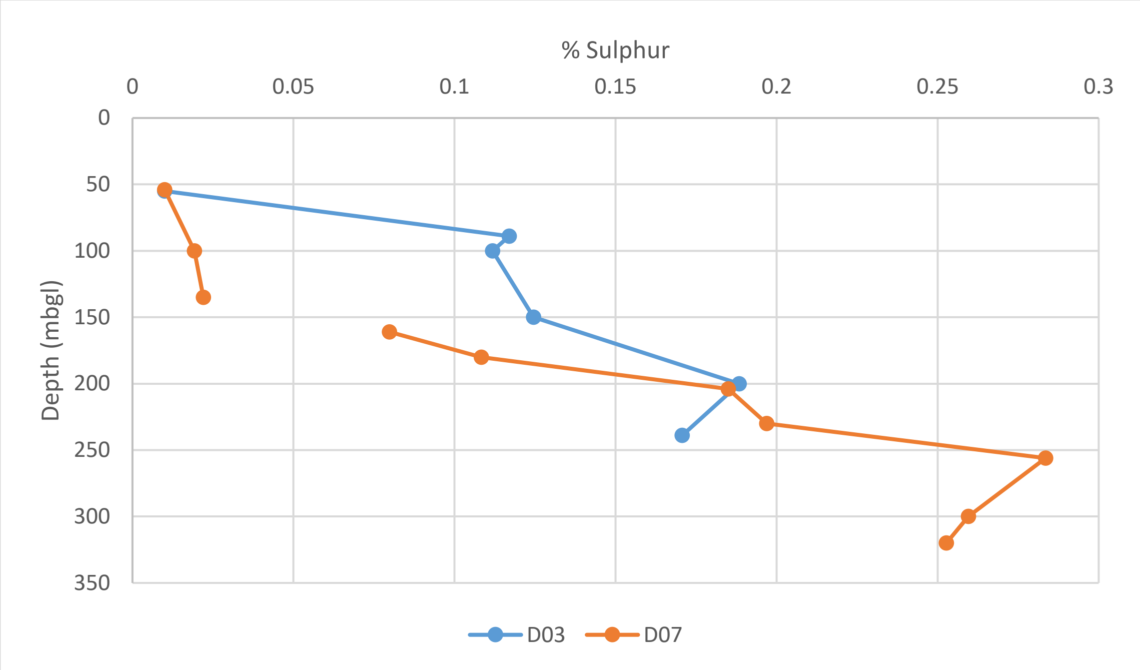

Figure 9-9 % sulphur with depth

The vertical profile of acid drainage generation potential for borehole D03 and D07 is shown in figures 9-10 and 9-11.

Acid potential increases with depth in borehole D07, especially below 150 m. This can be attributed to the increase in the LOI fraction of the rock (figure 9-5). Borehole D03 shows an opposite effect, with NP increasing with depth and rocks from below 150 m being potentially acid generating.

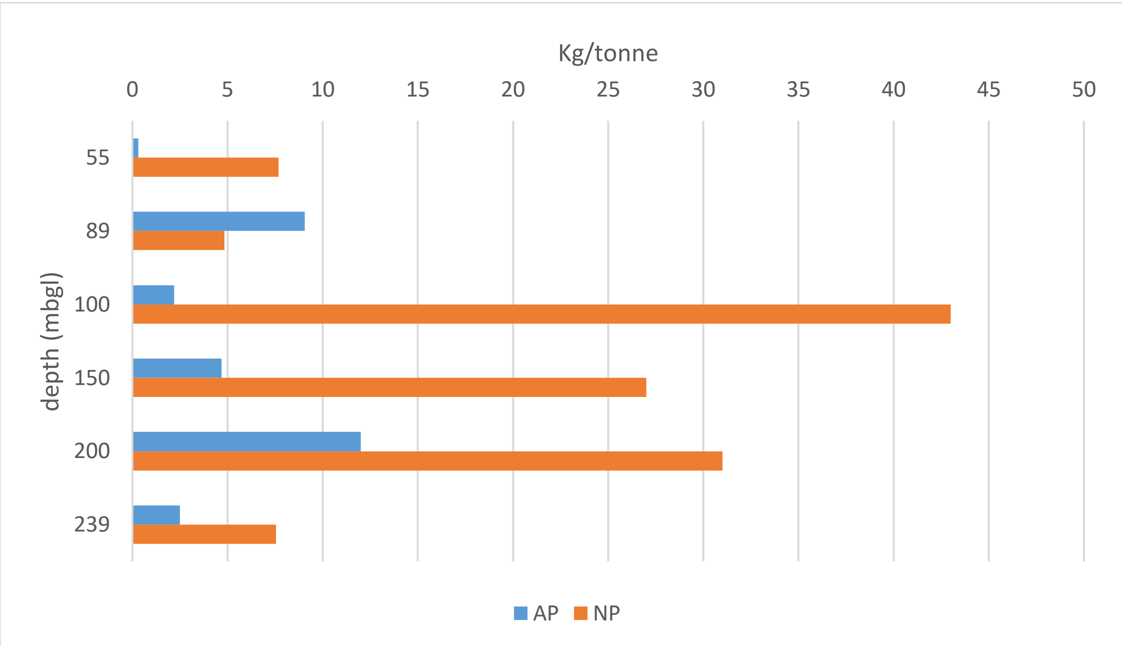

Figure 9-10 Acid and Neutralisation potential versus depth for borehole D03

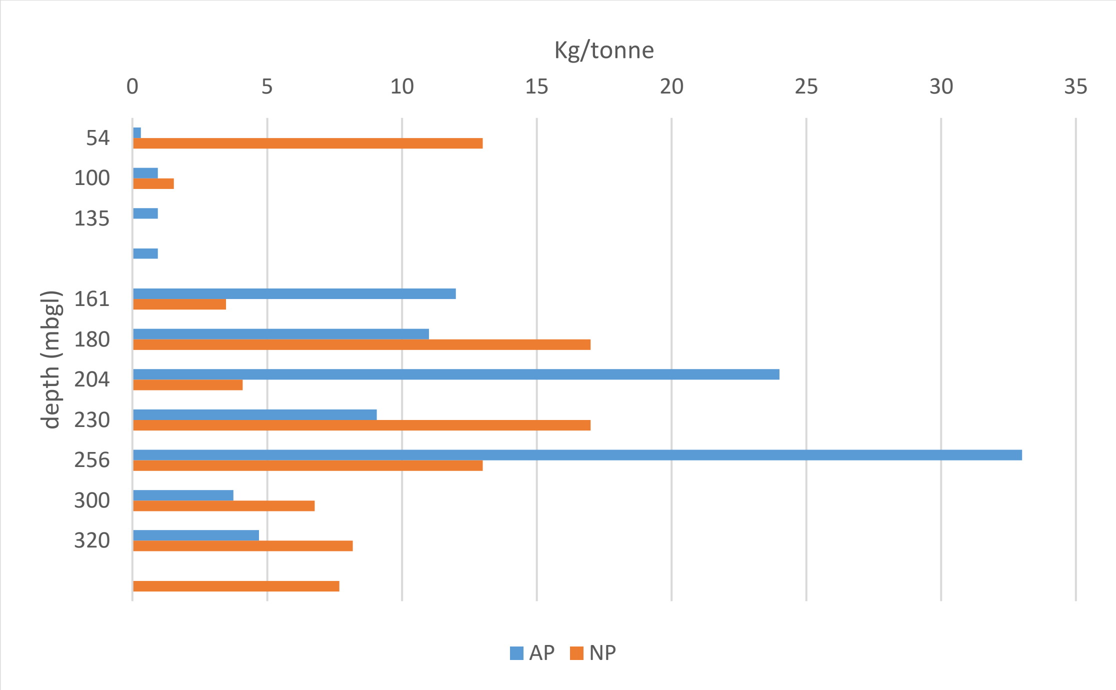

Figure 9-11 Acid and Neutralisation potential versus depth for borehole D07

The NP increasing with depth in borehole D03 and decreases in D07, which makes it difficult to postulate whether the waste rocks from deeper layers will have a significantly reduced NP or not from two boreholes. The reduction in NP and increase in AP appears to be associated with the high proportion of Kaolinite clays with increasing depth in D07 (figure 9-6).

To determine whether the waste rock dump as a whole will generate acid, ABA results need to be weighted by the layer thickness each sample represents and be considered as a cumulative whole. The thickness weighted ABA results with AP, NP and NNP compiled cumulatively with depth are shown in figure 9-12 and 9-13.

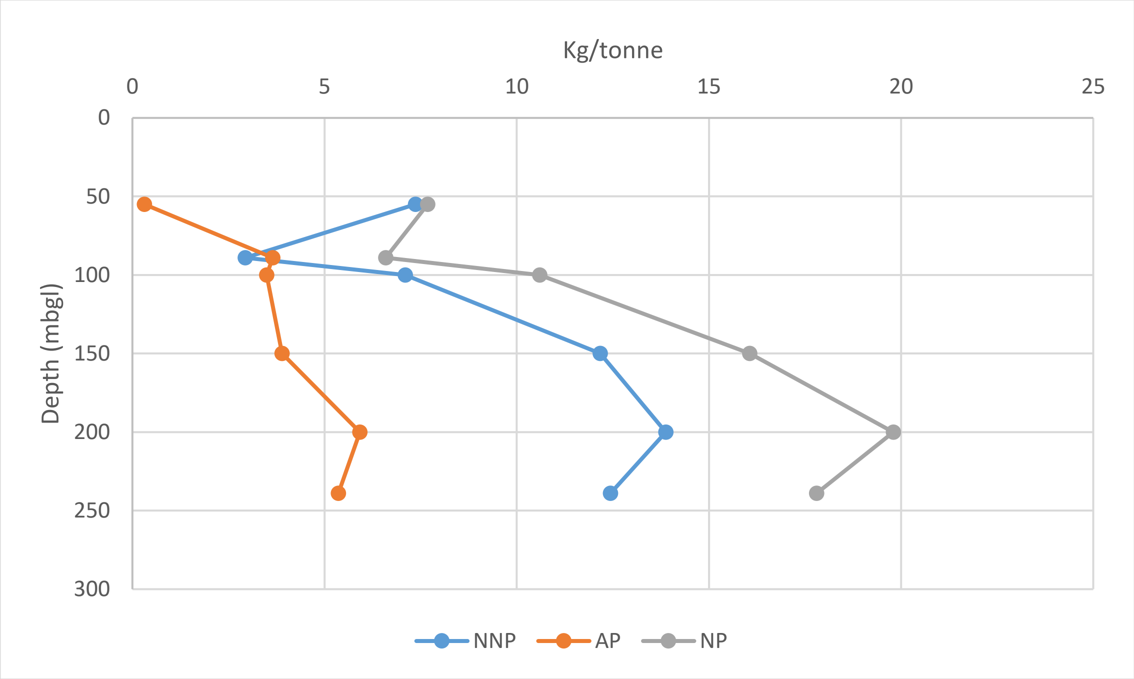

Figure 9-12 Cumulative ABA results with depth D03

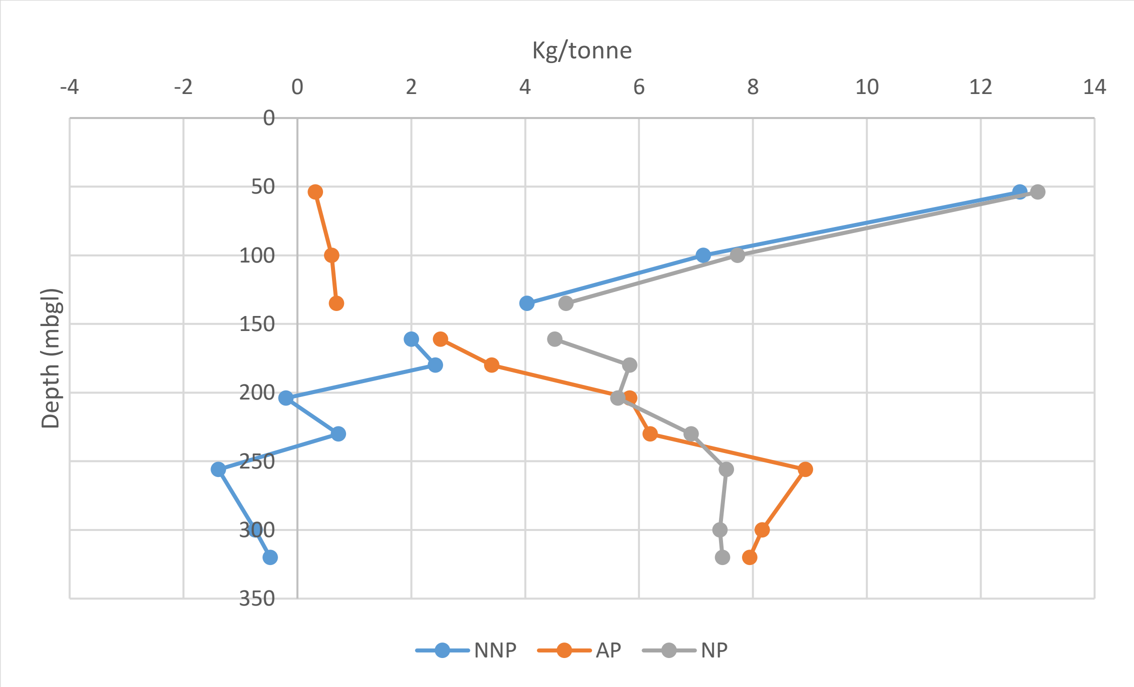

Figure 9-13 Cumulative ABA results with depth D07

In borehole D03 the increasing NP with depth results in an increasing NNP up to 20 kg/t, hence waste rock from lower and deeper layers is not potentially acid generating.

Borehole D07 exhibits the opposite, and the increasing AP with depth results in a cumulatively decreasing NNP and the entire waste rock pile from this profile will have a nett negative NNP and the pile would be potentially acid generating. The source of the acid generation is rocks from below 150 m.

9.12. Primary Contaminant Sources

The Geochemical study found that the coal is associated with metaliferous elements that may be of environmental concern.

The following lithological units are precautionary generally classified as potentially acid forming:

- Carbonaceous mudstone
- Carbonaceous shale
- Coal seam
- Coal and carbonaceous mudstone
- Coaliferous mudstone
- sandstone

The following lithological units are generally classified as non-acid forming:

- Calcrete
- Dolerite
- Mudstone

Static and kinetic leach tests identified the following constituents of concern:

- Sulphate
- Aluminium
- Iron
- Manganese
- Barium
- Nickel
- Lead
- Molybdenum
- Selenium

The primary source of these elements is the acid forming carbonaceous waste, which is to be deposited in the bottom of the pit after life of mine.

9.13. Leachate Quality

Based on the comparison of the kinetic and static leach test results, it is proposed to use the following concentrations of the constituents of concern as a source term for model applications:

- The highest concentrations observed in the kinetic leach tests as a source term for the life of mine.
- The highest concentrations observed in the static acid rain leach tests as a source term for post closure simulations.
- A gradual decrease in source concentrations from life of mine to post closure scenarios.

The rationale for the proposed source terms is the continuous addition and atmospheric exposure of fresh waste rock during life of mine and a gradual isolation of waste rock material disposed in the pits after mine closure due to flooding of backfilled pits.

The source term concentrations for constituents of concern leached by rainwater through waste are summarised in table 9-5. These concentrations reflect the quality of leachate before mixing with groundwater inflows into the pits, and the maximum concentrations of 800 mg/l of sulphate taken as a worst-case scenario.

Table 9-5 Maximum concentrations of constituents of concern

[mg/L]	Life of Mine	Post Closure
SO_4	1000	800
Al	1	0.27
Fe	10	10
Mn	3.5	3.5
Ba	2	2
Ni	0.25	0.2
Pb	0.1	0.02
Mo	0.25	0.25
Se	0.06	0.06

10. CONTAMINANT TRANSPORT MODELLING

The extent of potential contamination plumes emanating from the waste dumps was simulated using MODPATH, part of the MODFLOW suite of models, which traces the pathlines of water particles as derived from the groundwater flow calculated by MODFLOW. This allows both the ultimate fate of water through a contaminated zone to be traced by forward modelling, or the origin of water particles entering a borehole or stream to be traced by reverse modelling.

The fate of any contamination emanating from the waste dumps is of concern as a potential source of groundwater contamination and seepage to surface water. This plume can carry contaminants up to the concentrations given in table 9-5. When the mine is in operation no contamination can emanate from the site since the cone of depression created by the mine results in local groundwater flow being orientated towards the pit. To determine the extent of the contamination plume emanating from the mine once abstraction stops, the movement of water particles from the waste dumps was simulated with MODPATH using forward modelling.

A reverse simulation was undertaken to derive the capture zone of the mine (water within that zone will ultimately reach the mine).

10.1. Design and Operation

During the life of mine, stockpiles separating soils, carbonaceous waste discard and non-carbonaceous overburden are planned. The carbonaceous stockpiles, which are potentially acid and contaminant generating, are located adjacent to the pit, and the cone of depression from mine dewatering is expected to induce any leachate into the pit.

After the life of mine, the carbonaceous waste is to be deposited in the bottom of the pit, so that flooding of the waste prevents further oxidation. Due to bulking, it is estimated that 25-30% of the non-carbonaceous overburden will remain at surface as a foot print, rising above the former ground surface.

The pits and dumps are to be compacted and vegetated, progressively reducing the ingress of oxygen and water over time.

10.2. Transport Modelling Objectives

The contaminants described in chapter 9 may pose a future threat to human health and the environment if transported in sufficient quantity from the pits where they are permanently disposed through groundwater and discharged to surface water or to abstraction wells. Such threats provide the impetus for solute transport modelling.

This concern substantiates the primary objective of the 3D transport model: to predict the potential for future contaminant migration.

There are multiple secondary objectives of this study. Application of the transport model also serves to quantify the risks associated with contaminant migration. Model results may identify areas which may be vulnerable to contaminant migration and water quality hazards, and zones where contaminants migrate off the mine property.

10.3. Transport Modelling Approach

10.3.1. *Source Term Modelling*

The modelling approach utilised time-varying source term for the transport model by the variable recharge into the waste dumps, resulting in variable leachate production.

The recharge rate to groundwater under interim dumps was assumed to be substantially higher than natural due to the open rock surface and no vegetation. The Excess rainfall that cannot infiltrate the underlying compacted soil was assumed to runoff as toe seepage and not recharge groundwater. For the final waste dump, recharge was assumed to decrease over time as the pits were compacted and vegetation is established. However, since consolidated rock will not exist, recharge will be significantly higher than background conditions.

The following recharge rate was assumed:

Life of Mine: 20% of rainfall to interim dumps

Following the end of life of mine the following recharge was applied to the final dump:

Day	0 – 1095:	Linear decrease from 70% of rainfall to 20%
Day	1095-2190:	Linear decrease from 20% of rainfall to 10%
Day	2190-:	10% of rainfall

Recharge rates to the dumps are significantly higher than the calibrated 0.3% of rainfall on Karoo geology in the calibrated flow model.

10.3.2. *Solute Transport modelling*

The transport model was based upon the calibrated, saturated flow system of the two-layer groundwater flow model. The transport model therefore shares the same model domain as the groundwater flow model.

The 3D solute transport model was applied to predict the migration of constituents of concern (table 9-5).

MODPATH can only simulate solute transport advection. Dispersion, precipitation, degradation and sorption were not included; hence the results are conservative. Hydrodynamic dispersion is the mixing of solute in groundwater and incorporates the effects of both molecular diffusion and mechanical dispersion. Mechanical dispersion represents mixing caused by local variations in the groundwater velocity field. Except for systems in which groundwater velocities are very low, mechanical dispersion is significantly greater than molecular diffusion. Dispersion is minor in flowing groundwater, and precipitation is minor unless concentrations exceed the saturation index.

10.3.3. *Transport Parameters*

The values of effective porosity assigned to the various model layers and the filled mine pits were set to:

	Background	Mine fill
Layer 1	0.01	0.35
Layer 2	0.005	0.2

Effective porosity determines the velocity of plume migration, consequently a low value is a conservative approach, however, porosity must be higher than specific capacity.

10.4. Predictive Solute Transport Results

The migration of the contaminant plume from the interim waste dumps is shown in figures 10-1. The migration of the contaminant plume from the discards, which is the dump containing carbonaceous material and which poses the most risk of contaminants is directed towards the pit, hence does not pose a risk to surrounding properties. The plume from the waste rock, containing the low sulphur rock from the overburden migrates towards the pit and westwards towards Martha. Westward and eastward migration is curtailed by the cone of depression created by the pit (figure 8-10).

25 years after Life of mine, the contaminant plume from The Duel is oriented towards the Makhado Project East Pit due to the residual cone of depression remaining in the pit.

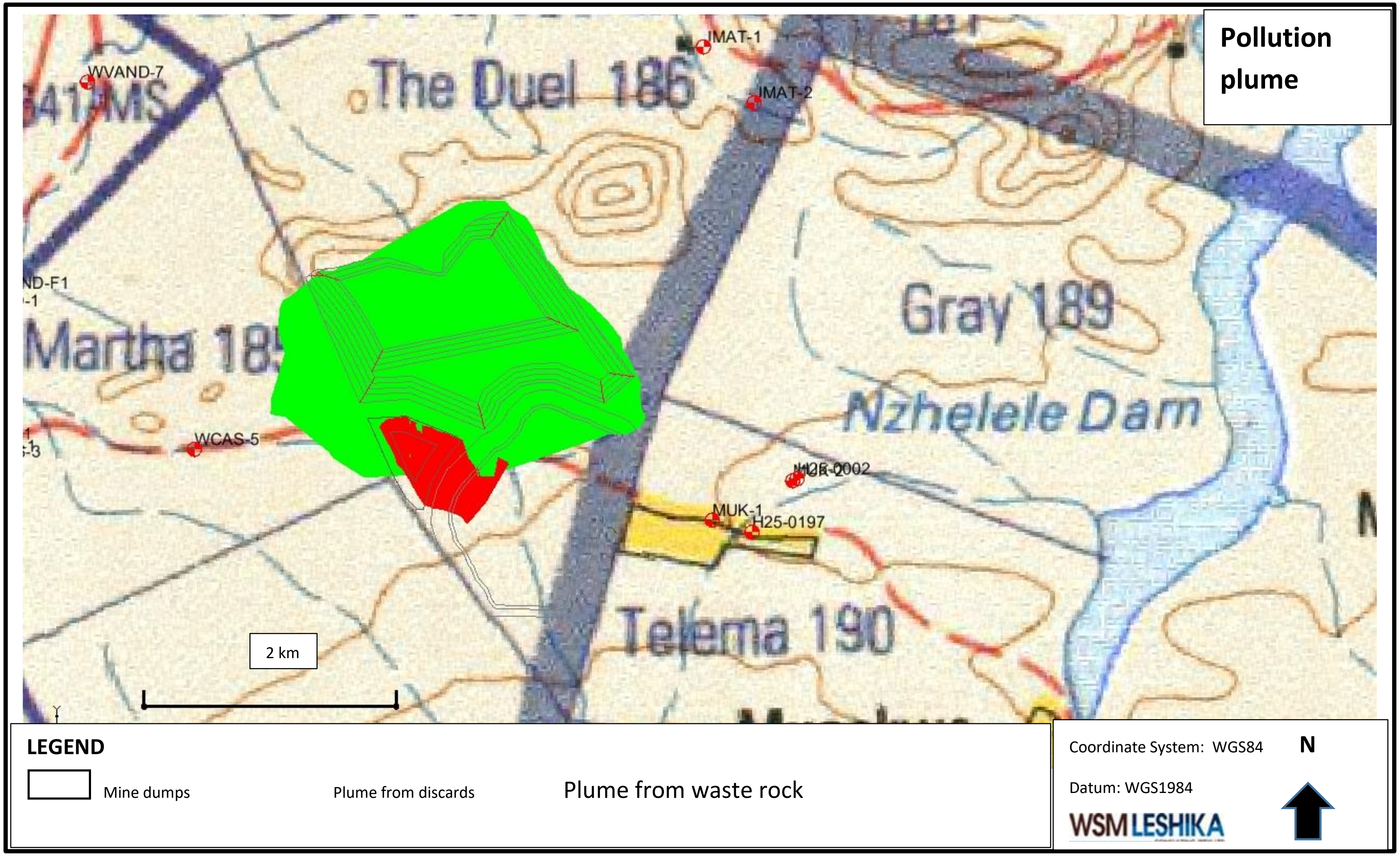

Figure 10-1 Contaminant plume 16 years after start of mine

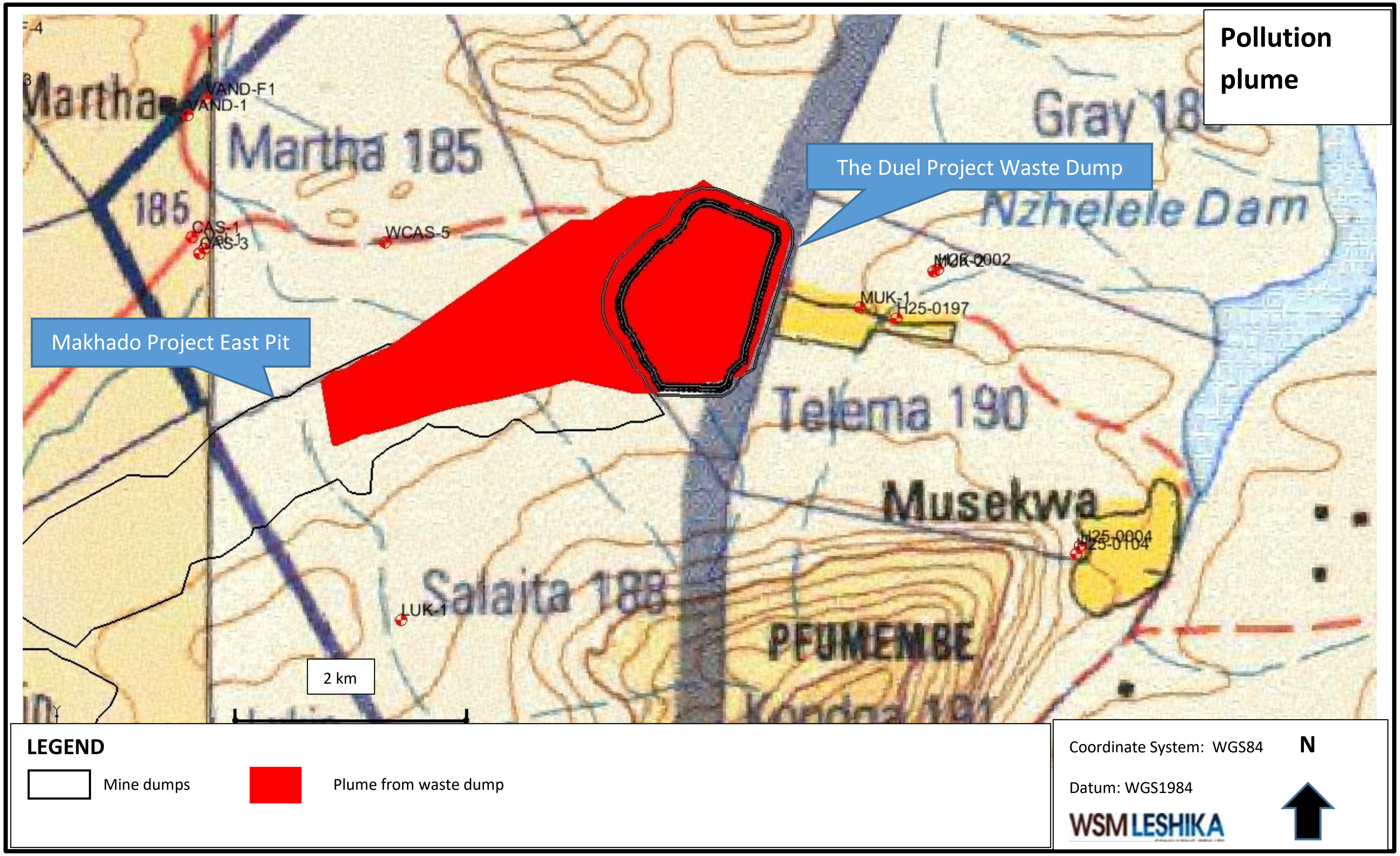

Figure 10-2 Contaminant plume from final waste dump 25 years after Life of Mine

11. GROUNDWATER IMPACT ASSESSMENT

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 11-1).

Table 11-1 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 11-1. 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 11-2.

Table 11-2 Impacts on groundwater

Impact	Extent	Duration	Severity	Probability	Risk estimation	Without mitigation	Mitigation
Loss of water to Nzhelele dam	2	4	2	5	3	Loss of seepage to the dam and a groundwater gradient reversal will cause a reduction of	No mitigation possible

Impact	Extent	Duration	Severity	Probability	Risk estimation	Without mitigation	Mitigation
						inflow to the dam of 750 m^3/d.	
Loss of groundwater to irrigators in Nzhelele valley and at Aventura resort	2	4	1	2	1	Drawdown from The Duel is constrained by the Nzhelele dam and a range of hills to the north from The Duel to Nairobi hence does not extend as far as the Nzhelele valley	
Drawdown in water levels having an impact on water levels and other users around the mine	2	4	3	5	4	Extreme - Drawdown from mining and mine wellfield extends to surrounding farms will exceed 10 m on Martha, Gray and Telema. The impact on Martha is in combination with drawdown from Makhado. Utilisation of this water is low, but it is an only source of supply.	Provision of alternative water supply

Impact	Extent	Duration	Severity	Probability	Risk estimation	Without mitigation	Mitigation
Impact on Makushu water quantity	2	4	3	5	4	Drawdown will be over 50 m,	Provision of alternative water supply
Impact on Makushu water quality						The contamination plume does not migrate towards the community	None required
Decant from pits post-mining	2	5	2	1	1	Low probability as pit is located on a groundwater divide with deep groundwater levels	None required
Increased salinity of aquifers downstream of mining due to cut-off of clean upstream water	2	4	1	4	2	Low – Cutting off groundwater flow from the Soutpansberg will reduce dilution of Karoo groundwater, however, this aquifer is not utilised due to salinity	No mitigation possible
Decrease in regional water quality	2	4	1	3	1	Low – the Karoo aquifer is already high in sulphates and salts and not utilised	Placing carbonaceous material at bottom of pit below water level
Migration of pollution plume after full recovery of	2	4	1	4	1	Low- after submergence of carbonaceous material, they	

Impact	Extent	Duration	Severity	Probability	Risk estimation	Without mitigation	Mitigation
groundwater levels						will no longer produce AMD	

12. SUMMARY AND CONCLUSIONS

12.1. Conclusions

Mining at the Duel will involve open cast mining along extended open cuts down to 270m below surface, as well as underground mining.

Groundwater use for the properties within a two-farm margin around the MRA area is approximately 57 ML/annum. Nearly half this volume is for water supply to communities on the farm Telema adjacent to The Duel project.

The Duel sits on a local groundwater divide between groundwater drainage to the east towards Nzhelele dam and west towards the Mutamba River. The present depth to groundwater is between 25-40 mbgl. Some localized dewatering is evident east of The Duel and groundwater levels have dropped 20 m from natural conditions. This is due to pumping around Makushu village, where low yielding boreholes are being extensively utilised.

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. Due to the extent of mining operations planned for the Greater Soutpansberg area, impacts must be seen as cumulative rather than independently for each mine.

The impacts of mining on the water balance will include:

- Abstraction of groundwater for existing users will be reduced from 1794 Kl/d to 1350 Kl/d due to the lowering of the water table as a result of the cumulative impact of mining. Abstraction will be reduced on the farm Telema for communities reliant on groundwater by 130 Kl/d; the farm Martha/Boas utilising 75 Kl/d will be impacted by lowering groundwater levels; the farms Gray and Nairobi where groundwater is used for stock watering will also have potential abstraction reduced.
- Water level drops at Makushu on the farm Telema, adjacent to The Duel reach 60 mbgl.
- Inflows to the Nzhelele Dam from groundwater will reduce from 1100 m^3/d to 750 m^3/d.

- The total dewatering volume required at The Duel from mines will vary from 750 m^3/d to 2000 m^3/d. The bulk of inflows represent the volume lost from aquifer storage (dewatering). The remainder of inflows represent groundwater flow intercepted by the pits, which would have discharge elsewhere, such as the Nzhelele Dam.
- The coal at the Duel is generally below 2% sulphur and pyrite can be 15% by weight. ABA tests indicate sulphur is less than 1% in the waste rock, including carbonaceous material and the % sulphur can rise to 0.18-0.28% at depths below 150 m. Two core samples indicate a Nett positive and a nett negative NNP, however the acid generating rock all occurs at below 150 m, hence if this waste rock is deposited at the bottom of the pit after Life of Mine, where it will be submerged, AMD will be mitigated.
- The migration of the contaminant plume from the interim discard dump during mining, which is the dump containing carbonaceous material and which poses the most risk of contaminants is directed towards the pit, hence does not pose a risk to surrounding properties. The plume from the waste rock, containing the low sulphur rock from the overburden migrates towards the pit and westwards towards Martha. Westward and eastward migration is curtailed by the cone of depression created by the pit.
- 25 years after Life of mine, the contaminant plume from The Duel is oriented towards the Makhado Project East Pit due to the residual cone of depression remaining in this pit.

12.2. 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, and 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, specifically in the Soutpansberg N and S of the mine, and in the Karoo E and W of the open pit (figure 12-1).
- 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 from interim dumps 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 to update the geochemical predictions
- All abstraction including dewatering, irrigation, plant and domestic use, needs to be measured on at least a quarterly basis.

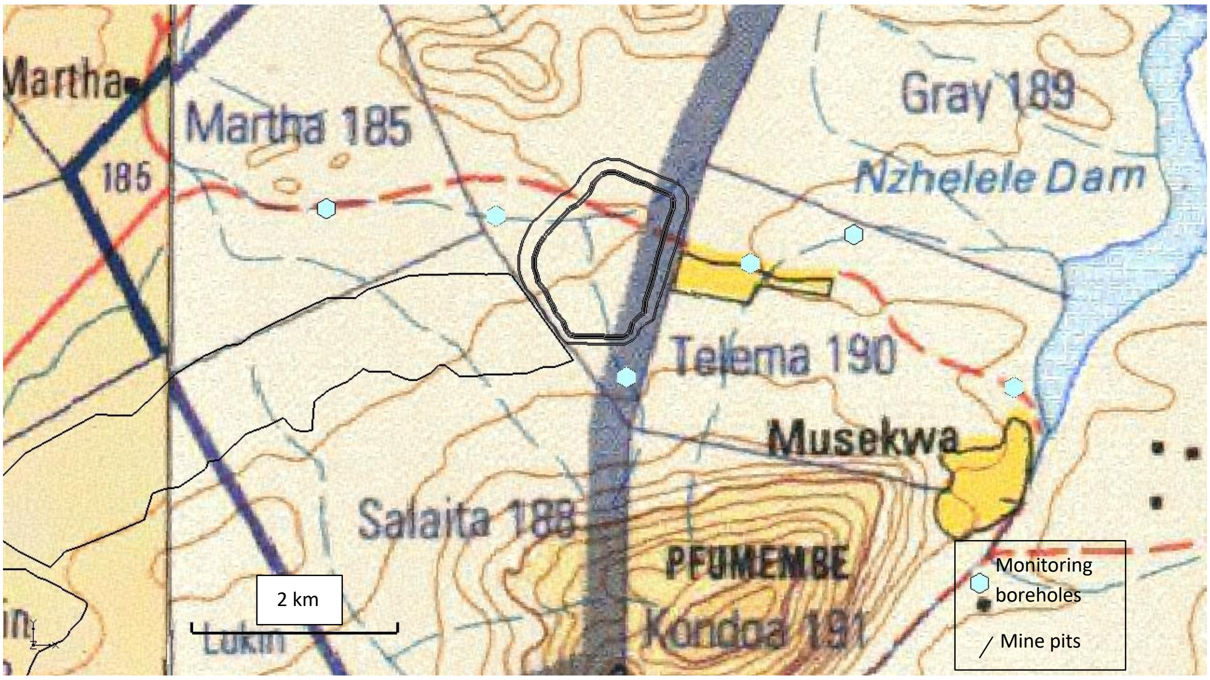

Figure 12-1 Proposed monitoring borehole sites

The network should be maintained and protected from vandalism and damage by vehicles. Table 12-1 lists a proposed monitoring schedule.

Table 12-1 Monitoring schedule recommended

	Weekly	Monthly	Quarterly	Annually
Monitoring boreholes		Water level pH Electrical conductivity	pH Eh Electrical conductivity Nitrates Chemical oxygen demand Ca, Mg, Na, K, T-Alk, Cl, SO_4, F, Al, Fe, Mn	Same as Quarterly except the addition of analysis for metals by ICP scan if changes in Eh, pH and EC are observed
Domestic use borehole if established for future use on the site	pH Electrical conductivity Faecal coliforms[1]	pH Electrical conductivity Nitrates Chemical oxygen demand	pH Eh Faecal coliforms Electrical conductivity Nitrates Chemical oxygen demand Ca, Mg, Na, K, T-Alk, Cl, SO_4, F, Al, Fe, Mn	Same as Quarterly except the addition of analysis for metals by ICP scan if changes in Eh, pH and EC are observed
Groundwater abstraction		Cumulative readings		
Leachate		pH Electrical conductivity	pH Eh Electrical conductivity Nitrates Chemical oxygen demand Ca, Mg, Na, K, T-Alk, Cl, SO_4, F, Al, Fe, Mn	Same as Quarterly except the addition of analysis for metals by ICP scan if changes in Eh, pH and EC are observed

It is recommended that an Environmental Monitoring Committee (EMC) be established and that these monitoring activities be done in conjunction with the neighbouring farmers, mines and communities in order to obtain a greater regional perspective and ensure transparency.

The monitoring programme should be audited for compliance to the stated objectives and adapted when and where required.

All the monitoring data needs to be collated and analysed on at least a bi-annual basis and included in management reports. This information will also be required by government departments for compliance monitoring.

After 2 years from start of mining, the monitoring information collated should be used to update the groundwater flow and geochemical models. These models should thereafter be updated on at least a 5-yearly basis. Management and mitigation plans should be continuously adapted using the monitoring data.

12.3. 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, some limitations can be noted:

- Limited and inaccurate data on actual groundwater usage, hence abstraction estimates are based on hectares observed under irrigation and population size in communities. Registered water use on WARMS 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.
- Data collected in a relatively wet period
- Aquifer storage data based solely on best estimate and inflows into the bulk sample pit undertaken at the Makhado Project. It was assumed that storage in the aquifers at The Duel is similar.
- The timing and scheduling of other mines in the region is at a planning stage and deviations in timing and depths will impact on inflows to other mines and impacts. This is especially significant for the timing and mining plans of Makhado Project East Pit and The Duel

12.4. 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 the Makhado Project. 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 major groundwater users.

- Derivation of local more detailed multilayer models at a monthly time scale for each mine once more detailed mining plans become 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.
- Mining Plan: The modelling study is based on the CoAL proposed mining plan.

12.5. Mitigation Measures Proposed

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

- Enter negotiations with surrounding land owners and communities impacted regarding compensation or alternative water supply.
- Coordinate mining with the Makhado Project East pit to simultaneously mine and benefit from the combined cone of depression, minimising combined inflows, total abstraction volumes and the duration of significant impact

To minimise acid generation and manage leachate the mining plan proposes to:

- Deposit mine wastes in the open pit, controlling the migration of high sulphate leachate.
- The horizons that are potentially acid generating, the coal middlings and carbonaceous mudstones should be placed at the bottom of the pit, where they will be submerged below the water table, preventing oxidation
- Interim stockpiling of carbonaceous material should be on lined dumps with a leachate collection system
- Grass cover should be re-established, as soon as possible after top soiling to minimise infiltration of water through residue material
- Monitoring boreholes should be installed in appropriately selected sites prior to commencement of mining to detect changes in water quality and water levels with time.

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