OCCURRENCE OF GROUNDWATER IN THE PHALABORWA IGNEOUS COMPLEX

By

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DECLARATION

I hereby declare that this dissertation submitted for the degree Masters in the Faculty of Natural and Agricultural Sciences, Department of Geohydrology, University of the Free State, Bloemfontein, South Africa, is my own work and have not been submitted to any other institution of higher education. I further declare that all sources cited or quoted are indicated and acknowledged by means of a list of references.

D. Brink

May 2011

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GLOSSARY OF HYDROGEOLOGICAL RELATED TERMS

AQUIFER	Aquifer means a geological formation which has structures or textures that hold water or permit appreciable water movement through them. [Source: National Water Act (Act No. 36 of 1998)].
AQUIFER SYSTEM	A heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.
AQUIFER TESTING	The process whereby an aquifer is subjected to pumping from a borehole under controlled test conditions in order to determine the hydraulic parameters of the groundwater system through its response to the stress of abstraction.
BLOW YIELD	The volume of water per unit of time from the borehole during drilling (l/s).
BOREHOLE	Includes a well, excavation, or any other artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer {from National Water Act (Act No. 36 of 1998)}.
BOREHOLE TESTING	The process whereby a borehole is subjected to pumping under controlled test conditions in order to determine the performance characteristics of a borehole (see aquifer testing).
CONFINED AQUIFER	An aquifer overlain by a confining layer of significantly lower hydraulic conductivity in which groundwater is under greater pressure than that of the atmosphere; also known as an artesian aquifer.
CONFINING LAYER	A layer of low permeability material overlying an aquifer, which restricts the vertical movement of water.
CONCEPTUAL MODEL	A conceptual model includes designing and constructing equivalent but simplified conditions for the real world problem.
EVAPOTRANSPIRATION	The loss of moisture from the combined effects of direct evaporation from land and transpiration from vegetation.
EFFLUENT RIVER	A river fed directly by groundwater, the surrounding water table or piezometric surface is above the base of the stream.
FRACTURE	Cracks, joints or breaks in the rock that can enhance water movement.
FRACTURE FLOW	Water movement that occurs predominantly in fractures and fissures.
FRACTURE ZONE	A zone of cracks or fissures within rocks.

GLOSSARY OF HYDROGEOLOGICAL RELATED TERMS	
FRACTURED AQUIFER	An aquifer that owes its water-bearing properties to fracturing caused by folding and faulting (see secondary aquifer).
GEOHYDROLOGY	The study of the properties, circulation and distribution of groundwater.
GROUNDWATER	Water found in the subsurface in the saturated zone below the water table or piezometric surface i.e. the water table marks the upper surface and groundwater systems.
GROUNDWATER FLOW	The movement of water through openings and pore spaces in rocks below the water table i.e. in the saturated zone.
HARD-ROCK	Igneous, metamorphic and sedimentary rocks that lack adequate primary interstices to function as a primary aquifer.
HYDRAULIC CONDUCTIVITY	Measure of the ease with which water will pass through earth material; defined as the rate of flow through a cross section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (m/d).
HYDRAULIC GRADIENT	The slope of the water table or piezometric surface. It is a change of hydraulic head over specific distances.
INFILTRATION	The downward movement of water from the atmosphere into the ground.
OUTCROP	The occurrences of host rock at the ground surface.
PERMEABILITY	The ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of an aquifer under the unit hydraulic gradient in unit time (expressed as $m^3/m^2/d$ or m/d). It is an intrinsic property of the porous medium and is independent of the properties of the saturating fluid.
PIEZOMETRIC SURFACE	An imaginary or hypothetical surface of the piezometric pressure or hydraulic head throughout all or part of a confined or semi-confined aquifer; analogous to the water table of an unconfined aquifer.
RADIUS OF INFLUENCE	The maximum extent of the cone of depression during test pumping.
RECHARGE	The addition of water to the zone of saturation, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.
REST WATER LEVEL	The groundwater level in a borehole not influenced by abstraction or artificial recharge; synonymous with static water level. No groundwater levels are ever accurately static as they continually respond to recharge, discharge and abstraction.

GLOSSARY OF HYDROGEOLOGICAL RELATED TERMS

RIVER	A physical channel in which runoff will flow from higher o lower ground and to the sea.
ROCK	Any consolidated or unconsolidated earth material, which forms part of the earth's crust, specifically excluding soil.
RUNOFF	All surface and subsurface flow from a catchment, but in practice refers to the flow in a river i.e. excludes groundwater not discharged into a river.
SANITARY SEAL	The surface seal in the annulus between the borehole sidewall and the casing which is filled with bentonite or bentonite cement mixture to prevent surface water and pollution from entering the borehole.
SECONDARY AQUIFER	An aquifer in which water moves through secondary openings and interstices, which developed after the rocks, were formed. This secondary opening form as results of weathering, fracturing and faulting.
SEMI-CONFINED AQUIFER	An aquifer that is partly confined by layers of lower permeability material through which recharge and discharge may occur; synonymous to leaky aquifer.
SOIL	The usually thin upper surface layer of the earth's crust comprising living organisms, organic matter, decomposed rock or unconsolidated sediments, water and gases with properties attributable to the interaction of its parent material, time, climate fauna and flora.
SPECIFIC CAPACITY	The rate of discharge of a borehole per unit of drawdown, usually expressed as m^3/d.m. Calculated by dividing the yield of the borehole by drawdown induced by abstraction.
STORAGE COEFFICIENT	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.
STREAM	A small narrow river; often used interchangeably with river.
SUSTAINABLE YIELD	Water level must not drop below a specified level in the borehole after abstracting water from the borehole for a long time (e.g. 2 years) without any recharge taken place.
TEST PUMPING	See aquifer and borehole testing.
TRANSMISSIVITY	The rate at which a volume of water is transmitted through a unit width of aquifer under a unit hydraulic head (m^2/d); product of the thickness and average hydraulic conductivity of an aquifer.
UNCONFINED AQUIFER	An aquifer with no confining layer between the water table and the ground surface where the water table is free to fluctuate.

GLOSSARY OF HYDROGEOLOGICAL RELATED TERMS	
WATER TABLE	The upper surface of the saturated zone of an unconfined aquifer at which pore pressure is at atmospheric pressure, the depth to which may fluctuate seasonally.
YIELD	The amount of water from a borehole, aquifer or water source within a specified time.

Abbreviations and Units

BIC	Bushveld Igneous Complex
CDT	Constant Discharge Test
pH	Hydrogen Potential
EC	Electrical Conductivity
MAP	Mean Annual Precipitation
s	Storativity
SDT	Step Discharge Test
T	Transmissivity
a	Annum
cm	Centimetre
d	Day
km^2	square kilometre
L	Litre
m	Metre
m^2	square metre
m^3	cubic metre
ma	million years
mamsl	metres above mean sea level
mbgl	metres below ground level
mg	Milligram
mm	Millimetre
mS	milliSiemen
Mt	Mega ton

Abbreviations and Units	
s	Second
t	Ton
PMC	Palabora Mining Company
PIC	Phalaborwa Igneous Complex
NPM	North Pyroxenite Mine
NSPP	New South Pyroxenite Pit
PEP	Pyroxenite Expansion Project
PP & V	Phalaborwa Phosphate & Vermiculite
IDC	Industrial Development Corporation
WS	Water Strike

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CHAPTER 1: Introduction

The PIC (Phalaborwa Igneous Complex) is situated near Phalaborwa and has intruded in to the Bushveld Igneous Complex. Foskor (Pty) Ltd is currently one of the world's leading phosphate and phosphoric acid producers, with approximately 95% of South Africa's production (Roux et al., 1989).

Open pit mining operations in the Phalaborwa Igneous complex has been ongoing since the 1950's. The mining depth off the existing PMC (Palaborwa Mining Company) pit is 800m (Figure 1). Foskor (Pty) Ltd is planning to operate two open pit phosphate mining operations in the PIC to mining depths of +/- 600m. The current North Pyroxenite Mine (NPM) which is currently +/- 160m deep will be expanded and is situated in the north western corner of the Phalaborwa Igneous Complex (PIC) and the New South Pyroxenite mine (NSPP) which is situated in the southern portion of the PIC (Figure 1).

This thesis was made possible as part of the Pyroxenite Expansion Project (PEP) at Foskor (Pty) Ltd NSPP mining operations.

The PEP project started when Foskor proposed to expand its current pyroxenite mining operations by extending PMC PP & V (Phalaborwa Phosphate & Vermiculite) area. The proposed Pyroxenite Expansion Project (PEP) involved the mining of the PP &V area, construction of an ore stock pile and a conveyor belt to transport the pyroxenite to Foskor's existing processing plant. The PP & V pit area is located just south of PMC's main pit and will be expanded, under Foskor, into one pit called the New South Pyroxenite Pit (NSPP) (Figure 1).

As the pit footprint will expand the Loole Creek will have to be diverted to prevent water flowing into the NSPP pit. The Loole Creek has been diverted before and currently flows in a stone-pitched channel that will have to be extended for the NSPP.

The occurrence of groundwater in the Phalaborwa Igneous complex for pit dewatering purposes is of major importance for the phosphate mining industry and furthermore it is important to monitor the impact of the mining activities on groundwater and the environment. The study area is drained by two rivers the Selati and Olifants rivers which are supporting a large ecosystem in the area including part of the National Kruger Park.

This thesis focuses on the occurrence of groundwater in the Phalaborwa Igneous Complex at the NSPP and NPM areas. The findings of the PEP project were used as basis of this thesis as well as relevant groundwater drilling, borehole yields and test pumping information from the North Pyroxenite Mine.

1.1. Objectives of Thesis

The objectives of this thesis are:

- To determine the occurrence (quantity) of groundwater in the PIC with respect to dolerite dyke upper and lower contact zones;
- Occurrence of groundwater in fractured zone associated with dolorite dykes;
- Occurrence of groundwater in weathered and fractured zones in the host rock;
- Characterize the prevailing groundwater situation;
- Determine current groundwater level distribution and flow directions;
- Determine baseline groundwater quality; and
- Assess the impact of phosphate mining on the groundwater system on existing users, during both operational and post closure phases of open cast mining.

1.2. Scope of work

The scope of work followed to complete this thesis is:

- Literature review;
- Hydrocensus;
- Geophysical survey;
- Drilling of groundwater exploration/monitoring boreholes;
- Pump testing of monitoring boreholes;
- Water sampling and analyses;
- Conceptual model; and
- Groundwater Impact assessment.

Figure 1: Open Cast Pit Mining Activities in the Phalaborwa Igneous Complex

1.3. Structure of the Thesis

This thesis is structured as follows:

Chapter 1 Introduction

This chapter gives an introduction on the thesis, the topic and its relevance and importance and focussing on the reasons, as well as the objectives and scope of work of the thesis.

Chapter 2 Literature Review

Chapter 2 covers the literature reviewed. The chapter focuses on the background information and the importance of phosphate mining globally and in South Africa. It also is summarise two relevant case studies/hydrogeological reports reviewed, with a discussion on the study objective and summary of the main findings.

Chapter 3 Description of the Study Area

Chapter 3 provides a detailed description of the study area based on existing data and reports. Descriptions include location, drainage, topography, climate, temperature, rainfall, wind and evaporation.

Chapter 4 Geology and Hydrogeology

This chapter provides a description of the regional geology and the geology of the NSPP and NPM areas. It also contains a section on the hydrogeology of the study area.

Chapter 5 Hydrocensus and Geophysical survey

Chapter 5 provides a description of the hydrocensus and geophysical surveys undertaken in the NSPP study area. The hydrocensus were done to collect relevant and updated information of existing boreholes. The geophysical survey purpose was to assist with the selection of drilling sites for exploration and monitoring boreholes.

Chapter 6 Drilling of Monitoring/testing Boreholes

This chapter provides a description of the drilling and results of the monitoring boreholes drilled at the NSPP study area and drilling conducted at the NPM during the beginning of 2011.

Chapter 7 Aquifer Testing

Chapter 7 provides a description on the pump testing preformed on the monitoring boreholes of the NSPP study area and test pumping preformed at NPM during the beginning of 2011. The aim of the aquifer testing was to determine the hydraulic parameters of the aquifer system.

Chapter 8 Groundwater Chemistry

This chapter provides a description on the groundwater sampling and analytical results of the NSPP.

Chapter 9 Conceptual Groundwater Model

Chapter 9 provides a groundwater conceptual model for the NSPP which is the main basis of the thesis. It also provides a description on the conceptual model and hydraulic parameters of the NPM area.

Chapter 10 Impact Assessment

This chapter provides an impact assessment of open pit phosphate mining on groundwater.

Chapter 11 Conclusions

Chapter 11 provides a description of the conclusions of the thesis.

Chapter 12 Recommendations

Chapter 12 provides a description of recommendations derived from this thesis.

Chapter 13 Comparison with Findings of Previous Case Studies and Study Limitations

This chapter provides a comparison with previous case studies regarding aquifers zones, aquifer thickness, depth of water strikes and yields obtained.

Chapter 14 References

Chapter 14 provides a list of literature and internet references used.

Chapter 15 Appendixes

This chapter contains appropriate appendixes and CD with folders containing appropriate thesis documentation and results.

CHAPTER 2: Literature Review

2.1. Phosphate Mining Globally

2.1.1. Introduction

Phosphate rock is a general term referring to rock with high concentrations of phosphate minerals, most commonly those of the apatite family with the general formula $Ca_5(PO_4CO_3)_3(F,OH,Cl)$. Phosphate is essentially a non-renewable resource, and present deposits and new phosphate fields are of major importance in the phosphate mining industry.

A major global phosphogenic event took place during the late Proterozoic and Cambrian times in al continents except, as yet Antarctica. Many of the phosphate deposits have been made in relatively recent times and in terms of exploration potential there seems to be no geological reason to suppose that no further Proterozoic or Cambrian age deposits will be discovered. The shielded areas of Africa South America and Siberia offer considerable promise by virtue of their large size and needs to be systematically explored. Unfortunately large areas of the African and South American shields occur in tropical regions with deeply weathered rocks, thick soil and in some places dense tropical forests, making exploration and prospecting extremely difficult (Roux et al.,1989).

Phosphate mining industry consists of both open pit and underground mining operations although the underground mining has decreased since all new developments over the last 15-20 years have been opencast mining (Roux et al.,1989).

Phosphorus is the 11th most abundant element in the earths crust. It occurs in trace amounts in almost all rock types, but is fairly concentrated in certain basic and ultra basic alkaline igneous intrusions, marine sedimentary phosphorates and guano (Cook et al., 1986).

Phosphate mining is also of interest because of the abundance of elements such as uranium, rare earths, vanadium and fluorine which may be extracted as by products during fertilizer production. Furthermore some sedimentary phosphatic rocks and their associated sediments are believed to be important petroleum source rocks (Cook et al., 1986).

It is the second most abundant mineral in the human body, surpassed only by calcium. It makes up about 1% of body weight and is largely confined to the skeleton in addition to an important part of the active structure of the muscles, central nervous systems and the energy circuits.

Phosphorus is essential to all living cells and is one of the three major nutrients required by plants, controlling the transfer and storage of energy at the cellular level and playing an important role in metabolic processes.

For general use in the fertiliser industry, phosphate rock or its concentrates preferably have levels of 30% phosphorus pentoxide (P_2O_5), reasonable amounts of calcium carbonate (5%), and <4% combined iron and aluminium oxides.

Worldwide, the resources of high-grade ore are declining, and the beneficiation of lower grade ores by washing, flotation and calcining is becoming more widespread. Continued demand is predicted for phosphate fertilisers in an effort to feed a growing world population.

Ninety percent of phosphate mined is used to produce chemical fertilisers. Phosphate products are also used in animal feeds, as a leavening agent in baking powder and flour, as an additive to beverages and in pharmaceuticals. Industrial uses include water softening, rust proofing, fire proofing, in insecticides and detergents, and for the manufacture of elemental phosphorus (sunkar resources).

Phosphorus crystallises into two physical forms as white phosphorus with a tetrahedral structure and as red phosphorus which exists under polymeric chains. Phosphorus is generally found in mineral forms, as phosphates, and is most often insoluble.

Phosphate deposits can be classified into three types:

1. The most economically significant are marine sedimentary deposits of phosphorites which are typically argillaceous to sandy sediments containing stratified concentrations of calcium phosphate, mainly as apatite;
2. Other deposit types are, apatite-rich igneous rocks; and
3. Modern and ancient guano accumulations.

Figure 2 indicates the distribution of the three types of deposits globally indicated as a circle for sedimentary deposits, a square for igneous and cross for island deposits.

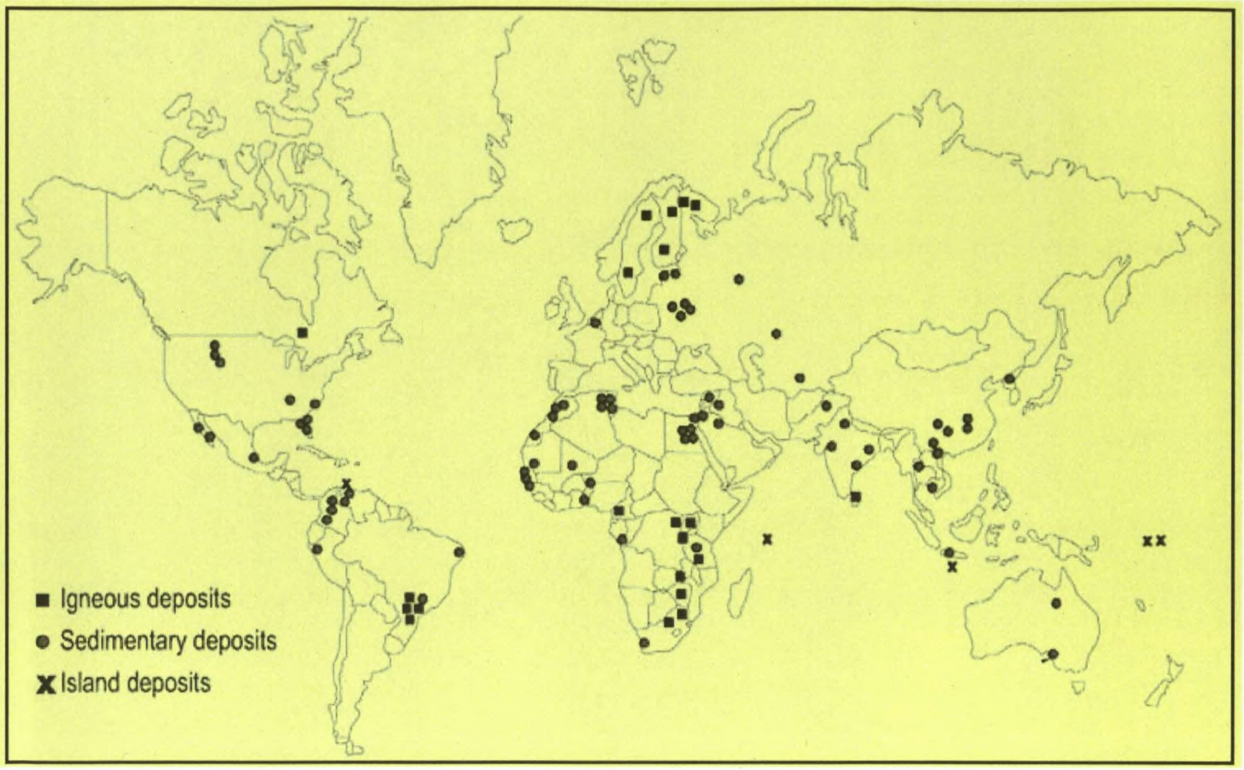


Figure 2: Phosphate Deposits of the World (from internet Use of Phosphate for Suitable Agriculture.mht)

2.2. Phosphate Deposits

2.2.1. Igneous Phosphate Deposits

Economically phosphate deposits of apatite are generally found in intrusions of alkaline rocks, nepheline syenites and carbonates.

The alkaline igneous deposits generally occur in ancient shield areas probably emplaced along zones of crustal weakness. These intrusions are often elliptical to near circular in plan and extend as pipe or cone shaped intrusions to several kilometres below surface. Carbonatites are consistently associated with non-calcitic alkaline rocks and often form the central core or plug of the intrusion or on the form of concentric ring dykes (Cook et al.,1986).

Nepheline syenites are characterised by high alkali content and low silica, pyroxene, amphibole and high content of minerals which are rare in other rocks (apatite, sphene, zircon and garnet). These high alkali low silica rocks are essential rich in volatile elements such as fluorine, chlorine and phosphorus and in elements such as titanium, zirconium, columbium and tantalum as well as in rare earth minerals (Cook et al.,1986).

Weathering of carbonatites has played an important role in producing economic apatite deposits. The soluble calcite is leached away leaving a residuum of less soluble minerals such as apatite, magnetite, pyrochlore, barite and zircon. The residuum is unconsolidated and alteration takes place to depths of up to 50m by rainwater along cracks and fissures (Cook et al.,1986).

2.2.2. Sedimentary Phosphate Deposits

Sedimentary phosphate deposits are laid down in moderately shallow marine environments. The majority are continental shelf sediments and are classified according to there occurrence in to two major tectonic positions (Cook et al.,1986):

- Epeiric or stable platform; and
- Geosynclinal where deposition took place along a subsiding basin.

The major conditions for phosphate deposition to take place are summarised as follows:

- Upwelling of cold, nutrient (phosphate) rich water into shallower, warmer environments. Phosphate is soluble in cold water, and usually ocean water temperature decrease with depth. At the ocean surface phosphorus is extracted by marine organisms where it is fixed into their teeth and bones or is incorporated into other organic matter. When the marine organisms die off the phosphatic material sinks and accumulate on a shallow sea bottom or reach a depth and water temperature where the phosphate are dissolved. Major upwelling currents return dissolved phosphate to shallower ocean regions.
- Upwelling of nutrient rich seawater encourages the fertile growth of marine life in all stages from algae, plants, fish and mammals. In an oxidizing environment on the shallow ocean floor, the phosphate is dissolved from the organic remains of marine organisms and forms a highly phosphate rich interstitial solution near the sediment and water interface.

The following stages however are more variable and are dependent on local conditions such as pH, oxidation/reduction state and temperature. Phosphate may precipitate as colloid to develop into a structure less form of apatite known as cellophane. Phosphate may replace carbonate from the calcium carbonate of shells, ooliths or unconsolidated lime mud. Phosphate may also form on its own as ooliths and pellets (Cook et al.,1986).

- Diagenetic phosphatization of the sediment may take place, irrespectively whether the sediment is calcareous, siliceous or clayey.

- Reworking of phosphatic sediment by current action, may upgrade the deposit by winnowing out non phosphatic particles or by sorting and re-deposition of the phosphatic grains.

- A major role player in the upgrading of phosphatic sediments are sub aerial weathering.

2.2.3. Guano and guano derived Deposits

Most of the large deposits of guano are formed by the accumulation of seabird excrement at nesting sites and colony on islands. Bats and other cave dwelling mammals form smaller deposits, which is of negligible economically importance.

Seabird deposits are mainly confined to islands and low altitude coastal regions, with upwelling nutrient rich ocean currents are the basis of the food chain. Fresh seabird droppings contain 22% nitrogen and 4% phosphate as P_2O_5. After decomposition the phosphate concentration increase to 10-20% P_2O_5 . Leached guano contains up to 32% P_2O_5.

Slightly decomposed guano deposits contain soluble ammonium and akela oxalates, sulphates and nitrates and a variety of magnesium and ammonium-magnesium phosphates. Highly decomposed guano consists chiefly out of calcium phosphates, monetite and whitlockite.

In high rainfall areas the soluble phosphates are drained to the rock substrate where they reprecipitate. The mineralogy of these phosphatised rocks derived from guano deposits depends on the composition of the host rock. Major deposits of guano derived deposits are found on he islands of Nauru, Ocean Christmas, Makatea and Curacao (Cook et al., 1986).

2.3. Phosphate Production and Reserves

2.3.1. Production

Since recorded production began in Suffolk, England, in 1847, almost 2 billion tonnes of phosphate rock have been mined worldwide (Cook et al.,1986).

Between 1960 and 1970 annual phosphate production doubled from 39 Mt to 81 Mt reaching 124 Mt in 1974. World production in 1999 was 141 Mt, with the main producers being the USA (40%), the former Soviet Union (23%) and Morocco (14%).

Figure 3 indicate the world phosphate production in mega ton per annum for 2008.

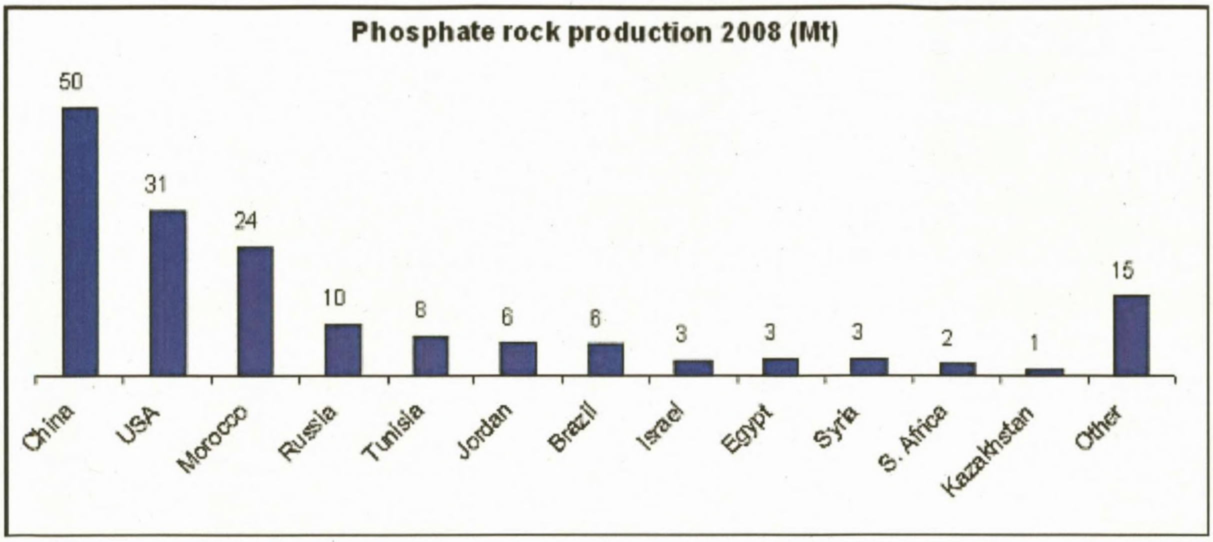


Figure 3: World Phosphate Production by Country (Internet Source, Sunkar Resources)

2.3.2. Reserves

A mineral reserve can be defined as a mineral deposit which can be mined profitably under prevailing or local price conditions, whereas a resource is presently uneconomic for reasons of grade, location, depth below surface or other adverse factors (Cook et al.,1986).

The U.S Bureau of mine published in 1976 the world phosphate reserves as indicated in Table 1.

Table 1: 1976 World Phosphate Reserves

World Phosphate Deposit	Reserve Mt
North America	3 222
South America	80
Europe	830
Africa	22 080
Asia	460
Oceania	1 120
World Total	**27 792**

The British Sulphar Corporation estimates of reserves and resources which were compiled from various reports are indicated in Table 2. Figure 4 show the phosphate rock reserves as estimated by British Sulphar Consultants.

History Continue

The Second World War brought the importation of phosphate to a standstill for three years, which is also the average half-life of phosphatic fertilizer in the soil. During 1946 after the war there was a possibility of food rationing and the possibility of a phosphate mine was investigated as a matter of strategic importance (Roux et al., 1989).

In 1951 the State acquired the necessary claims from Dr Merensky, and the Industrial Development Corporation (IDC) established the Unie-Fosfaat- Ontginnings maatskappy (Eiendoms) Beperk to develop the phosphate deposit. A few years later, the name was changed to the Phosphate Development Corporation Limited and in 1987 to Foskor Limited (Roux et al., 1989).

Phosphate production started in 1954 under difficult conditions. With the nearest railhead 60 km away, all transportation was done by truck over dirt roads. The country's fertilizer factories were not used to igneous phosphate rock and the scale of the mining operation was too small to be economical. Criticising of the State for starting the venture, cause them to considered closing it down rather than investing more money on the production of phosphate (Roux et al., 1989).

In 1961 the first profits were reported after fertilizer producers have adapted to the new rock and production was increased to economic levels. Together with the production of Amcor's smaller mine at Langebaan the phosphate production was sufficient by 1969 to satisfy the country's entire phosphate needs (Roux et al., 1989).

In 1976 expansions were commissioned that gave Foskor a substantial export capability. Today one-third of the production is consumed domestically, one-third is converted to phosphoric acid and fertilizer for export, and the rest is exported as phosphate rock (Roux et al., 1989).

Foskor has been very successful as a State-owned corporation and apart from the original investment of £2710 000 in the 1950s, no further State financing was used for the phosphate production. The home market for phosphate rock is not protected artificially either by import restrictions or by import duties. Foskor's competitors in Europe, namely the USA, the USSR, North and West Africa, and the Middle East, all have head grades in excess of 18% phosphate and are within 100 km of harbours, and enjoy relatively short shipping distances to their customers (Roux et al., 1989).

Phalaborwa is situated more than 800 km from Richards Bay, the long-term average head grade is only 7% phosphate and it is a very long haul to markets in Europe and the Far East.

Today Foskor's rock costs 20 to 27% less delivered at Richards Bay and 35 to 40% less delivered at Potchefstroom, than imported phosphatic rock (Roux et al., 1989).

2.5.2. Phosphate Mining Process

The phosphate mining activities at Foskor Phalaborwa involve conventional open-pit mining methods for hard rock. The process involved drilling, blasting, and haulage of the broken rock to the crushers in 92 to 150 t rear-dumper trucks (Roux et al., 1989). The phosphate (P_2O_5) open pit mining process is illustrated in Figure 8.

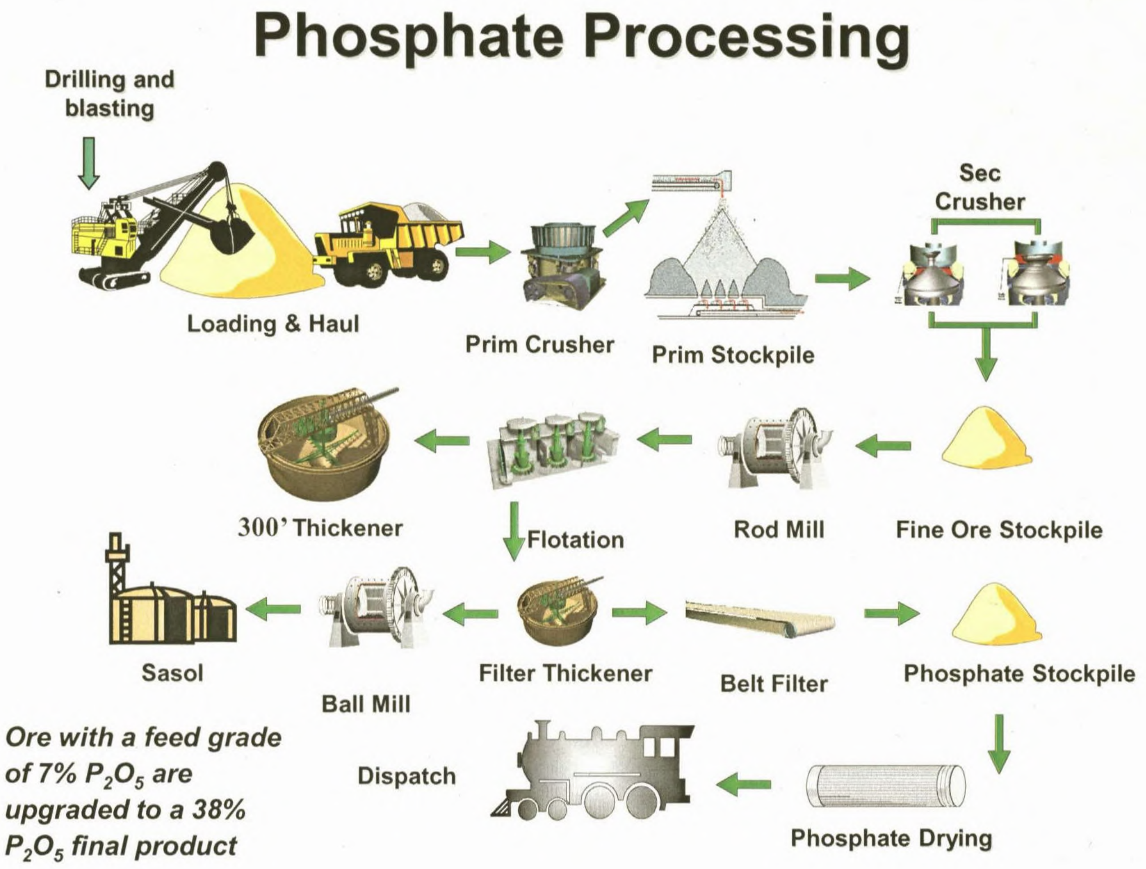


Figure 8: Phosphate Processing (from Foskor (Pty) Ltd)

The phosphate mining process involves crushing, grinding and slurrying of the ore, from which the apatite is recovered as a mineral concentrate (referred to as phosphate rock) by means of froth flotation.

The distribution of percentage of phosphate minerals in the PIC are indicated in Figure 9.

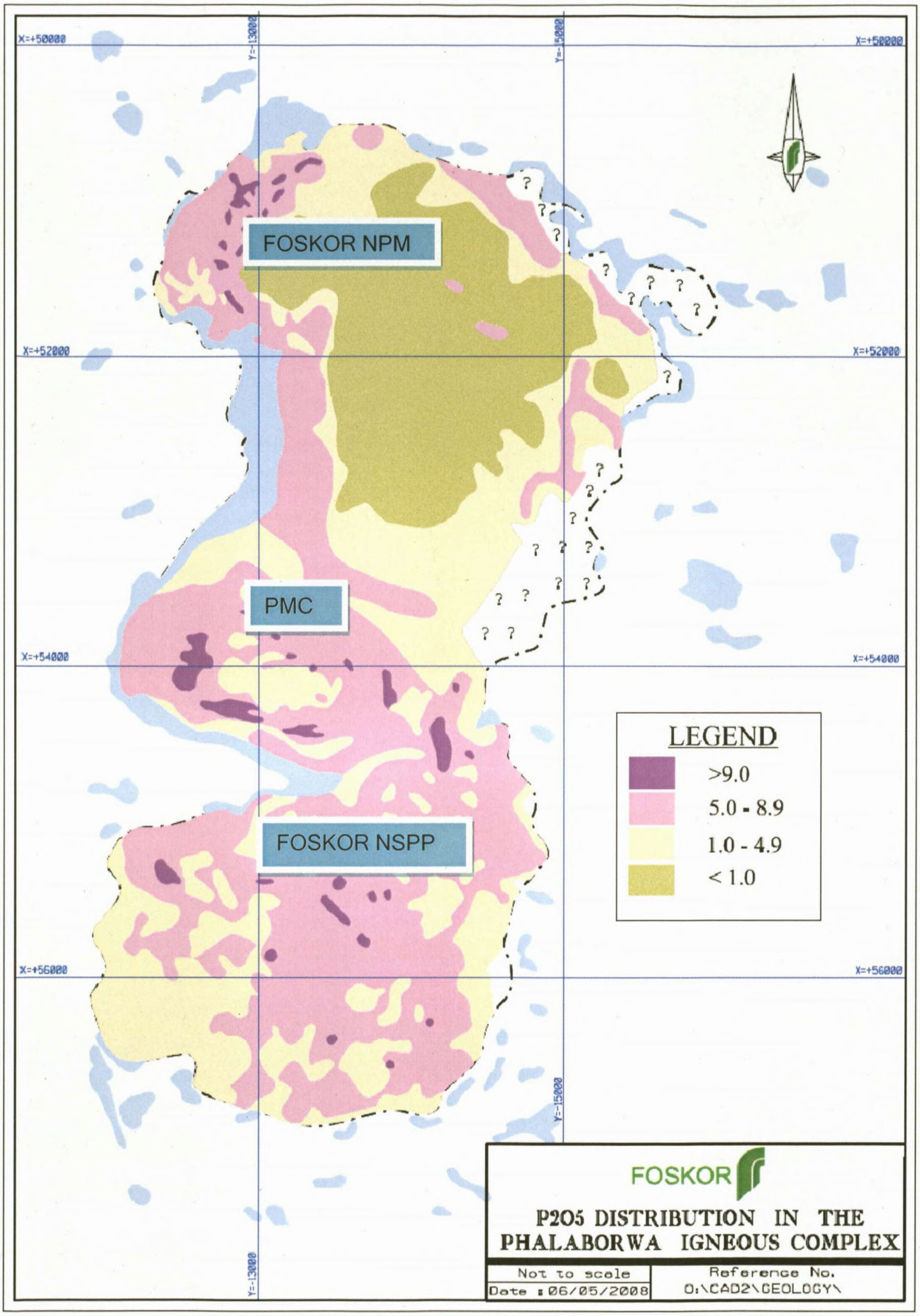


Figure 9: Percentage (%) Phosphate Distribution in the PIC (from Foskor (Pty) Ltd)

2.6. Phosphate Minerals in the PIC

2.6.1. Foskorite

Foskorite (Figure 10) ore is composed out of 35% magnetite, 25% apatite, 18% calcite and 22% serpentine/olivine, phlogopite and copper-sulphides.

Figure 10: Foskorite (from Foskor (Pty) Ltd)

2.6.2. Pyroxenite

Pyroxenite ore consists primarily out of apatite (Figure 11) which is the phosphate source, diopside (Figure 12) and phlogopite (Figure 13) which are waste minerals. The average apatite content of Pyroxenite ore is 16% and the average P_2O_5 content is 7.2%.

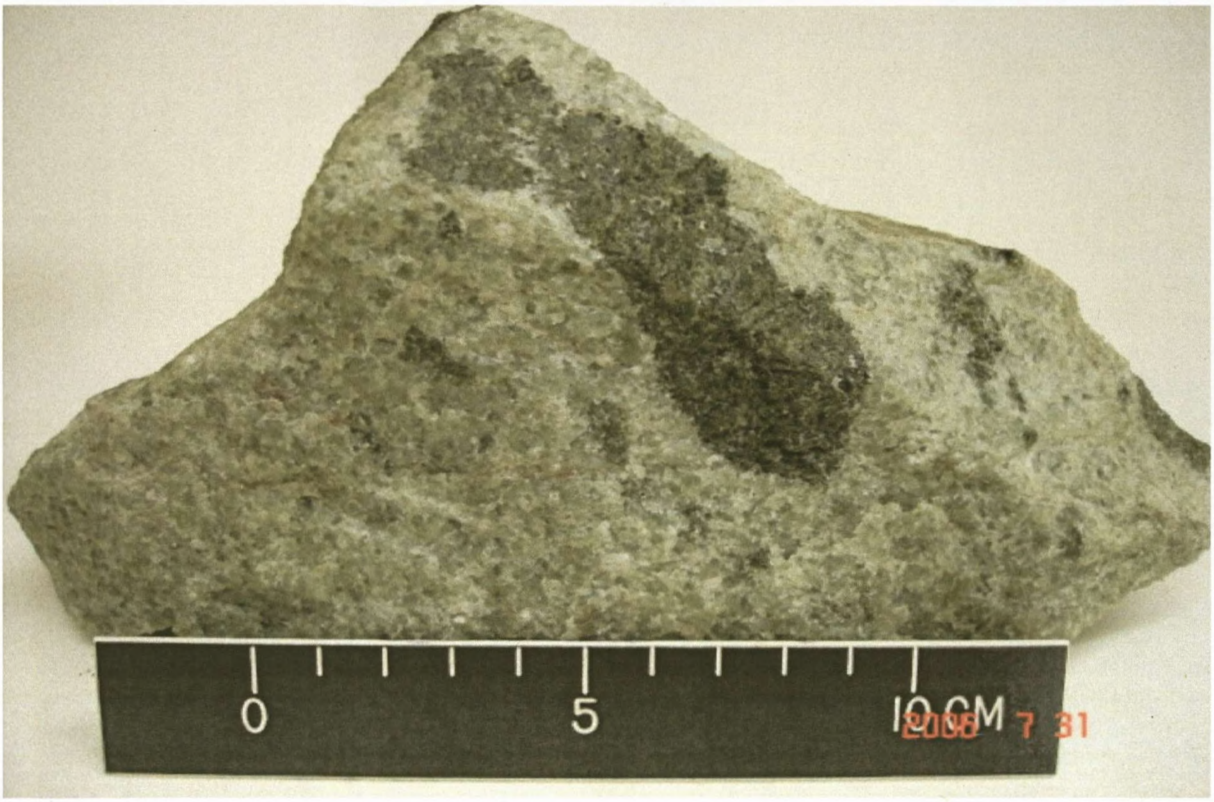


Figure 11: Apatite (from Foskor (Pty) Ltd)

Figure 12: Diopside (from Foskor (Pty) Ltd)

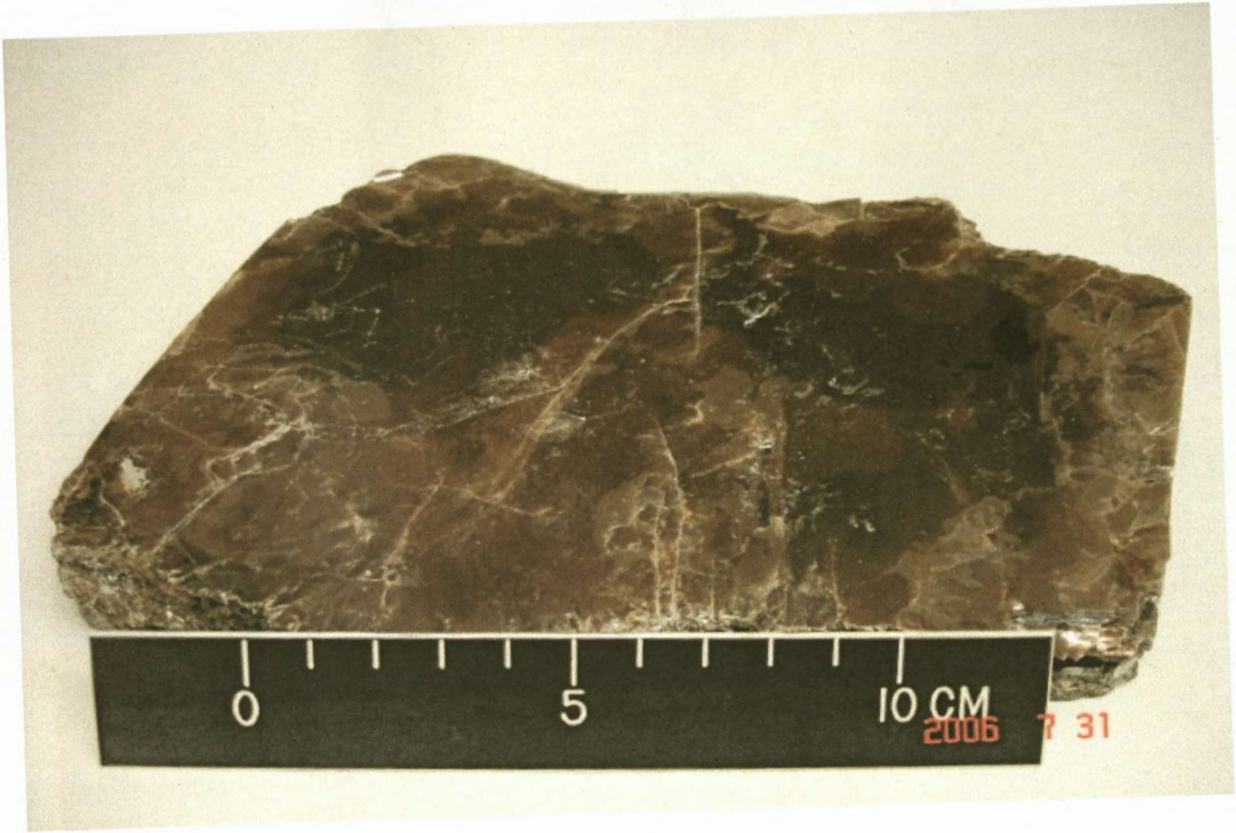


Figure 13: Phlogopite (from Foskor (Pty) Ltd)

2.6.3. Other Economic Minerals in the PIC

PMC are mining copper from carbonatite (Figure 14) and vermiculite (Figure 15) from the PIC.

Figure 14: Carbonatite with copper-sulphides (from Foskor (Pty) Ltd)

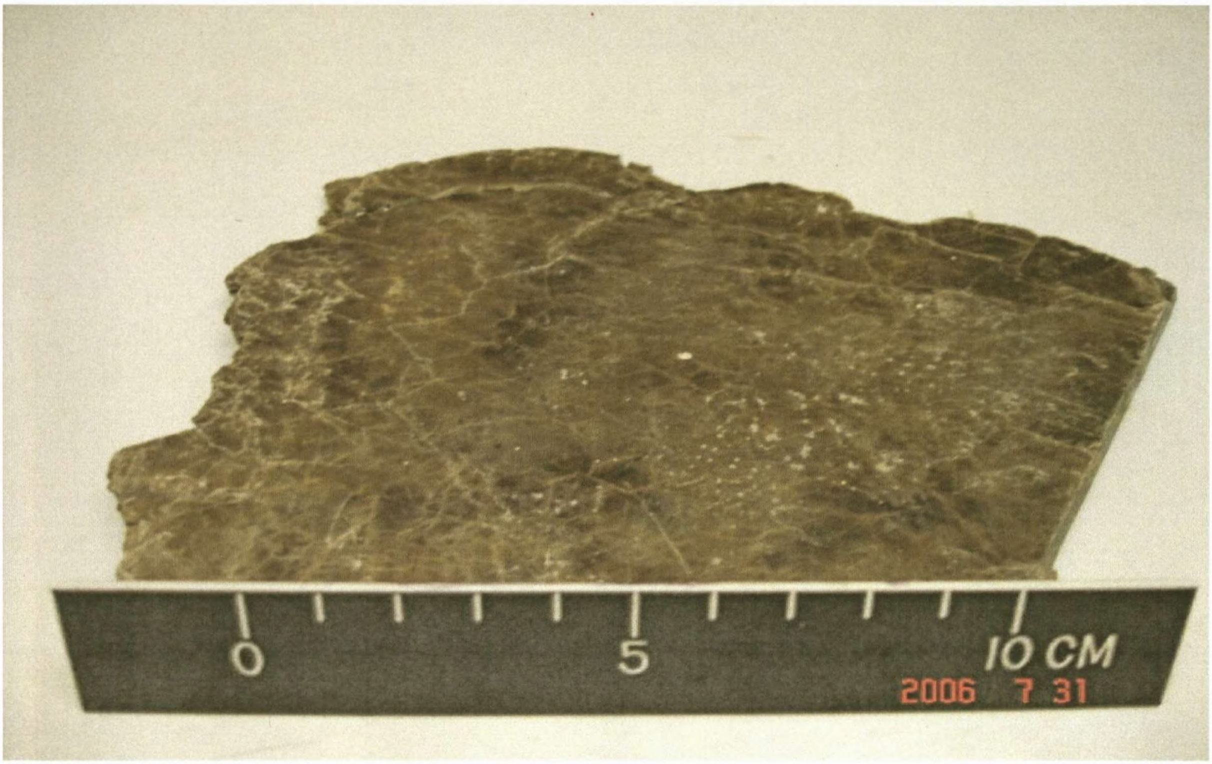


Figure 15: Vermiculite (from Foskor (Pty) Ltd)

2.7. Uses of Phosphate

Phosphate is widely used as ingredients for:

- Phosphate fertilizer;
- Phosphorus based chemicals;
- Cleaning agents;
- Dental creams;
- Tooth pastes;
- Flame retardants;
- Stabilizer in plastics;
- Corrosion inhibitors;
- Phosphoric acid in soft drinks such as Coke;
- Canned foods;
- Fire extinguishers;
- Antifreeze; and
- Latex paints.

2.8. Conclusion

It is evident that a major global phosphogenic event took place during the late Proterozoic and Cambrian times in al continents except, as yet Antarctica. Many of the phosphate deposits have been made in relatively recent times and in terms of exploration potential there seems to be no geological reason to suppose that no further Proterozoic or Cambrian age deposits will be discovered (Hanekom et al.,1965).

The development of fertilizer raw material resources in Africa and South America in light of their poor soil fertility and growing population is critical. Taken in to account the declining phosphate deposits of the world, the increasing population and food demand, phosphate mining remains one of the world's most essential mining activities.

Mining methods will need to be developed that can deal with lower non economic grades of ore. Flotation methods needs to be developed that can coped with impurities such as magnesium, iron and aluminium.

2.9. Previous Case Studies

A literature review of two applicable previous case studies was conducted with the aim to obtain an understanding of the study area, and to define key concepts around which the study should be build.

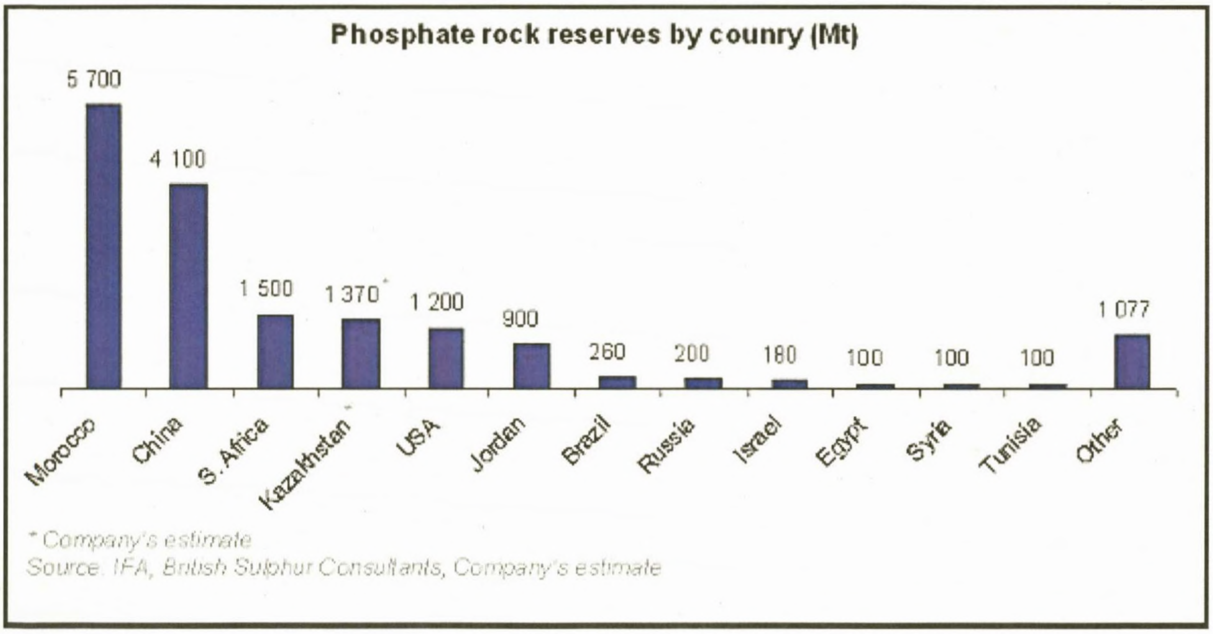
The two case studies (Hydrogeological reports) reviewed are listed in Table 3. The borehole positions of the two case studies are shown in Figure 16.

Table 3: List of Case Studies Reviewed

Case Study	Report Title	Author	Date
I	Report on the Design of Dewatering System For the PP&V Open Pit and Proposed PP&V North Pit - Report No.960	Demmer, T., Northern Environmental Geohydrological Consultants	November 2001
II	Phalaborwa Mining Company Deep seepage Investigation in the Cleveland Game Park Report on Area 2 - Scavenge Well Field Implementation - Report No. 856/2	Hubert, G. L., EMA Consulting Hydro geologists and Groundwater Geophysicists	March 2001

Table 2: Phosphate reserves according o the British Sulphur Corporation

World Phosphate Deposit	Reserve Mt	Sub Economic Resources Mt	Total Mt
North America	4 770	12 500	17 270
South America	642	3 500	4 142
Europe	480	500	980
U.S.S.R.	800	11 000	11 800
Africa	7 106	65 200	72 306
Asia	1 590	5 300	6 890
Oceania	140	3 990	4 130
World Total	**15 528**	**101 990**	**117 518**



* Company's estimate

Source: IFA, British Sulphur Consultants, Company's estimate

Figure 4: Phosphate Rock Reserves per Country (Internet Source, Sunkar Resources)

Figure 5 show the major phosphate reserves per country in billion tonnes and Figure 6 the phosphate fertilizer production and consumption in million tonnes in 2007.

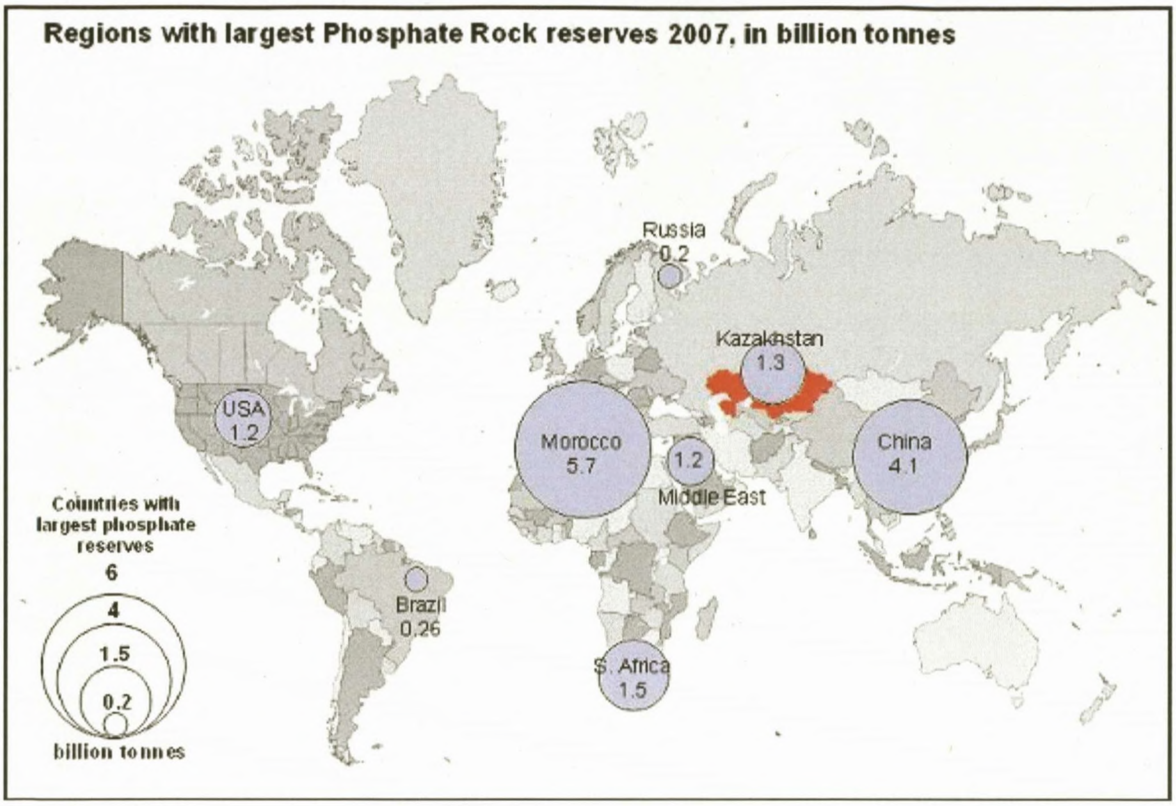


Figure 5: World Map showing major Phosphate Reserves in Billion Tonnes (Internet Source, Sunkar Resources)

Figure 6: World Phosphate Fertilizer Production and Consumption in 2007 (Internet Source, Sunkar Resources)

2.4. Phosphate Mining in South Africa

The commercial phosphate deposits in South Africa are confined to igneous and marine sedimentary geological environments (Figure 7).

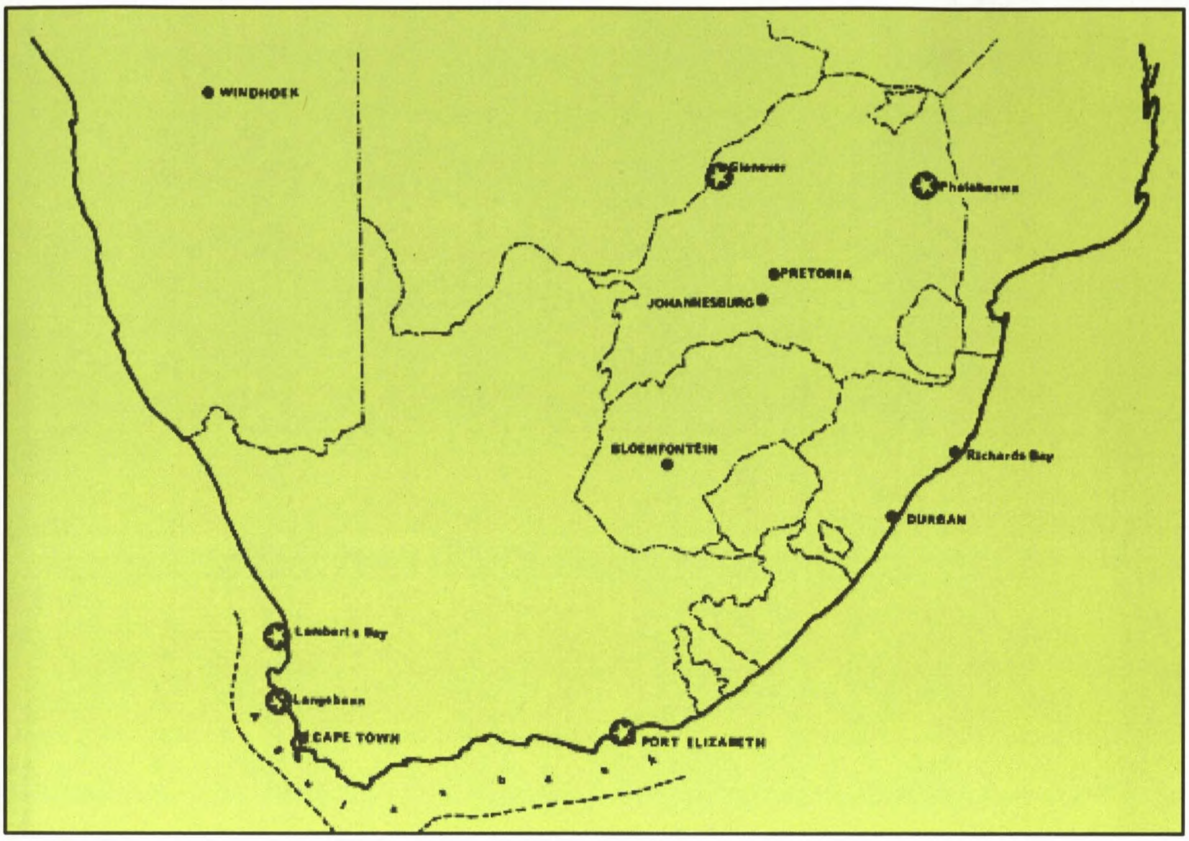


Figure 7: Phosphate deposits in South Africa (From Phosphate in South Africa, May 1989)

The igneous environments are the most important one in South Africa with the Phalaborwa Igneous Complex supplying roughly 95% of the phosphate production of the country (Roux et al., 1989).

2.4.1. Marine Sedimentary Deposits

The Marine sedimentary deposits are confined to the western and southern coastal regions of the country. These deposits comprises of both off shore and onshore deposits (Roux et al., 1989).

2.4.1.1. Off Shore Deposits

The off shore phosphate deposits occur on the continental shelf at Agulhus Bank, stretching from Cape Town northwards towards Lamberts Bay and eastwards towards Port Elizabeth.

The phosphate deposits consist of scattered nodules and sand, with depths ranging from 100 to over 1000 m. The nodules are relatively low grade, with approximately 16% phosphate average and are not amenable to upgrade. Although off shore mining technology has progressed significantly during the past two decades, it is doubtful whether these deposits can be exploited economically since finding a market for such low grades of material will be difficult (Roux et al., 1989).

2.4.1.2. Onshore Deposits

Onshore deposits occur sporadically from Saldanha Bay in the south towards Lamberts Bay in the north. Samancor has been exploiting the New Varswater deposit in the vicinity of Langebaan since 1943. Individual deposits in this area are reported to have contained 1 Mt (Mega ton) to almost 50 Mt of ore, grading from 8% to 12.8% phosphate (Roux et al., 1989).

The ore consists of phosphatic sand horizons and is overlain by limestone and/or younger sand deposits. The phosphate occurs in the form of the mineral francolite (carbonate apatite), which is soluble in citric acid and thus suitable as a direct-application fertilizer (Roux et al., 1989).

The New Varswater ore body was deposited on a raised beach, which was cut into a posphatic sandstone horizon. Rounded beach pebbles and phosphatic sandstone has accumulated, and give rise to a 1m thick irregular layer of brown phosphatic sandstone, which forms the base of the ore body. Although the average grade of this basal layer is 15% phosphate, the phosphate is mostly present as cement binding the quartz grains. Because the phosphate slimes when the sandstone is comminuted, and becomes too fine for beneficiation, this layer is not mined (Roux et al., 1989).

These basal horizons are overlain by an ore body consisting of phosphatized shell fragments, skeletal remains of marine and terrestrial animals, and phosphate pellets nucleated on quartz, ilmenite, and feldspar. Diagenetic changes resulting from the dissolution and re-precipitation of the phosphate have given rise to slab-shaped layers of consolidated phosphatic sand. The overall average grade of the ore body is 9% phosphate, but the slab-like layers constitute the richest part, grading from 15 to 25 % phosphate. The ore body covers an area of 2,6 km^2 and has an average and maximum thickness of 11 and 24 m respectively, and is overlain by an overburden of limestone and quartz sand that is up to 51 m thick. It is situated 11 km from the sea and is raised 30 m above sea level (Roux et al., 1989).

2.4.2. Igneous Deposits

Igneous deposits of carbonatite-peralkaline complexes, of which the Phalaborwa Complex is by far the most significant, represent the major type of host rock for phosphate in South Africa, as well as for precious minerals of copper, zirconium, and uranium. There are also a number of other carbonatitic complexes in South Africa and its neighbouring territories that have been mined for phosphate, or are potential phosphate sources (Roux et al., 1989).

The *Glenover complex* in the northwestern Transvaal was mined on a small scale until 1984, at which stage the high- grade reserves were exhausted (Roux et al., 1989).

Apatite also occurs in appreciable concentrations in the upper zone of the *Bushveld Complex,* but so far no economic deposits have been located.

The geology of the *Phalaborwa Complex* has been the subject of numerous publications and reports. It comprises a pipe-like intrusion that is 2030 million years old, emplaced in Archaean granite-gneiss. The main body is roughly kidney-shaped, measuring 1.5 to 3.5 km in width and 6.5 km in length. It is made up of three coalescing and concentrically zoned lobes designated Northern pyroxenite, Loolekop, and Southern Pyroxenite. Deep diamond-drill holes have shown that the contacts and mineral banding are essentially vertical, and that the general geological features, as well as the extent of the mineralization, are essentially continuous to a depth of at least 1000 m (Roux et al., 1989).

The greater part of the Phalaborwa Complex (about 95 per cent) consists of pyroxenite zones containing varying proportions of pyroxene (diopside), phlogopite, and apatite. The pyroxenitic rocks exhibit large variations in grain size and are usually medium- to coarse-grained. Where they are exceptionally coarse-grained, they are referred to as pegmatoid. Apatite occurs in all the pyroxenitic zones except the central part of the Northern Pyroxenite.

The phosphate content of the pyroxenite is between 6 and 7.5% phosphate on the average (15 to 19% apatite). The foskorite (serpentine-magnetite-calcite-dolomiteapatite) zone contains the highest concentrations of apatite, and is at present the major source of the phosphate produced at Phalaborwa. The average *in situ* grade of the foskorite is in the region of 10% phosphate (25% apatite). The carbonatite contains an average of only 3.5% phosphate, and does not qualify as a phosphate ore. The apatite has a hardness of 5 on the Mho scale and a relative density of 3.2. It occurs in the form of:

- Prismatic crystals, often poikilitically enclosed by diopside, phlogopite, calcite, and magnetite, and therefore early in the crystallization sequence. The crystals are euhedral to subhedral and they vary in size from 0,001 to 0,150 mm in the pyroxenites, and are much larger in the foskorite (up to 1 cm) and up to 15 cm in the pegmatoid;
- Sugary aggregates between other minerals; and
- Granular, monomineralic veins, dykes, bands and segregations that may represent a late stage of enrichment.

The colour of the apatite can be light green, grayish green, white, or pink. It is mainly fluorapatite, but subordinate amounts of hydroxyapatite and chlorapatite also occur, the latter most prominently in the foskorite-pyroxenite contact zone (Roux et al., 1989).

2.5. Phalaborwa Igneous Complex

2.5.1. History

In the seventeenth century, the tribes of the Monomotapa empire were driven south by Rozwi invaders from the north. One of the tribal groups below a chief named Malatji wandered as far south as Bushbuck Ridge, where they settled temporarily. They were metalworkers in search for iron and copper, eventually finding a huge deposit that they named Phalaborwa, meaning - *Better than the South.* They produced iron hoes, axes, spearheads, and arrowheads. They also processed oxide copper into bangles, necklaces, and copper rods called -Lirale, which were used as a form of money. There are indications that the Phalaborwa metal economy of was felt deep into Mozambique and as far south as the Witwatersrand, but it was ruined in the nineteenth century by the arrival of cheap metal from Europe (Roux et al., 1989).

Malatji's people replaced the existing Shokane tribe at Phalaborwa, a tribe of people so primitive that they are reputed not to have known the use of fire. In 1965, when blasting operations in the foskorite zone started, a shaft 6 m deep and less than 1m wide was revealed and at the bottom of which charcoal was found. Radio-carbon dating indicated the charcoal to be 1200 years old. The origin of these ancient miners is unknown and may well remain one of the Bushveld's unsolved mysteries (Roux et al., 1989).

During 1904 the Phalaborwa Complex was rediscovered by E.T. Mellor, and was subsequently studied by such distinguished geologists as Cohen, Wilson-Moore, Du Toit, and Merensky.

A small company named South African Phosphates Ltd mined high-grade apatite pockets in the pyroxenite starting 1930 to 1934. They ground the mineral, bagged it, and sold it as fertilizer. The apatite was apart from being insoluble to plants, more expensive than imported Moroccan phosphate rock, and the operation soon went insolvent.

The Transvaal Ore Company was established in 1937 by Dr Hans Merensky, and the company started mining vermiculite in 1940. He also launched a prospecting operation in 1945 to delineate the extent of the apatite mineralization. The deposit was found to be vast, but of low grade by the standards of the time to be of any economic importance (Roux et al., 1989).

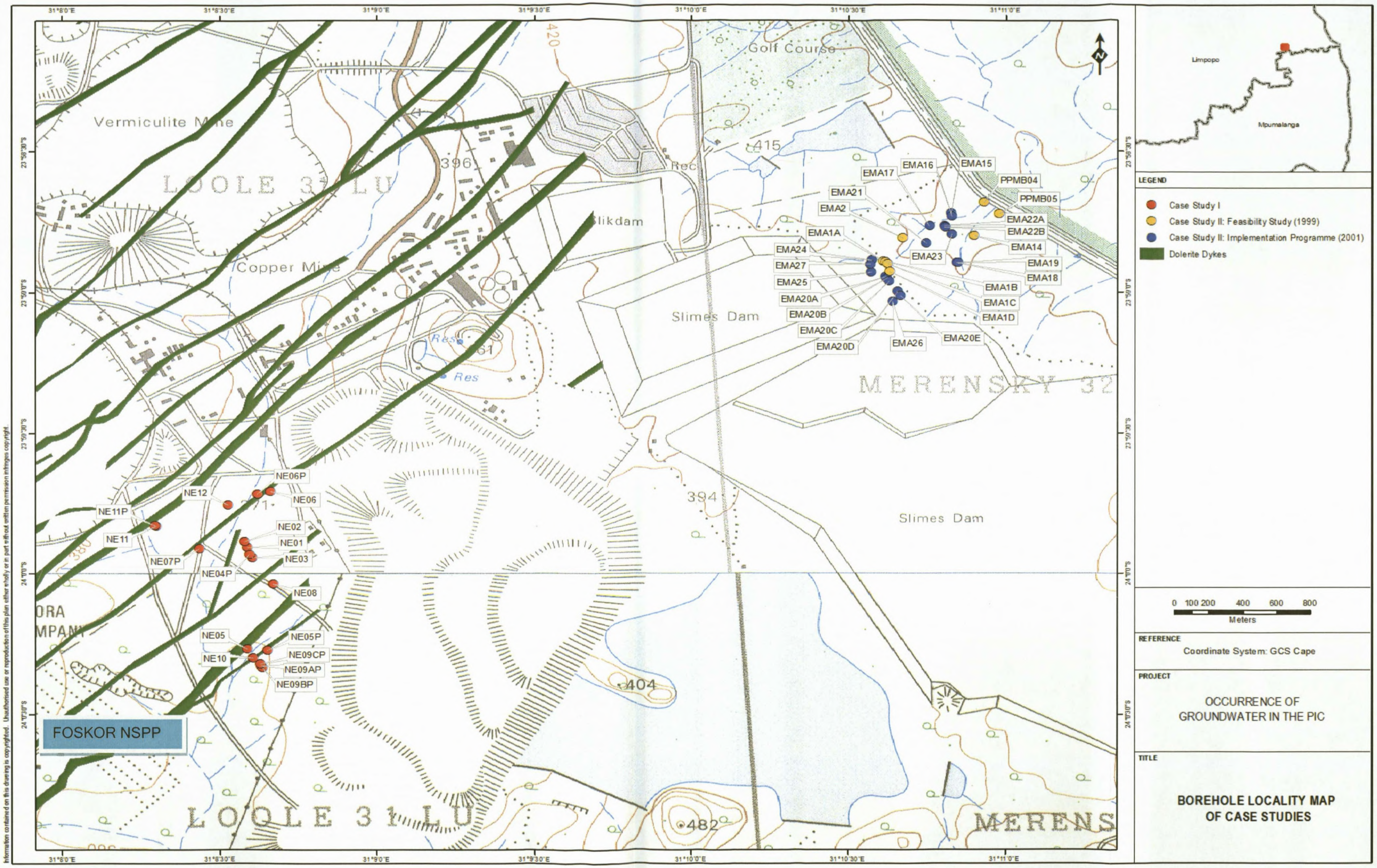


Figure 16: Borehole Positions of Case Studies I and II

2.9.1. Case Study I

The investigation of this study involved:

- The reporting and testing of the existing PP&V dewatering system;
- A geophysical survey to select drilling positions;
- Drilling of 17 monitoring/exploration boreholes;
- Test pumping of boreholes;
- Data interpretation;
- Preparation of a numerical model;
- The design of a dewatering well field; and
- Operational and management recommendations of the existing dewatering boreholes.

The study targeted the contact zones of the north east south west striking dykes, the drilling results of the 17 exploration boreholes are summarised in Table 4.

Table 4: Summary of Drilling Results of Case Study I at PP&V North Pit Area

Borehole No.	Depth (m)	Depth of Water Strike (mbgl)	Yield of Individual Strikes (l/s)	Final Blow Yield (l/s)	Geology Intersected	Weathered Thickness (mbgl)	Drilling Target	Fractured Thickness (mbgl)
NE01	75	16/17,18/24,36/42	1.8,4.3,2.7,2.2	11	Pyroxenite	5-33	Edge of dolorite dyke	33-42
NE02	60	24,30,42/43	0.6,1.9,0.25	2.75	Pyroxenite	4-26	Edge of dolorite dyke	26-43
NE03	72	25/26,30,36,48	0.25,3.8,2.8,1.9	8.75	Pyroxenite	2-30	Edge of dolorite dyke	30-44,48
NE04P	12	None	Seepage	Seepage	Pyroxenite	1.5-12	Between dykes	-
NE05	72	19/20,22,24,32/33, 42/43,46/47	1.5,1.1,1.5,0.7,0.8	7.3	Pyroxenite/Dolerite	4-18	Edge of dolorite dyke	18-24,32/33,42/43,46/47
NE05P	12	4	0.3	0.3	Dolorite	0-4	Probing on dyke	4-5
NE06	60	23	0.3	0.3	Granitic-gneiss	0-20	Edge of dolorite dyke	20-31,51/52
NE06P	18	None	Dry	Dry	Dolorite	0-7	Probing on dyke	7-8,13
NE07P	10	>0.5	Localised saturation		Dolorite	2-4	Probing on dyke	4-5
NE08	60	24,30,36/37,48	0.5,1.1,0.4,0.2	2.2	Pyroxenite	4-35	Between dykes	36-48
NE09AP	36	None	Dry	Dry	Pyroxenite	3	Edge of dolorite dyke	-
NE09BP	12	None	Dry	Dry	Pyroxenite	3	Away from dyke contact zone	-
NE09CP	42	None	Dry	Dry	Pyroxenite/Dolerite	2	Edge of dolorite dyke	6-16
NE10	54	36	<0.1	<0.1	Dolerite/pyroxenite	1-9,20-25	Edge of dolorite dyke	9-20,25-52
NE11	66	18,22/23,33/34	1.47,5.86,1.5,	8.8	Dolorite/pyroxenite	3-16.5	Edge of dolorite dyke	16.5-22
NE11P	10	None	Dry	Dry	Dolorite	0-4	Probing for dyke	4-8
NE12	60	2,18,22,34	Seepage,0.49,0.12,0.27	1.15	Pyroxenite	3-14	Between dykes	14-27,34

2.9.1.1. Case Study I Main Findings

- The study confirmed that the weathering ranges from 14 -35 m with an average of 25 m and fracturing various from 22 to 52 m with an average of 45 m. The variation in weathering and fracturing is characterised of anisotropic secondary aquifers.
- Water srikes intersected in 9 of the cased boreholes ranges from 16-48 m. Blow yields range from 0.1 l/s to 11 l/s. The wide range of water strike depths and blow yields is indicative of anisotropic aquifer conditions.

Seven of the boreholes were subjected to test pumping and results are summarised in Table 5.

Table 5: Summary of Constant Discharge Test Data - PP&V North Pit Area

Borehole No.	Observation BH	Test Yield (l/s)	Remarks
NE01	NE02,NE03,NE35	14.5	Drawdown at NE02,NE03,NE35
NE02	NE08,NE03,NE35,NE01	1.6	No drawdown at observation boreholes
NE03	NE08,NE02,NE35,NE01,NE04P	7.68	Drawdown at NE35 and NE04P
NE05	PGSMB20	10	0.37m at PGSMB20
NE08	35,NE03	2.7	No drawdown at observation boreholes
NE11	NE11P,NE07P,NE12	5.4	1.97m drawdown at NE11P
NE12	-	1.2	-

- The pump testing confirms that the dolerite contact zone aquifers are linear;
- Transmissivity values range between 3 m^2/d to 120 m^2/d;
- Storativity are mostly $>1x10^{-2}$ indicating the aquifers is hydraulically unconfined;
- As no interference was recorded in BH35 and NE08 when NE02 and NE03 was tested respectively, the assumption is made that the dolerite dykes acts as hydraulic barriers, confirming the preferential expansion of the drawdown cones along the dyke contact zones rather than laterally into the pyroxenite aquifer;
- An exception to this is the minor drawdown in NE10 recorded when NE05 was tested and drawdown was experienced across the dolerite dyke; and
- Groundwater flow is from north east towards the south west parallel to the dolerite dykes.

2.9.2. Case Study II

The investigation of this study confirmed the following:

- The presence of two aquifer systems, a shallow aquifer zone and a deep fractured aquifer system associated with the contact zones of the main dolerite dyke;
- The shallow aquifer is describe as small and localized. The Transmissivity of this aquifer system is approximately 60 m^2/day. The Electrical Conductivity (EC) is approximately 520 mS/m confirming contamination from leakage from the tailings dam;
- The presences of a deep contact zone aquifer were confirmed by three boreholes EMA15, EMA16 and EMA 17 along the north side of the main dolerite dyke investigated. This fractured aquifer system is water bearing from 30 m to 50 m below surface. The northern aquifer zone (northern side of the main dolerite dyke) is poorly developed and Transmissivity (T) is between 1 to 4 m^2/day. With the average storage capacity (s) of $5x\ 10^{-4}$. The testing has confirmed hydraulic connectivity between the boreholes drilled on the northern dolerite dyke contact zone. The Electrical Conductivity (EC) is approximately 649 mS/m to 704 mS/m confirming contamination of groundwater;
- The southern side of the main dolerite dyke investigated confirms the presence of a fractured aquifer system between 30 m and 82 below surface. The contact zone is described as pegmatite with well developed permeation characteristics. The T values ranges from 10m^2/day (EMA14), 60 m^2/day (EMA23) and 200 m^2/day (PPMB05). The average storage capacity is $3x10^{-4}$. Testing has confirmed hydraulic connectivity along the southern contact zone. Minor hydraulic connectivity was confirmed across the dolerite dyke at boreholes EMA17 and EMA23. Minor fracturing of the dyke is responsible for this continuity. The Electrical Conductivity (EC) is approximately 577 mS/m to 734 mS/m confirming contamination of groundwater;
- The contact zones of the southern dolerite dyke investigated are marginally developed;
- Tested borehole yields range from 0.3 l/s (EMA21) to 10 l/s (EMA23); and
- The groundwater flow direction from the west towards the east and mimic the topography gradient

A total of 18 boreholes were drilled during this project, six production (EMA16, EMA17, EMA21, EMA22B, EMA23 and EMA25), seven monitoring boreholes (EMA19, EMA20A, B, D and E, EMA26 and EMA27) and five boreholes were abandoned and backfilled after completion of test pumping. A summary of these boreholes drilling results together with the results of the feasibility study in 1999 are listed in Table 6. The feasibility study was done separately from this case study.

Table 6: Summary of Drilling Results of Case Study II

Borehole No.	Depth (m)	Depth of Water Strike (mbgl)	Yield of Individual Strikes (l/s)	Final Blow Yield (l/s)	Main Geology Intersected
Feasibility Study in 1999					
EMA1a	18	9-10	<0.05	<0.05	Dolerite
EMA1b	18	6-7	<0.05	<0.05	Dolerite
EMA1c	22	12	<0.1	<0.1	Dolerite
EMA1d	48	18-19	<0.1	<0.1	Dolerite
EMA2	60	29-30	<0.1	<0.1	Granitic-gneiss/dolerite
EMA13	30	-	<0.05	<0.05	Dolerite
EMA14	90	45,51,62/64,73/74,81,82	1.6,0.3,0.75,0.3,0.6	3.55	Granitic-gneiss - pegmatite
PPMB04	72	46/48,51/55,57/61,68,72	4.2,>5	>9.2	Granitic-gneiss - pegmatite/dolerite
PPMBO5a	78	25,34,42,52,58/59,72,74	2,0.75,1.6,4,8,2,>5	24	Granitic-gneiss - pegmatite
Implementation Programme					
EMA15	54	35,41,42	0.1,0.2,0.2	0.5	Granitic-gneiss
EMA16	66	30,38,40	0.6,0.4,0.5	1.5	Granitic-gneiss
EMA17	54	7/8,30/31,42,44/48	0.1,0.4,0.1	0.6	Granitic-gneiss/dolerite
EMA18	42	Dry	Dry	-	Granitic-gneiss/dolerite
EMA19	66	12,35	<0.1	<0.1	Granitic-gneiss/dolerite
EMA20A	9	3	Seepage	Seepage	Granitic-gneiss/dolerite
EMA20B	6	2/3	Seepage	Seepage	Granitic-gneiss
EMA20C	30	2/3	Seepage	Seepage	Granitic-gneiss
EMA20D	30	4/6	Seepage	Seepage	Granitic-gneiss/dolerite
EMA20E	30	1,2	Seepage	Seepage	Granitic-gneiss
EMA21	54	8/9,40/41,42,44/45	0.1,0.46,0.06	0.6	Granitic-gneiss/dolerite
EMA22A	18	13,15/16	Damp	-	Dolerite
EMA22B	24	14/15	0.55	0.55	Dolerite
EMA23	48	30/31,33/36,44	0.9,5.8,6.0	12.7	Granitic-gneiss/dolerite/pegmatite
EMA24	36	Seepage	Seepage	Seepage	Granitic-gneiss/dolerite
EMA25	24	4,7	2,6	7.3	Granitic-gneiss
EMA26	30	8.0	0.2	0.2	Granitic-gneiss/dolerite
EMA27	12	Seepage	Seepage	Seepage	Dolerite

Five boreholes were submitted to test pumping and the results are summarised in Table 7.

Table 7: Summarised Test Pumping Results of Case study II

Borehole No.	**Observation Boreholes**	**Test Yield (l/s)**	**Remarks**
EMA16	EMA15,EMA17,PPMB04	1.5	Drawdown at all monitoring boreholes
EMA17	EMA15,EMA16,SRK	0.45	Drawdown at monitoring boreholes EMA15,16
EMA21	EMA23	0.3	No interference
EMA23	EMA14,EMA19,EMA21,EMA22B,PPMBO5	10	Drawdown at all monitoring boreholes
EMA25	EMA20A,EMA20B,EMA20D,EMA20E,EMA24, EMA26,EMA27,PGSM3	3.6	Drawdown at all monitoring boreholes

CHAPTER 3: Description of Study Area

3.1. Introduction and Site Background

The area on investigation is situated on the PIC and Foskor is currently one of the world's leading phosphate (approximately 95% of South Africa's production) and phosphoric acid producers. It started out as a single mining company during1953, mining phosphate at the western side of Loolekop and ceased operations in 1966.

In 1957 Rio Tinto and New Mont Mining formed the Phalaborwa Mining Company LTD (PMC). PMC started mining the Loolekop carbonatite - foskorite complex prelimarry for copper in 1966. Foskor had to move there mining activities to the northern pyroxenite ore body (NPM).

In 1979 Foskor and PMC reached an agreement for PMC to extend their open cast mining and Foskor would receive certain quantities of ore, which was dumped and stockpiled. This made the mining of the NPM unnecessary and mining ceased in 1980.

Foskor currently operates an opencast mine (NPM - reopened in the nineties) and recovers foskorite ore from surface stockpiles in order to extract and beneficiates phosphate ore at a rate of approximately 26 million tonnes per annum.

About 75% of the annual production of 2.5 million tonnes of phosphate rock is transported by rail to Foskor's Richards Bay Plant for processing and export as phosphoric acid. The remainder is transported to various domestic consumers.

Foskor also produces small quantities of copper concentrate from its Phalaborwa operations. This generates a further, secondary income stream for the organization (Hanekom et al.,1965).

3.2. Location and Drainage

3.2.1. Location

The Foskor Pyroxenite Mine study area is located 6 km south of Phalaborwa and falls onto the 2331CC 1:50 000 topographical sheet. The study area falls within Quaternary catchment B72k within the Lepelle River (formerly the Olifants River Catchment) Catchment and within the Ga-Selati River Sub-catchment. The Foskor Pyroxenite Mine is situated in the Lowveld region of the Limpopo Province as indicated in Figure 17.

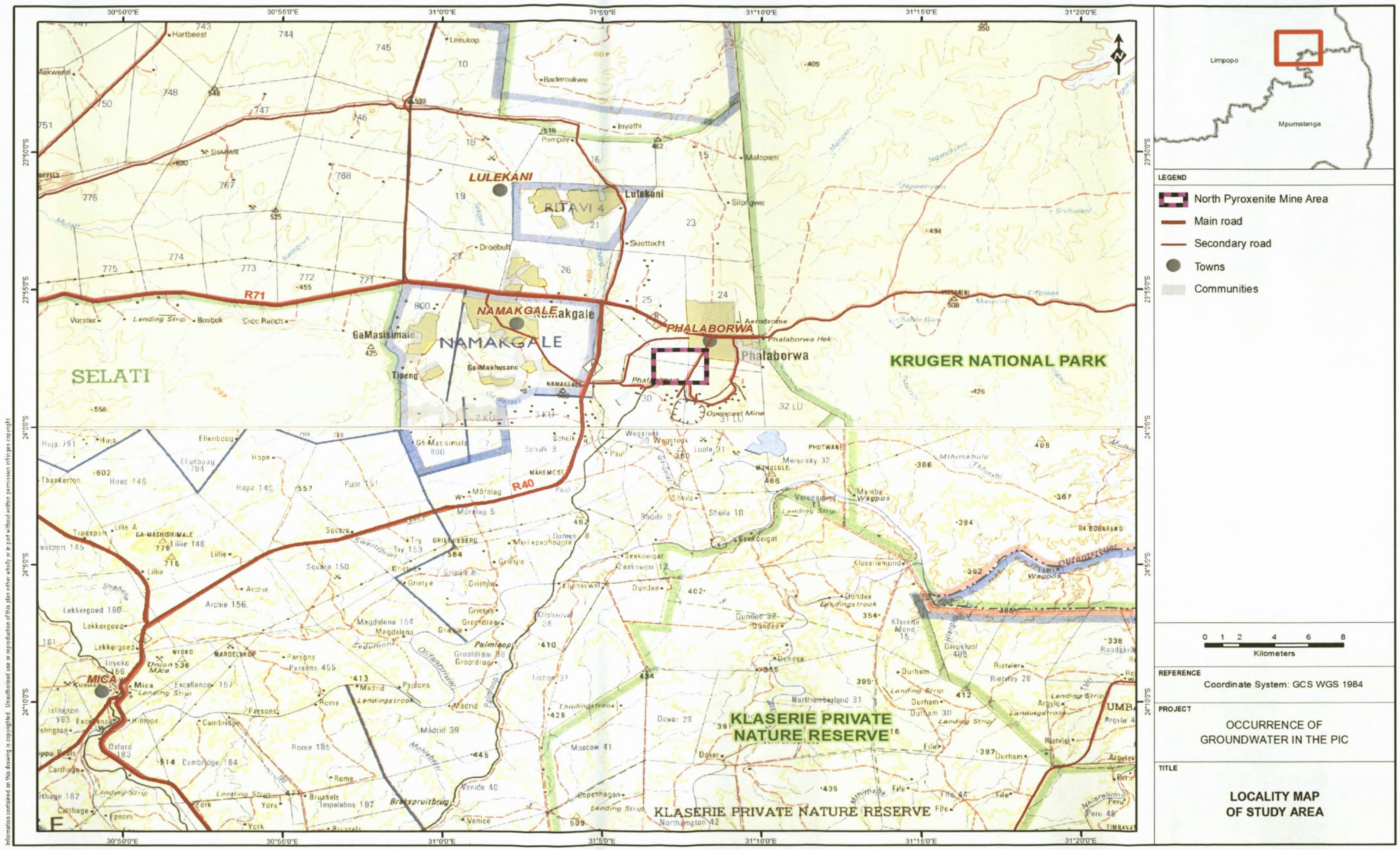


Figure 17: Locality Map of Study Area

3.2.2. Drainage

The study area is located in Lower Olifants hydrological area situated in the Lowveld region and is part of the bigger Olifants River Basin currently referred to as the Lepelle River Basin. The Olifants River Basin is located in the northeastern corner of South Africa and southern Mozambique (Figure 18). The bulk of the basin lies in Limpopo and Mpumalanga Provinces, with a small portion in Gauteng Province. The rivers flows from southwest to northeast and, upon leaving South Africa, enters Mozambique and joins the Limpopo river before discharging into the Indian Ocean about 200 km north of the capital Maputo.

The basin is divided into five hydrological areas usually regrouped in four ecological regions (Figure 18):

- The Upper Olifants which correspond to the Highveld region;
- The Upper Middle and Lower Middle Olifants represent the Middleveld region;
- The Steelpoort basin assimilated to the Mountain area; and
- the Lower Olifants situated in the Lowveld region

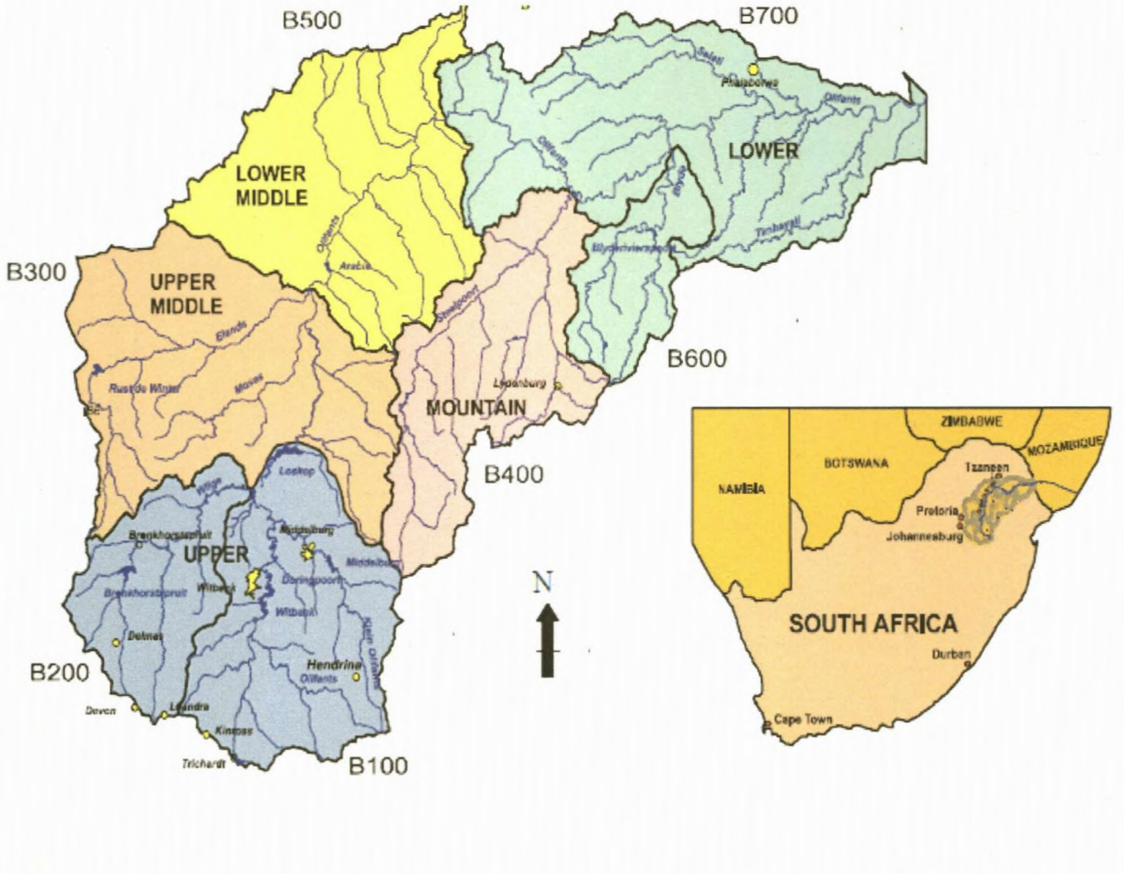


Figure 18: Main Hydrological Systems of the Olifants Basin (Mc Cartney, 2003)

The Lowveld region is approximately 360 m above sea level and is drained by the Olifants and the Ga-Selati Rivers. These rivers flow slowly eastwards at a gradient of 3 m per kilometre. The Olifants River is about 770 kilometers long and together with its tributaries drains 73,534 km^2. The main tributaries of the Olifants River Basin are indicated in Figure 19.

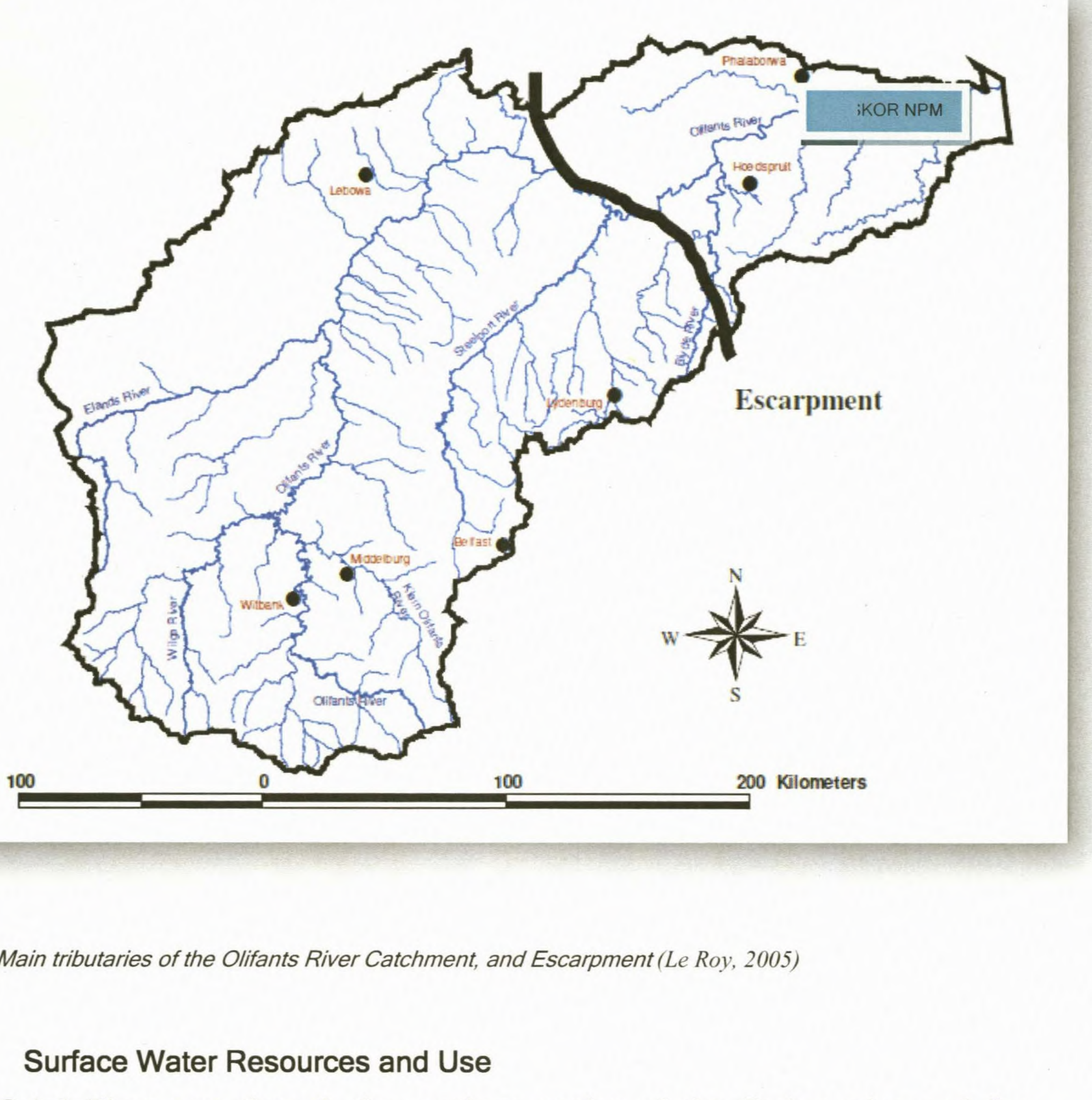


Figure 19: Main tributaries of the Olifants River Catchment, and Escarpment (Le Roy, 2005)

3.2.2.1. Surface Water Resources and Use

The Ga-Selati River runs through the southern portion of the Foskor mine and lies approximately 800 m from the proposed new NSPP.

The flowing together of the Ga-Selati River with the Olifants (Lepelle River) River is situated approximately 5 km downstream of Foskor's Selati Tailings Dam. Upstream of Foskor, Sasol Nitro used to operate a fertilizer production plant and associated waste facilities which have been closed down in 2010.

The lower Ga-Selati River above the confluence with the Olifants River flows in a south-easterly direction. The Ga-Selati River bed is incised into the shallow bedrock, which is often exposed in the form of outcrops. This shows evidence that flow in this river has been far higher than its current levels suggest.

Shallow mobile sand beds cover the outcrops in places. Surface flow upstream of the Foskor site in the Ga-Selati River bed during dry periods is very low.

The water authority for the area is the Limpopo Province Department of Water Affairs (DWA).

The key surface water users downstream of the Foskor mine site are shown in Table 8.

Table 8: Key water users downstream of the Foskor site

User	Quantity (m^3/d)	User
Kruger National Park	Unknown	Domestic and tourism use, and conservation of natural water environment
Klaserie game farms	Unknown	Drinking water for wildlife
Mozambique	Unknown	Domestic and irrigation use

3.3. Topography

Phalaborwa is situated in the Lowveld region of the Limpopo Province between the Drakensberg escarpment and the Lebombo Mountains, on the eastern border of the province. The Altitude of the bigger Olifants River basin is indicated in Figure 20. The Lowveld area lies at approximately 360 metres above sea level to the east of the escarpment.

The area is characterised by the typically flat to gentle undulating Bushveld landscape, densely covered with trees and shrubs. In the vicinity of Phalaborwa the Bushveld landscape is broken by the appearance of unevenly spread conical shaped syenitic hills, rising 50 m to 90m above the Bushveld landscape.

In the vicinity of the Foskor and PMC mines, the natural topography of the environment is altered considerably as a result of the development of open-cast mines, waste dumps, ore stockpiles and tailings dams. The two mining companies mine infrastructure cover an area of approximately 5 000 hectares. These dumps and dams are generally higher and much larger in volume than the conically shaped hills from the original environment. The natural surface gradient is in a southerly direction at about 1 m per 150 m.

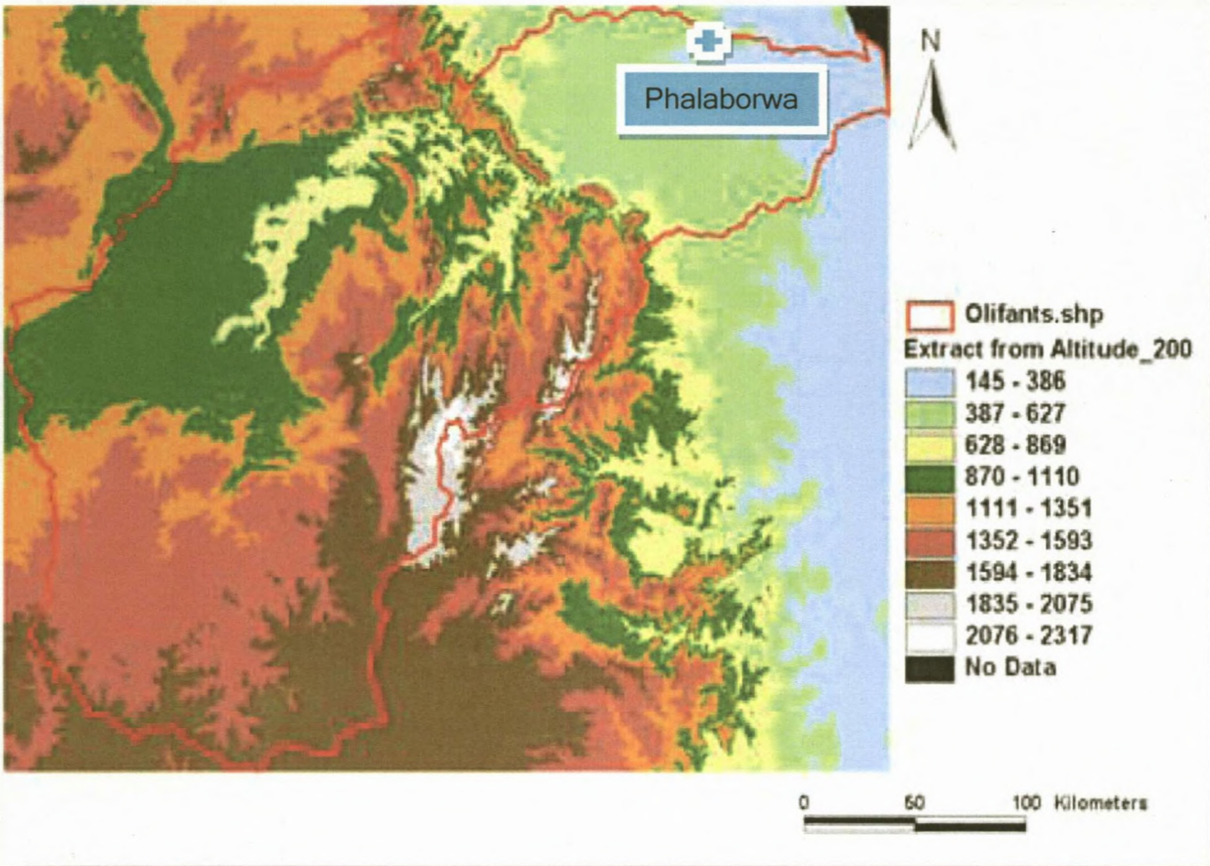


Figure 20: Altitude Map of the Olifants River Basin (From iwmi.org/library/benchmark, 1/18/2008))

3.4. Climate

The Phalaborwa area is situated in the Limpopo Province Lowveld Climatic Zone (Schulze, 1994), experiences typical subtropical, summer rainfall climatic conditions with hot summers and relatively warm winters.

The area can experience periods of high humidity, particularly in the first half of the year. The humidity averages between 80 and 85% from January to June and reduces to between 76 and 80% for the remainder of the year. Maximums of 97% have been recorded.

3.4.1. Temperature

The daily temperatures at Phalaborwa range from 18 to 30°C in summer and from 8 to 23°C in winter. Temperature extremes range from 43°C in summer and 2°C in winter.

Mean monthly temperatures at Foskor mine are listed in Table 9 and is graphically represented in Figure 21 from 1960 to 2008.

Table 9: Mean Monthly Temperatures (Minimum and Maximum) for Foskor mine from 1960 - 2006 (From Foskor (Pty) Ltd)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min (°C)	20	20	19	17	13	10	10	12	14	17	19	20
Max (°C)	32	31	31	29	28	25	25	27	28	31	31	31

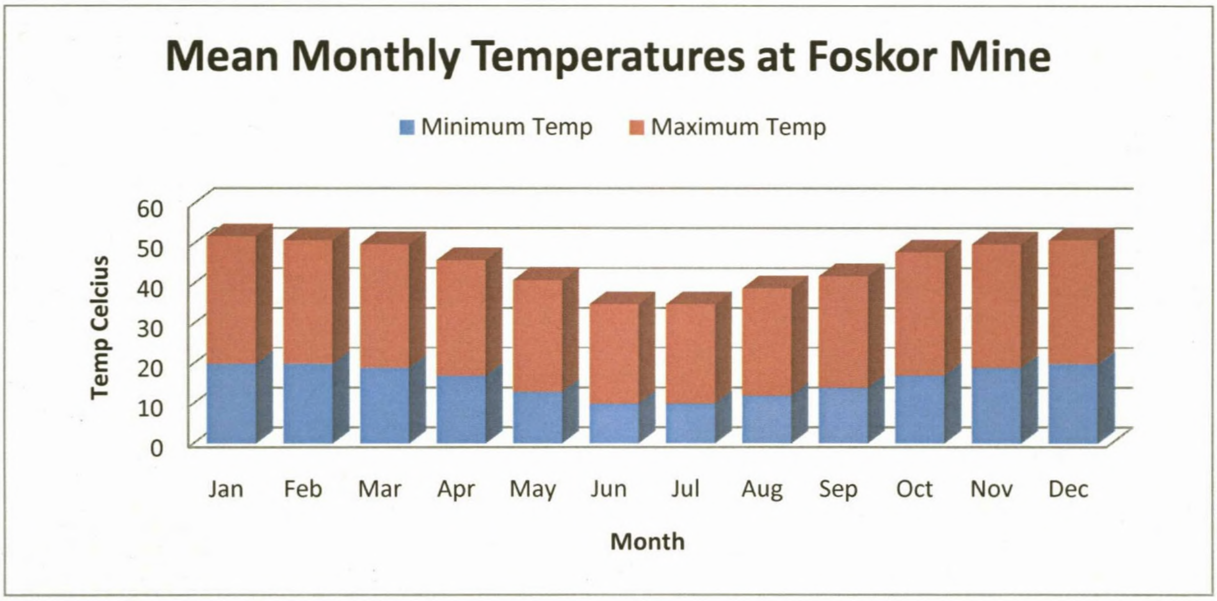


Figure 21: Mean Monthly Temperatures at Foskor Mine (1960-2006) (From Foskor (Pty) Ltd)

3.4.2. Rainfall

The study area is part of the Olifants River Catchment with the mean annual rainfall ranging from 300 mm/ annum to as high as 2000 mm /annum over the escarpment (Figure 22).

The study area is characterised by relatively low seasonal rainfall and the mean annual rainfall is 528 mm per annum. The rainfall varies from 250 mm to 700 mm per annum in low-lying areas and rapidly increases up to 2000 mm per annum with an increase in altitude in the escarpment region of the Lowveld. The number of rainy days ranges from 63 days per year over low-lying land to over 120 days per year against the escarpment.

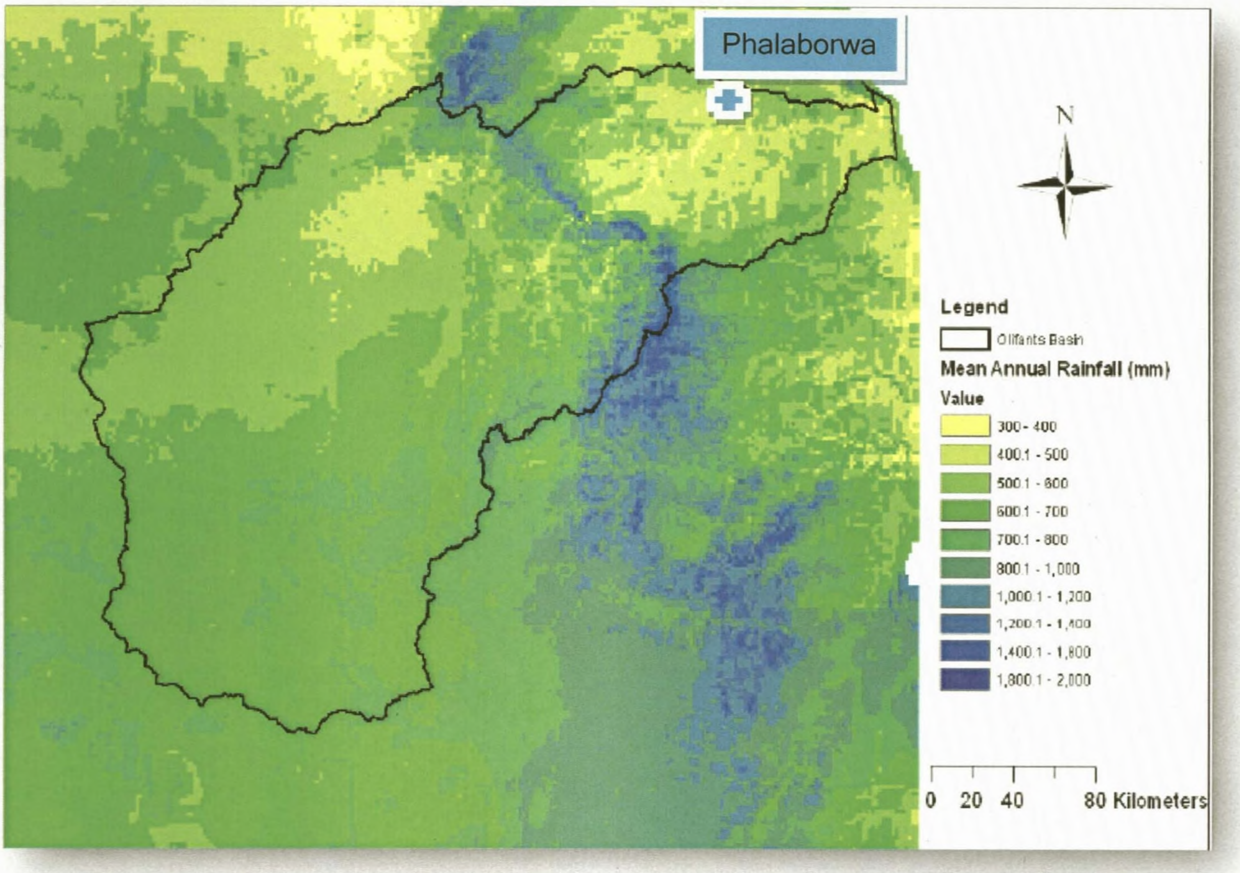


Figure 22: Mean annual precipitation (mm) across the Olifants catchment (Le Roy, 2005)

Rainfall in the area is in the form of thunderstorms and heavy showers in the mornings or early evenings, with hail occurrence uncommon.

The rainfall season is from November to March, with the maximum rainfall during December and January. The mean annual rainfall is approximately 528 mm per annum. The average rainfall at the Foskor mine is summarised in Table 10 and indicated graphically in Figure 23 for the period 1967-2006.

Table 10: Average Precipitation for Period 1967 to 2006. (From Foskor (Pty) Ltd)

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1967 - 2006	94	86	60	30	11	7	6	6	16	37	69	94	528

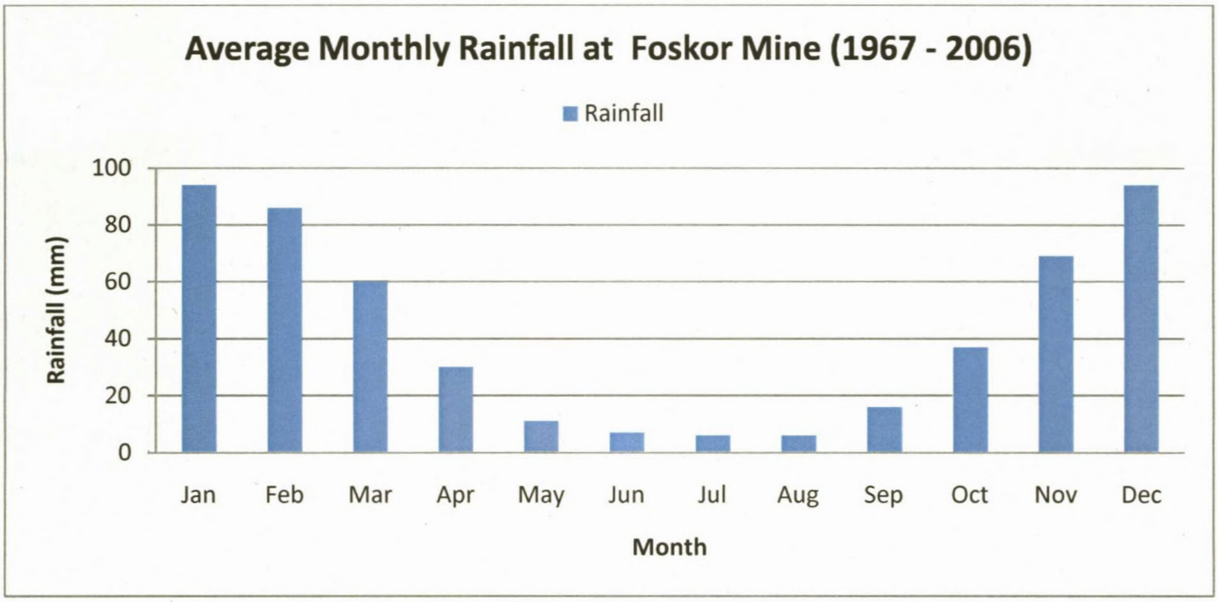


Figure 23: Average Monthly Rainfall at Foskor Mine (1967 - 2006) (From Foskor (Pty) Ltd)

The mean monthly rainfall distribution of three rainfall stations in the Olifants River Basin is indicated in Figure 24.

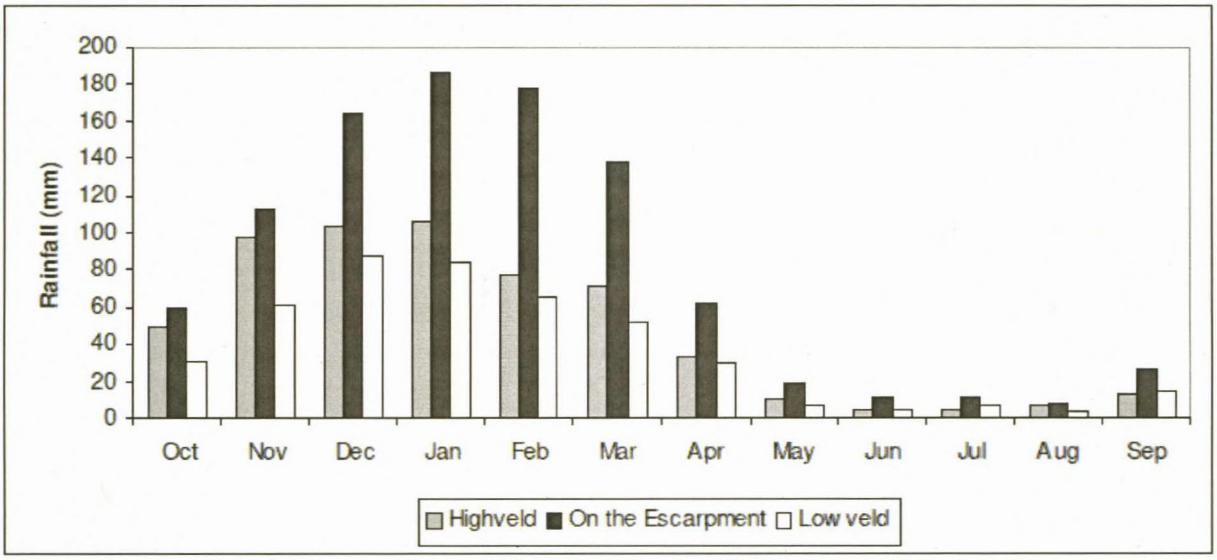


Figure 24: Mean Monthly Precipitation at three rainfall stations in the Olifants River Catchment (Le Roy, 2005)

3.4.3. Wind

The predominant wind direction at Phalaborwa is from a south-easterly direction for approximately 70% of the time. Wind speeds are lower in winter than in summer. Over 60% of the wind speeds experienced at Phalaborwa are between 1.1 and 3.5 m/s, with an average of 29% of the time experiencing calm conditions. Wind gusts up to 10 m/s have been recorded at the Palabora Mine Station, but on average, winds in the area do not exceed 8 m/s. On a diurnal basis, maximum wind speeds occur at night in all seasons.

3.4.4. Evaporation

Evaporation at Phalaborwa during the summer months is very high, with a total evaporation annually averaging approximately 1550 mm. The average monthly evaporation for the Phalaborwa Weather Station is shown in Table 11 and Figure 25. The lowest evaporation occurs in June with highest during October to January.

Table 11: Average monthly evaporation in mm noted at the Phalaborwa Weather Station (Golder Report No. 10113/8185/5)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
(mm/month)	159	137	134	108	93	75	83	113	146	173	163	166	**1550**

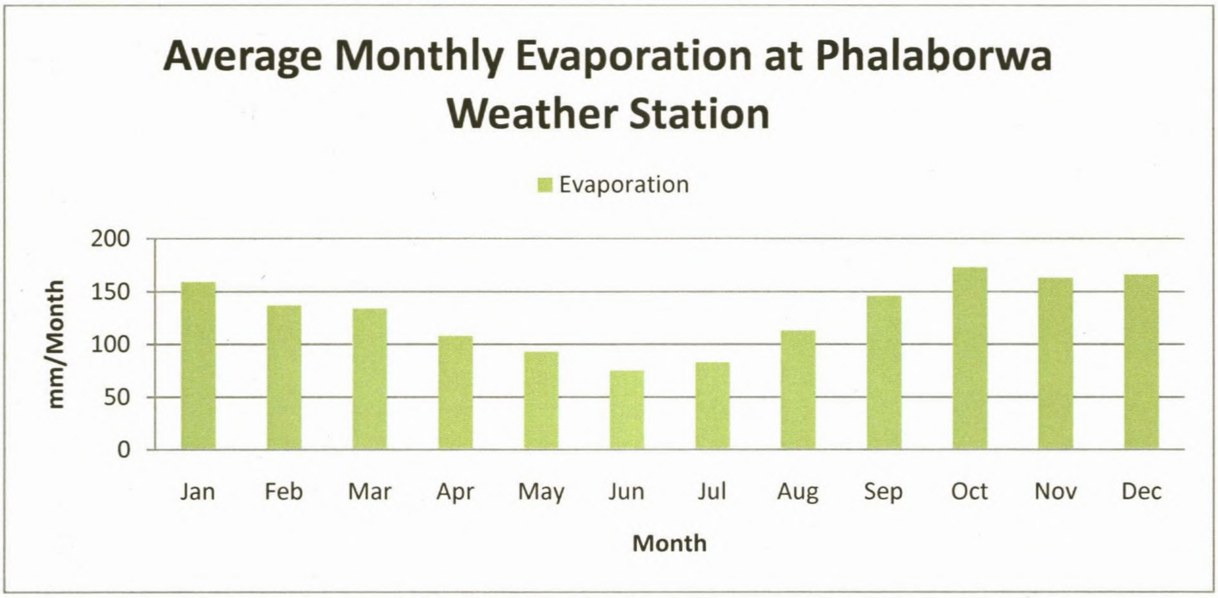


Figure 25: Average Monthly Evaporation at Phalaborwa Weather Station (From Foskor (Pty) Ltd)

Evaporation is by far the largest water consumer in the Olifants River Catchment and range from 1600 mm to 2600 mm (measured by A-pan) over the Olifants River catchment area *Figure 26*. The evaporation in the Olifants River catchment is higher to the north and west of the catchment and decrease to the south east. The lowest evaporation is over the escarpment area (1600 mm)

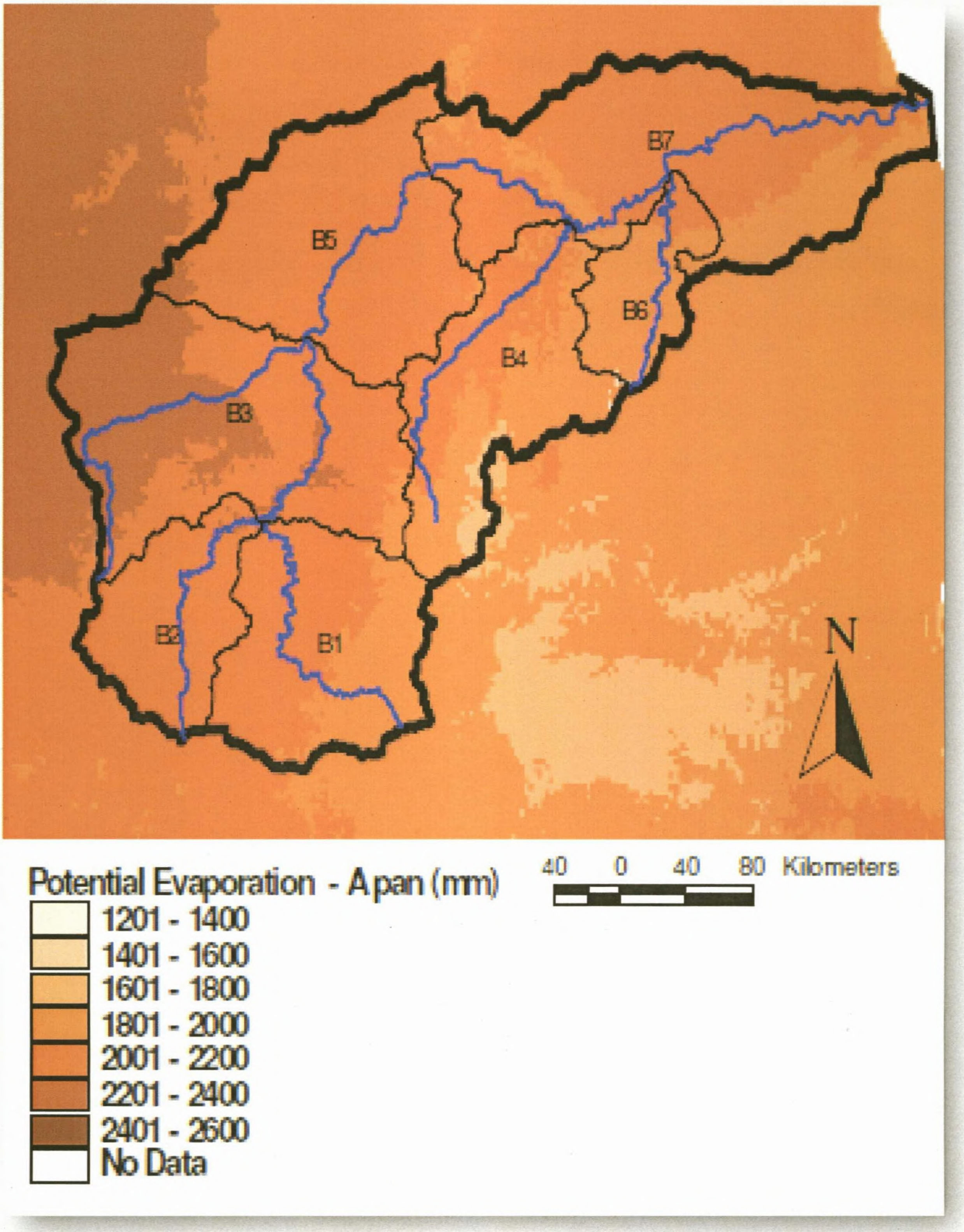


Figure 26: Mean annual A-pan potential evaporation for the Olifants catchment. (Le Roy, 2005)

CHAPTER 4: Geology and Hydrogeology

4.1. Regional Geology

The PIC (Phalaborwa Igneous Complex) is approximately two billion years old and is of the Proterozoic age. The PIC is intruded in Archaean granite and gneiss as indicated in Figure 27.

The Archaean rocks comprises out of biotite granite-gneiss, coarse grained quartz-feldspar rocks, porphyritic granite and fine grained aplitic granite. In some rock varieties muscovite is predominant. The major rock types of the Phalaborwa area is listed in Table 12 (Hanekom et al.,1965).

Table 12: Major Rock Types of the Phalaborwa Area

Age	Complex	Rock Type	Description
Mesozoic		Dolerite	
Proterozoic	Phalaborwa Igneous Complex	Transgressive carbonatite	
		Banded carbonatite	
		Phoscorite	
		Fenite	Altered from granite-gneiss
		Pegmatoid	Serpentine (olivine) - phlogophite vermiculite rock
		Feldspatic pyroxenite	
		Syenite	
		Pyroxenite	
	Archaean Complex	Granite and gneiss	
		Serpentine talc and amphibole schist	

Foliation is normally well developed in the bulk of the granite-gneiss, with an east west strike direction. The regional dip of the gneiss in the area surrounding Phalaborwa is steep towards the south often near vertical.

South of Phalaborwa along the Olifants river basin large scale of pegmatite intrusions is found in the granite-gneiss. In the Phalaborwa region plug like syenite intrusions predominate, with xenoliths of highly metamorphosed serpentine talc, talc tremolite and amphibole schist which occur in the granite-gneiss at a number of places.

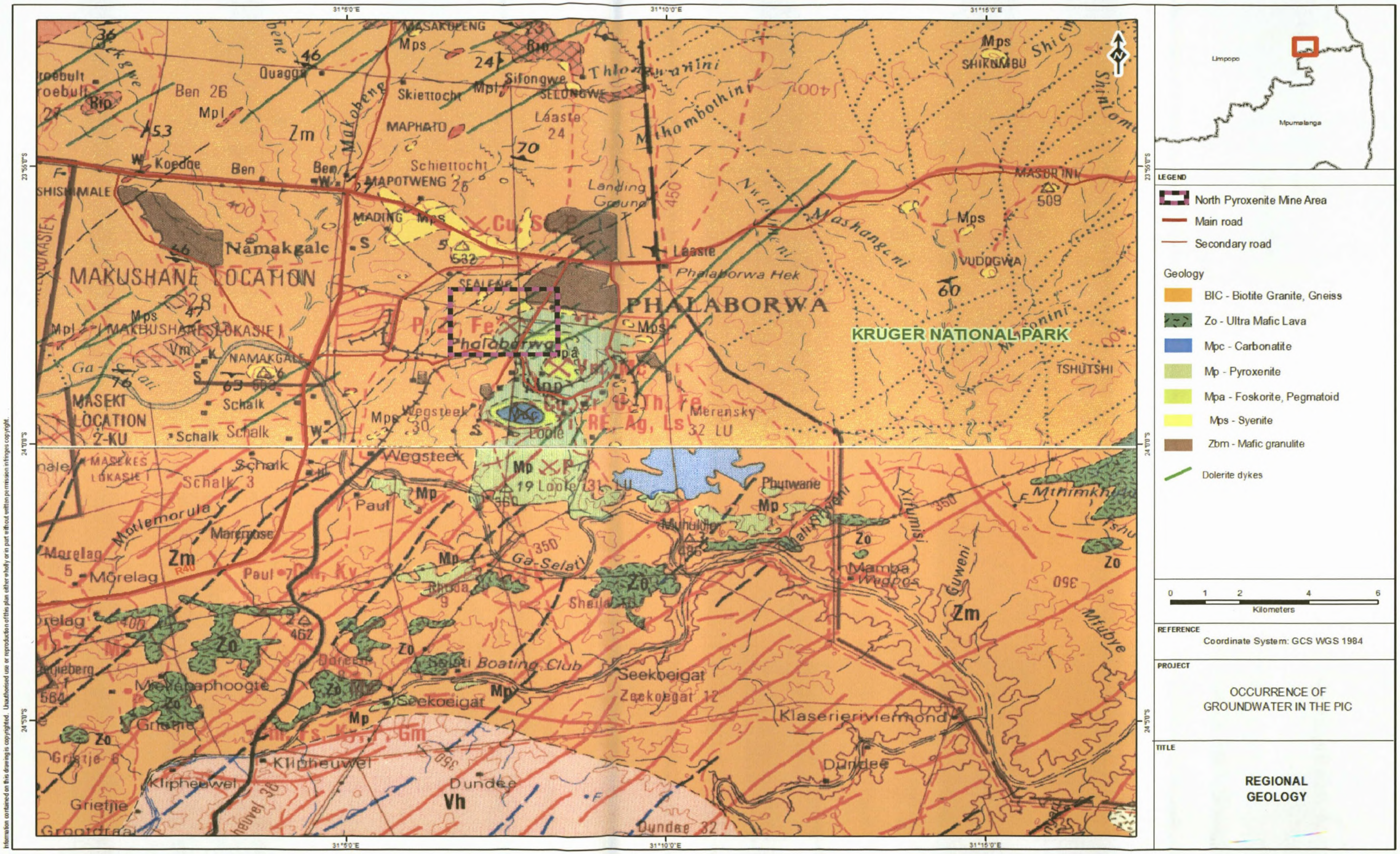


Figure 27: Regional Geology Map

Regional Geology (Continue)

Syenitic rocks are intrusive in the Archaean Complex. These isolated plug resembling bodies, occasionally also occur as ring dykes form prominent mount hills throughout the granite area.

The Syenite intrusions were preceded by the emplacement of differentiated suite of mafic rocks. These mafic intrusions were in the form of pipe like bodies, with each successive intrusion into the preceding one. This gave rise to the zonal distribution of pyroxenite, the pegmatoid bodies and the carbonatite which represents the central bodies of the PIC.

The pyroxenite is the most wide spread of the mafic intrusions and occupies the boundary portion of the PIC.

The PIC is kidney shaped in appearance, 6.5 kilometres in length in a north-south direction and 1.5 to 3.5 kilometres wide in an east-west direction.

Three pegmatoid bodies developed inside the pyroxenite body. One body to the north and one to the south of Loole kop and the third developed as a broad circular belt, enveloping the carbonite centre at Loole kop. Based on the zonal distribution of distinct mineralization in these pegmatoid bodies they are subdivided in to inner and outer zones.

The three coalescing and concentrically zoned lobes designated as the Nothern Pyroxenite, Loolekop and Southern Pyroxenite, positions were confirmed with deep diamond drilled boreholes which have shown that the contacts and mineral banding is essential vertical, and that the geological features as well as the extent of the mineralization are continuously to a depth of at least a 1000 m (Roux et al.,1989).

4.1.1. Dolerite Dykes

After emplacement and consolidation of the PIC members, extensive intrusion of Karoo age dolerite took place in the form of transgressive dykes. The strike direction of the dolerite dykes remains constant in a northeast direction, although they cut trough rock types of various compositions and texture.

The thickness of the dolerite dykes various from less than a centimetre to 45 m. Individual dykes tend to divide, with the dyke offshoots converging with nearby parallel dykes. Frequently some of the dolerite dykes with a 6 m thickness pinch out completely over a distance of 60 to a 100 m, whereas other dykes can be traced for long distances along their strike direction.

Because of greater susceptibility to erosion of the dolerite compared to most of the other rock types, selective weathering caused a complete decomposition and surface disappearance of dolerite dyke outcrops along large sections of the strike direction, essentially where cutting through granite-gneiss and syenite. Dry water courses have developed along the strike direction of many of these dolerite dykes, and appear as vegetation poor linear features on aerial photos and satellite imagery.

There is a clear contact zone between dolerite and other rock types (Figure 28), and chill zones are frequently developed along the margins of the dyke.

Figure 28: Dolerite Dyke Contact Zone with Host Rock in the NPM

Jointing of the dolerite is normally in a block like (Figure 29) nature and mainly in two directions, parallel and perpendicular to the strike direction and in both instances vertical or near vertical.

The regional geology of the area forms part of the Archaean granite-gneiss formation and controls most of the landscape features such as landform, soil, topography and vegetation.

Figure 29: Block like Jointing of Dolerite Dykes

4.2. Phalaborwa Igneous Complex-Geology

The geology of the PIC is illustrated in Figure 30 and the geology of the two phosphate mining pits is discussed as the NSPP and NPM below.

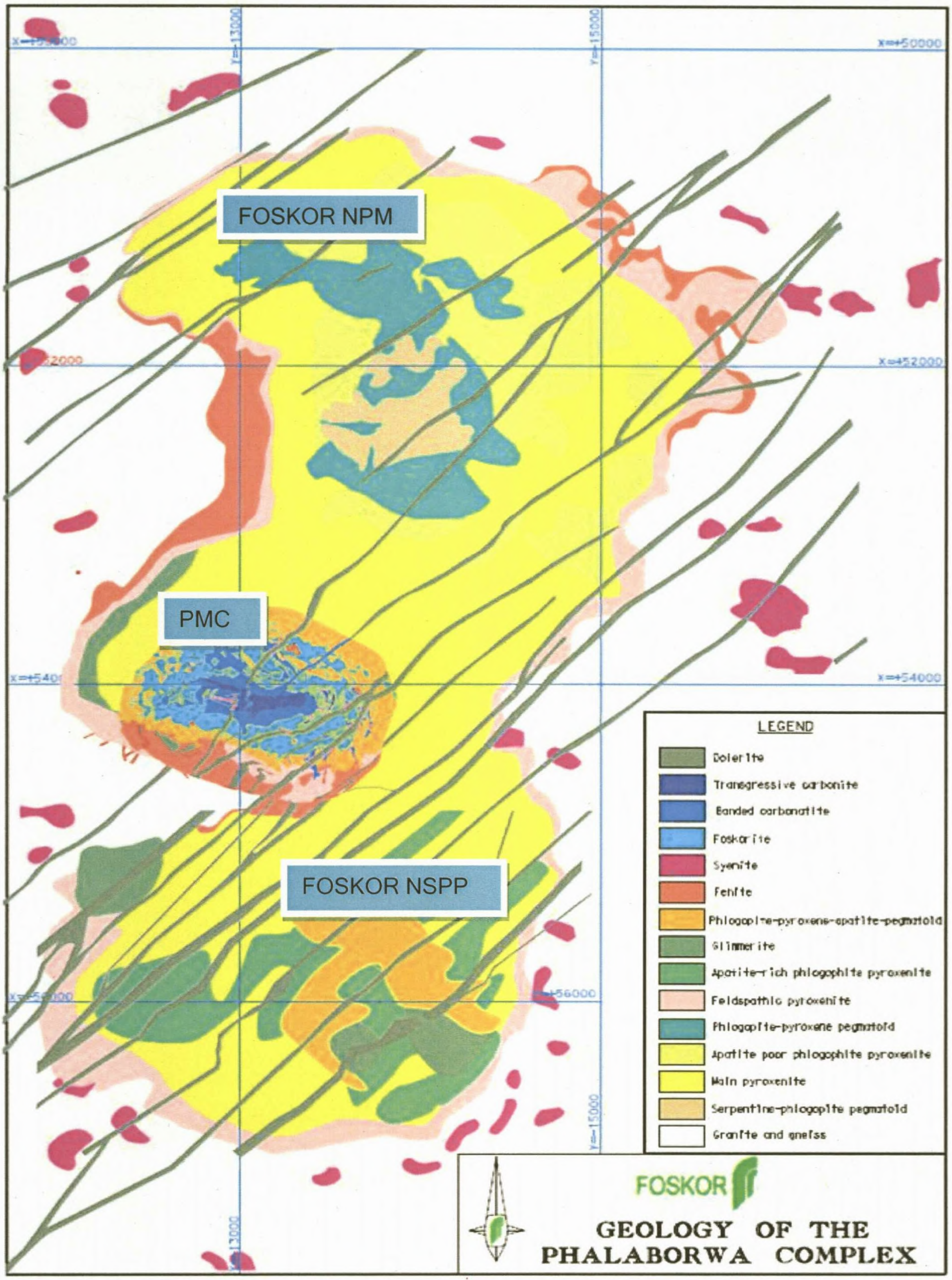


Figure 30: Geology of the Phalaborwa Igneous Complex (From Foskor (Pty) Ltd)

4.2.1. NSPP Geology

The NSPP investigation area form part of the Phalaborwa Igneous Complex, which was intruded into granite gneiss of the Basement Complex (Figure 31). The pit comprises pegmatoid surrounded by micaceous pyroxenite. The granite gneiss and the formation of the Phalaborwa Igneous Complex were intruded by dolerite dykes with a characteristic SW-NE direction of strike. According to Jasper Muller & Associates (1996) and E. Martinelli & Associates (1999), the dolerite dykes are permeable at shallow depths but become hard and impermeable at greater depths, giving rise to compartmentalisation of the Phalaborwa aquifer indicated in Figure 31.

The granite-gneiss is generally weathered to depths less than 20 m while the pegmatoid can be weathered to depths exceeding 40 m. Deeper fracturing and weathering are associated with the contact zones of the dolerite dykes that also act as preferential groundwater flow paths, due to enhanced permeabilities.

The pyroxenitic rocks consist of feldspathic pyroxenite, pyroxene phlogopite pegmatoid, massive pyroxenite and glimmerite.

Swarms of Karoo age dolerite dykes with a constant north-east to south-west strike direction intruded all the other rock types.

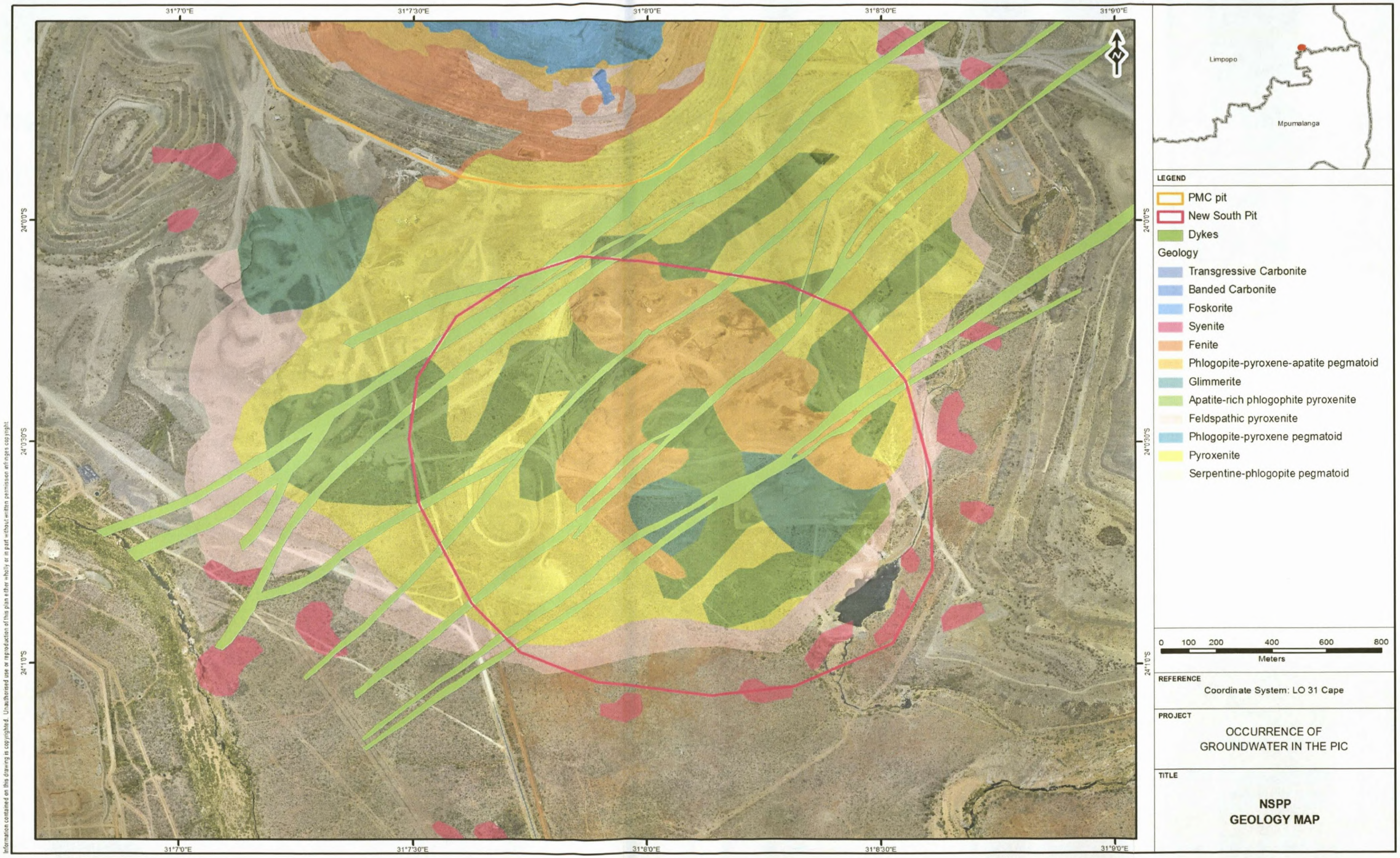


Figure 31: NSPP Geology Map

4.2.2. NPM Geology

The formation of the NPM is part of the Phalaborwa Igneous Complex was intruded into granite-gneiss lithology of the Basement Complex. The greater part of the complex (+/- 95%) consists out of pyroxenite zones containing varying proportions of pyroxene (diopside), phlogophite and apatite. The pyroxenite exhibits a large variation in grain size and is usually medium to coarse grained, but when it becomes coarse grained it is described as pegmatoid.

The northern pyroxenite pit consists out of phlogophitic and micaceous pyroxenite. Massive pyroxenite occurs to the south east of the pit, with pegmatoid deposits to the south western side of the mining area. The granite-gneiss and the Phalaborwa Igneous Complex formation were intruded by dolerite dykes with a prevailing SW-NE direction of strike.

The granite-gneiss is generally weathered to depths less than 20m while the pegmatoid can be weathered to depths exceeding 40m. Deeper fracturing and weathering is associated with the contact zones of the dolerite dykes that also act as preferential groundwater flow paths, due to enhanced permeabilities.

A north south striking fault zone occurs in the northern pyroxenite pit having displaced the dolerite dykes at the fault intersection. Figure 32 represents the geology of the NPM pit at 420 mamsl.

The pyroxenitic rocks of the PEP pit consist of feldspathic pyroxenite, pyroxene phlogopite pegmatoid, massive pyroxenite and glimmerite.

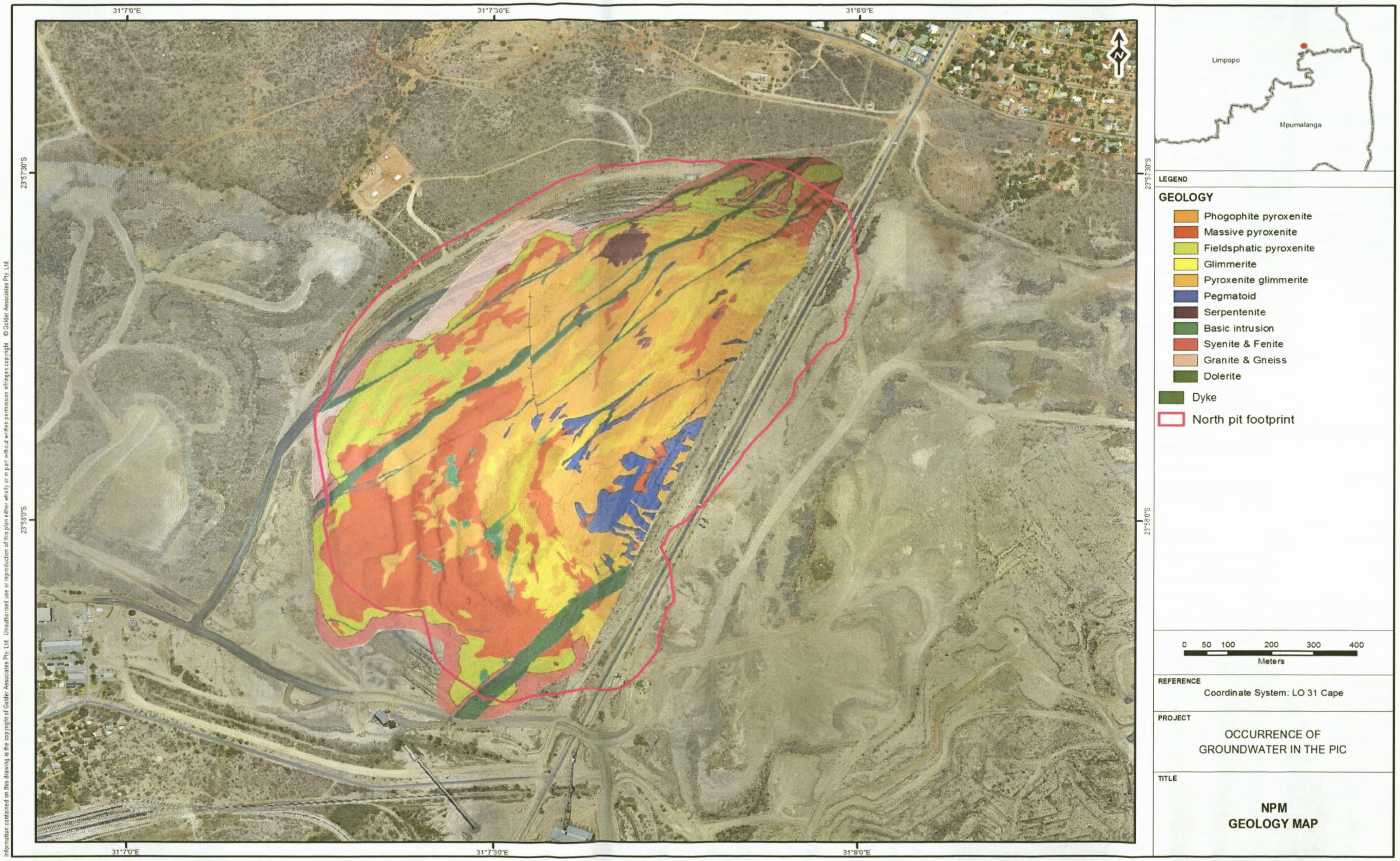


Figure 32: NPM Geology Map

4.3. Hydrogeology

4.3.1. Aquifer systems

An aquifer is a water bearing layer in the subsurface of the earth's crust. These characteristics vary according to porosity and permeability. Porosity is the percentage of open space in a rock. Permeability is the degree to which a rock allows the transmission of fluids through these pore spaces. Aquifers are divided in to two main categories (Figure 33):

I. Primary aquifer systems; and

II. Secondary or fractured aquifer systems.

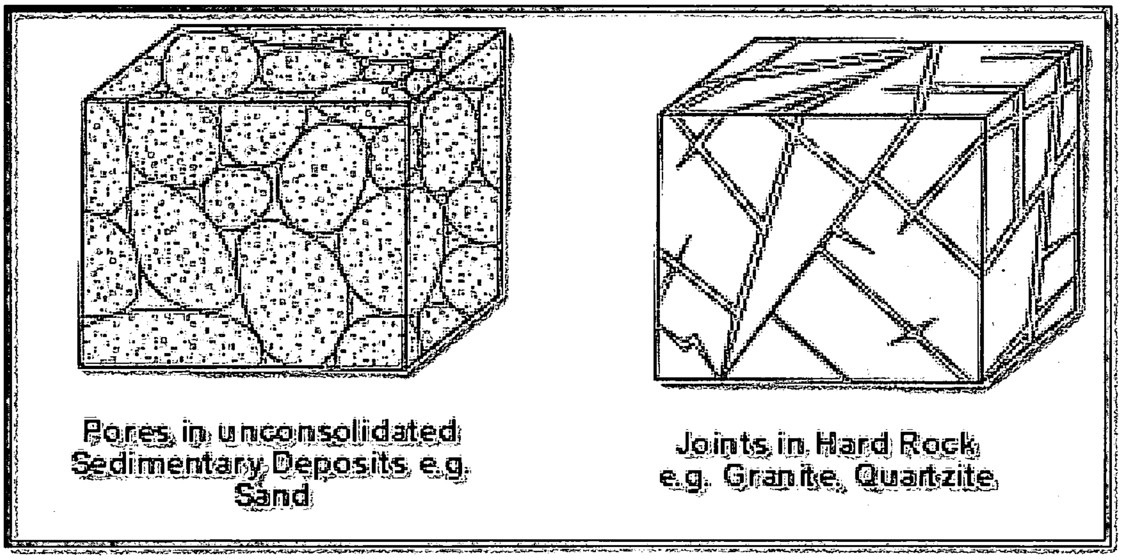


Figure 33: Primary and Secondary Aquifer Systems (From TMG Deep Aquifer Pilot Project.mht)

4.3.1.1. Primary aquifer systems

Aquifers in which water moves through the integranular spaces formed at the same time as the geological formation. These types of formation are mostly alluvial sand, gravels and coastal sands.

4.3.1.2. Secondary or fractured aquifer systems

The openings in these formations, through which groundwater moves were formed after the host rock was formed. The secondary opening formed as a result of weathering, fracturing, faulting and dissolution. The study area is classified as a secondary aquifer system resulting from faulting, fracturing and weathering in the Phalaborwa Igneous Complex.

Aquifers can further be classified into three main types of aquifers although complex combinations of the different types also exist:

- The confined (or artesian) aquifer(secondary aquifer)(Figure 34);
- The unconfined/water table (or free, phreatic) aquifer (primary aquifer or secondary) (Figure 34); and
- The semi-confined (leaky) aquifer (secondary aquifer).

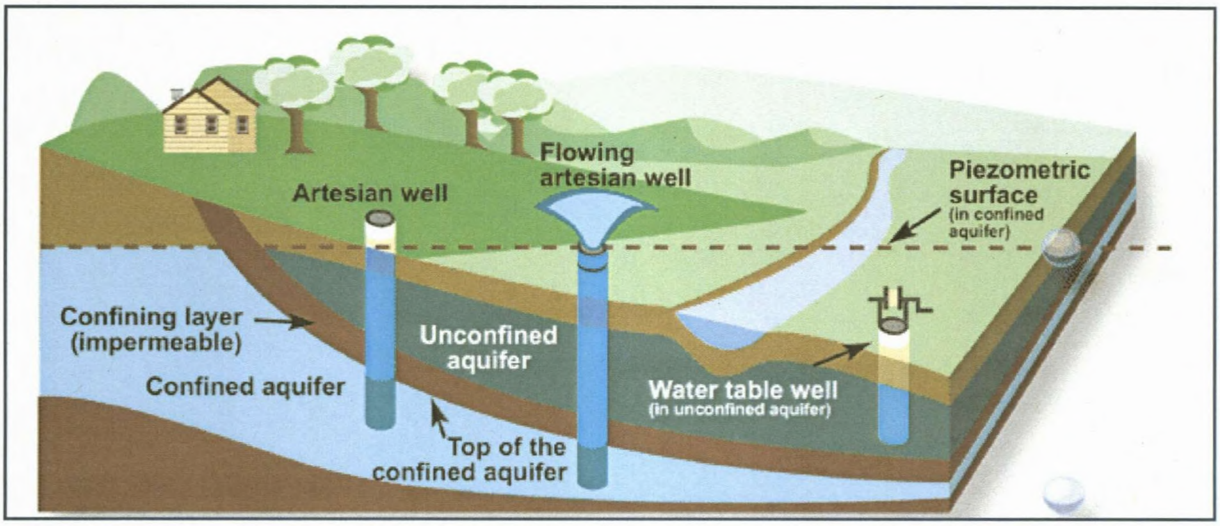


Figure 34: Unconfined and Confined Aquifer Systems (from Internet USGS, Water Science for Schools)

4.3.1.3. Confined (artesian) aquifer system

A formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric. A confined aquifer (Figure 35) has its upper and lower boundaries marked by aquicludes or confining beds and are fully filled with water which is usually under (artesian) pressure.

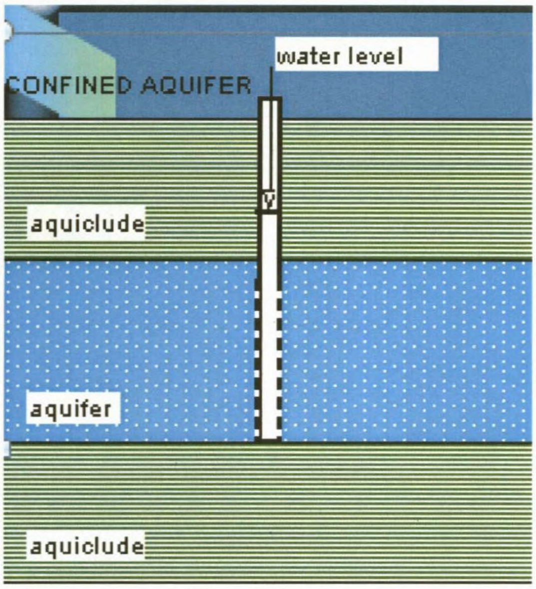


Figure 35: Confined Aquifer (IGS Lecture Notes 2009)

4.3.1.4. Unconfined (water table) aquifer system

This is an aquifer type where the water table is the upper boundary of the aquifer and with no confining layer between the water table and the ground surface (Figure 36). The water table is free to fluctuate up and down.

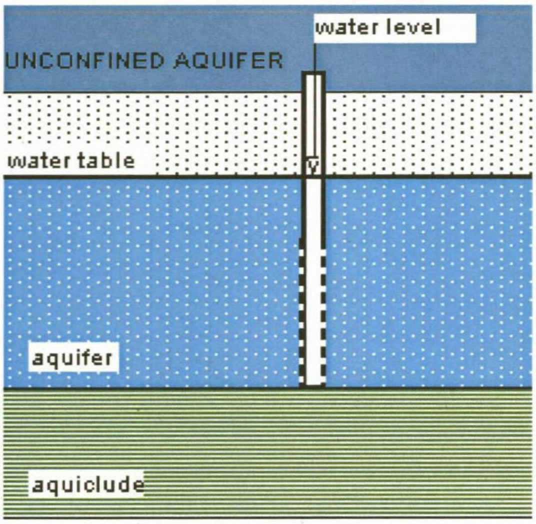


Figure 36: Unconfined Aquifer (IGS Lecture Notes 2009)

4.3.1.5. Semi confined aquifer system

Semi-confined and semi-unconfined aquifers are intermediate between confined and unconfined aquifers. Their confined character is often a result of the heterogeneous nature of the subsurface and has a piezometric surface rather than a water table. The aquifer is partly confined by layers of lower permeability material through which recharge and discharge may occur. These type of aquifers are also referred to as leaky aquifers (Figure 37).

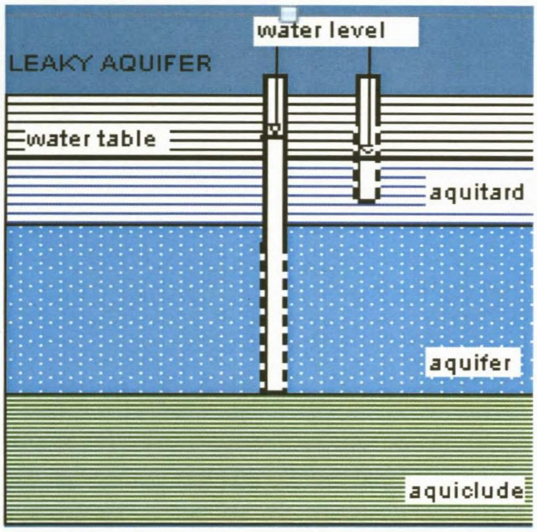


Figure 37: Leaky Aquifer (IGS Lecture Notes 2009)

4.3.2. Hydrology of Study Area

From the published hydrogeological maps (DWAF 1996) the average borehole yield for the investigation area is 1.5 l/s to 3.0 l/s. The probability of drilling a borehole with yield >2 l/s is 30% to 40% and for a drilling a successful borehole 40% to 60%. A successful borehole in the investigation area is taken as a borehole with a yield >0.1 l/s.

4.3.2.1. Aquifer Zones

Previous studies (case study I and II) confirm the presence of two known aquifers in the study area:

- A shallow weathered aquifer system associated with the weathered pyroxenite to a depth of 30 m; and
- A deeper fractured aquifer system associated with the contact zones of the dolerite dykes.

South-west and north-east striking dolerite dykes, act as preferred groundwater flow paths.

4.3.2.2. Groundwater Flow

The regional groundwater flow direction is to the south and south eastern direction towards the Ga-Selati River.

The water levels mimic the surface topography and flow is chiefly controlled by the dolerite dykes striking direction.

4.3.2.3. Groundwater Use

The surrounding land is mine-owned land. Apart from the abstraction boreholes within the NSPP area used by Foskor and PMC for dewatering and pollution control purposes, there are no other groundwater users.

4.3.2.4. Groundwater Quality

Foskor's groundwater quality monitoring network consists out of 69 monitoring boreholes, which are monitored mostly on a quarterly basis.

- The variables analysed quarterly for are: pH, EC, TDS, Ca, Na, Cl, SO_4, F, NO_3, Mg, K, Si, Total alkalinity,PO_4, NH_4, Cu, Fe, Mn, Ni, Se, Zn, Cd, and Pb.

- The groundwater contaminants of concern are calcium, magnesium, sulphate, fluoride and TDS.

- Groundwater monitoring records from Foskor and PMC are used as baseline water quality of the area.

CHAPTER 5: Hydrocensus and Geophysical Survey

5.1. Hydrocensus

5.1.1. Objective

A comprehensive hydro-census of the existing Foskor boreholes was completed of the Foskor premises from 30th May to the 1st of June 2009. The objective of the hydrocensus was to collect relevant and updated information of existing boreholes, which include the following information:

- Water levels;
- Borehole diameter and status;
- Construction where available;
- The height of the measuring point from ground level;
- GPS coordinates (WGS84 reference) and elevation; and
- Photographs of each located borehole.

5.1.2. Methodology

A total of thirty-two boreholes were surveyed within Foskor premises and the information is summarised in Table 13. Boreholes lying within the Phalaborwa Mining Company (PMC) premises were not surveyed due to logistical problems. Figure 38 indicates the position of the hydrocensus boreholes.

Water levels were measured by means of an electrical dip-meter and coordinates were measured with a hand held GPS in WGS-84 format. Other relevant information was documented and photographs were taken at each surveyed borehole.

Additional information for the boreholes, such as borehole depth and use of the boreholes, was supplied by Foskor.

Table 13: Hydrocensus Borehole Information

Borehole No	Latitude	Longitude	Elevation(m)	Depth (m)	Water level (mbgl)	Owner	Water use	Equipment	Condition of BH
KGM - B34	23.98857	31.11566	389	24.00	3.630	Foskor (PTY)Ltd	Monitoring	None	Capped
KGM - B44	23.98967	31.11421	385	30.00	1.250	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped
KGM - B28	24.00597	31.10949	390	Unknown	27.880	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped
KGM - B22	24.00761	31.09975	343	25.00	1.517	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B23	24.00856	31.10389	340	21.00	1.325	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B25	24.00856	31.10389	342	25.00	4.690	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B13	24.01194	31.09300	359	27.00	4.500	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B20	24.01556	31.08788	366	25.00	1.000	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B15	24.04255	31.08310	400	30.00	5.025	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B16	24.04325	31.10494	402	Unknown	Dry	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B18	24.04325	31.10494	374	25.00	11.155	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B1D	24.03669	31.11617	343	10.00	1.095	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B1A	24.03670	31.11620	343	10.00	0.220	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B1C	24.03671	31.11622	341	10.00	0.660	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B1B	24.03671	31.11616	341	10.00	Artesian	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B2	24.03652	31.11788	337	Unknown	0.190	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B17	24.03364	31.11596	345	20.00	2.080	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B4	24.02723	31.11755	331	20.00	3.305	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B3B	24.02754	31.11751	329	7.00	0.520	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B3A	24.02754	31.11751	330	7.00	1.210	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B3C	24.02754	31.11750	329	9.00	1.410	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B3D	24.02754	31.11751	329	7.00	0.950	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B5	24.02173	31.11534	338	20.00	1.210	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B6	24.01521	31.11185	341	10.00	Artesian	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B7	24.01430	31.11208	343	Unknown	1.895	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B9A	24.01215	31.10559	355	10.00	6.075	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B9B	24.01213	31.10537	355	10.00	5.260	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B9C	24.01200	31.10538	355	8.00	4.340	Foskor (PTY)Ltd	Monitoring	None	Metal Casing and Capped with padlock
KGM - B8	24.01110	31.10574	348	8.00	3.505	Foskor Mine	Monitoring	None	Metal Casing and Capped with padlock
KGM - B33	24.01454	31.12650	369	Unknown	23.570	Foskor Mine	Monitoring	None	Metal Casing and Capped with padlock
KGM - B11	24.01157	31.10353	364	10.00	0.895	Foskor Mine	Monitoring	None	Metal Casing and Capped with padlock
KGM - B10	24.01110	31.10373	338	25.00	0.670	Foskor Mine	Monitoring	None	Metal Casing and Capped with padlock

Figure 38: Hydrocensus Borehole Map

5.1.3. Results

The hydrocensus provide information on the depths of the existing boreholes, ranging from m 7 to 30m at Foskor and PMC side of the study area. All the existing monitoring boreholes were drilled in the shallow weathered aquifer system. These depths were used as a basis in constructing the new shallow and deep monitoring boreholes.

Deep monitoring boreholes were cased and sealed off to depths exceeding those of the existing and newly drilled shallow boreholes to ensure that possible links between shallow and deep water strikes were sealed off.

It also provides useful groundwater level information which was used to create a groundwater piezometric map of the PIC. The aim of the hydrocensus information in conjunction with the geophysical survey results were used to help understand the hydrogeological setting of the area of investigation.

5.1.4. Groundwater Monitoring System

Foskor's groundwater quality monitoring network consists out of 69 monitoring boreholes, (from which 32 were surveyed Figure 38) which are monitored mostly on a bi-annually or quarterly basis.

- The variables analysed quarterly for are: pH, EC, TDS, Ca, Na, Cl, SO_4, F, NO_3, Mg, K, Si, Total alkalinity,PO_4, NH_4, Cu, Fe, Mn, Ni, Se, Zn, Cd, and Pb.

- The groundwater contaminants of concern are calcium, magnesium, sulphate, fluoride and TDS.

5.2. Geophysical Survey

5.2.1. Objective

Applied geophysical techniques success relies on the presence of discontinuities or contrasts in the physical properties of materials or geology of the area. On this basis three different geophysical methods were selected to conduct the geophysical survey to select drilling targets for exploration and monitoring boreholes namely the:

- Magnetic method - contrast in the magnetic properties of earth materials;
- Electrical method - contrast in the electrical properties of earth materials; and
- Electromagnetic method - contrast in the electrical conductivities of earth materials.

The combined use of geophysical methods refines geological targets such as fault zones, dykes, fracture zones and deep weathering zones. See Figure 39 for data presentation example. It also limits lateral effects by power lines and man made structures and buried conductors.

A geophysical survey was conducted during May 2009 in order optimise the selection of drilling sites. The main objective was to investigate the dolerite dykes striking SW-NE in the vicinity of the new PEP pit. These geological structures act as preferential groundwater flow paths and form an important part of the water bearing features.

The target areas for the geophysical survey were the contact zones of the dolerite dykes with host rocks. The Survey focused around the region of the footprint of the new PEP pit to include targeted dolerite dyke in an up and downstream position of the proposed PEP pit.

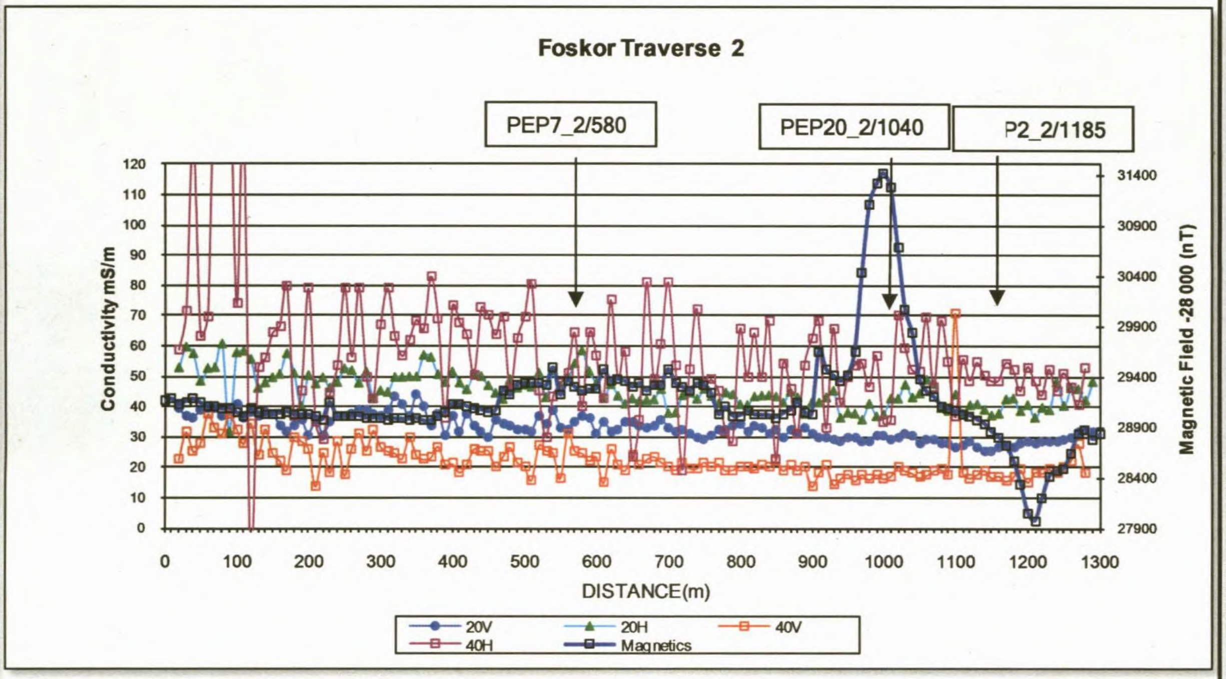
Traverse 5 was conducted next to the river to identified drilling targets and groundwater preferred path ways near the Selati River which could be linked with the pit.

5.2.2. Methodology

A total of eight geophysical traverses were conducted and comprised out of magnetic, electromagnetic and Earth Resistivity Imaging (ERI) methods. Mining activities restricted traverse positions to be completed along existing roads and protected flora and fauna areas were also inaccessible.

These traverses were conducted at 10 m station intervals, with all stations marked in the field and hand-held GPS was use to take coordinates at every 100 m intervals in WGS-84 format. Traverse positions are indicated on Figure 40 and geophysical traverse profiles are listed in Appendix A.

EM 34 and Magnometer



ABEM LUND 2D Resistivity Image

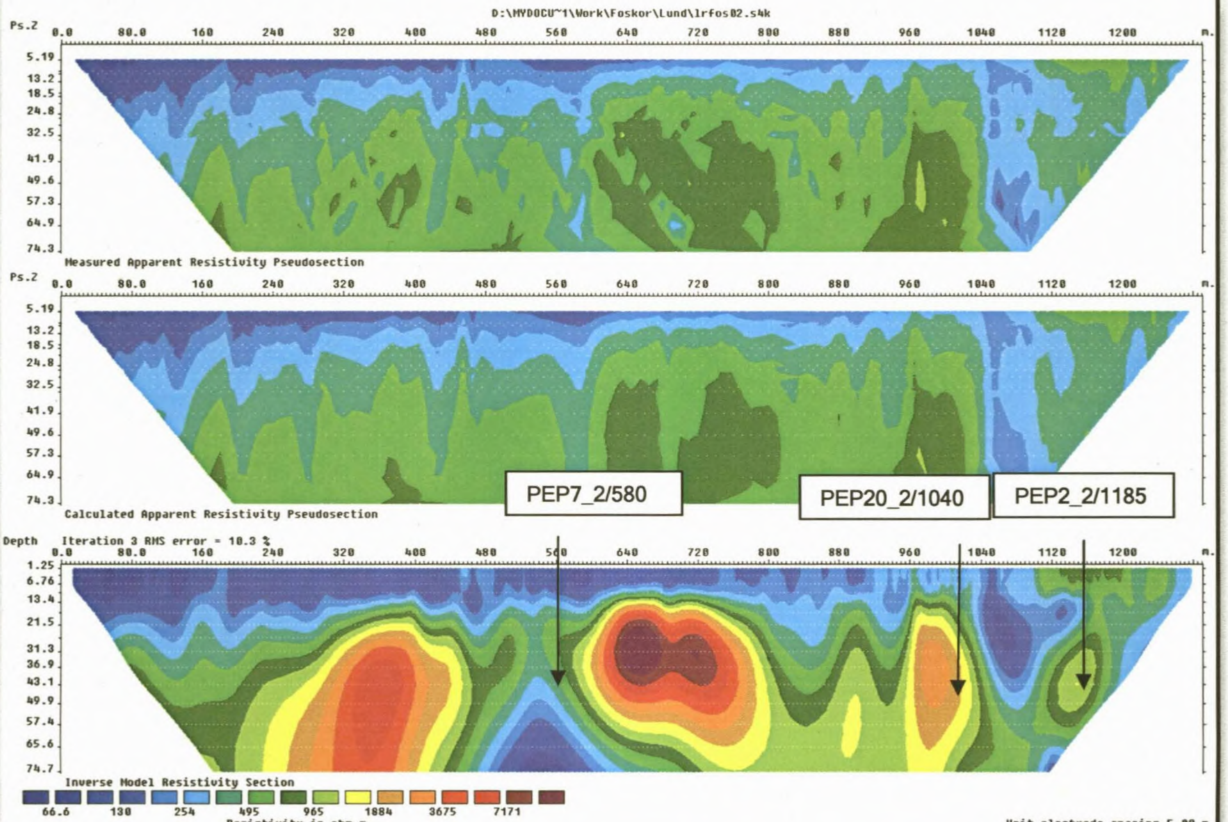


Figure 39: Example of Combined Geophysical Results - Traverse 2

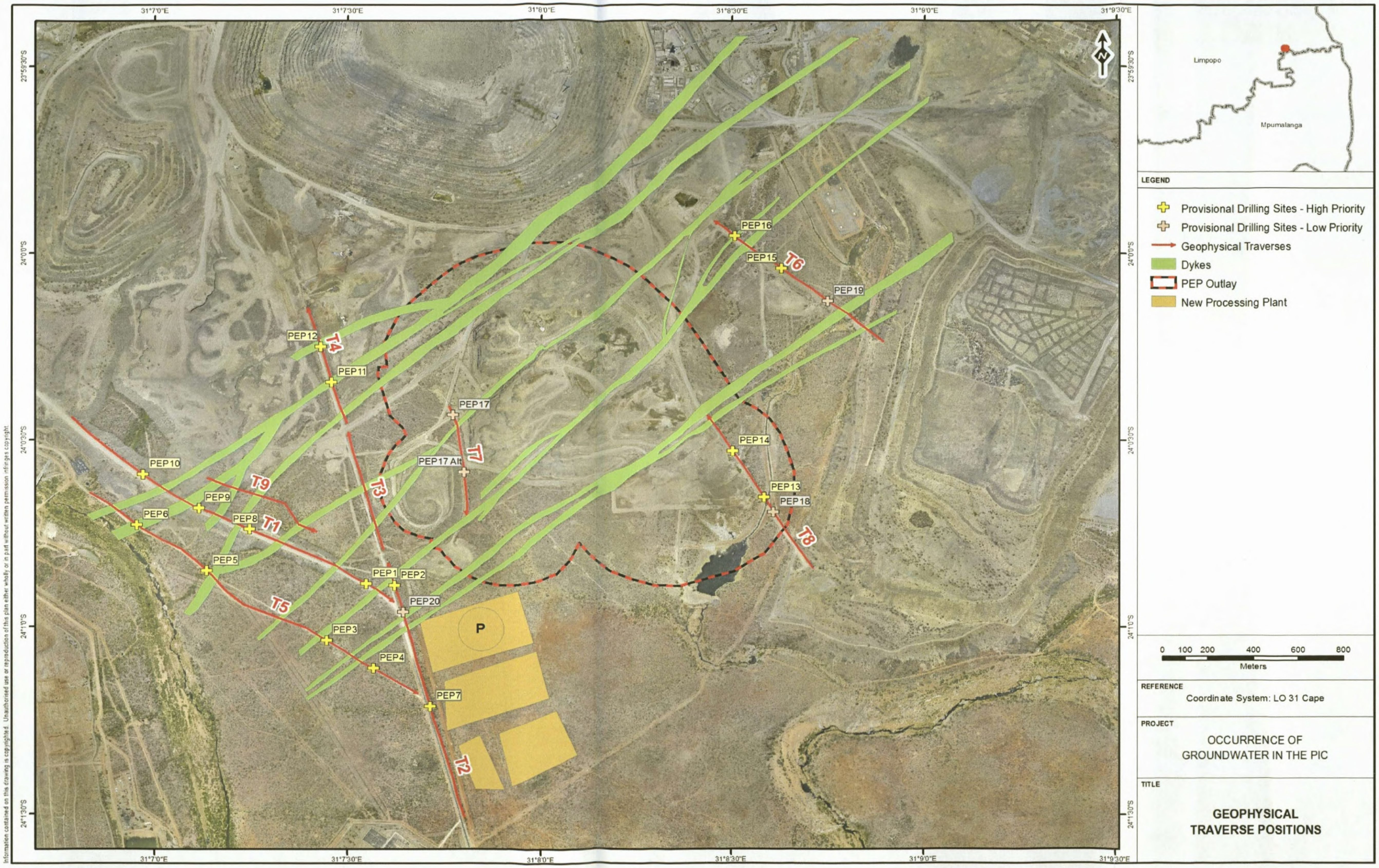


Figure 40: Geophysical Traverse Positions

5.2.3. Geophysical Methods

5.2.3.1. Magnetic Method

The aim of magnetic surveys is to investigate sub surface geology on the basis of anomalies in the earth's magnetic field resulting from the varying magnetic properties of underlying rocks. Different rock types have different magnetic susceptibilities, which may have remnant magnetism. The contrast in magnetic susceptibility and/or remnant magnetism gives rise to anomalies related to structures like intrusive dykes, faults, lithologic contacts and weathered/fractured bedrock. In groundwater investigations the total magnetic field is usually measured at 10-metre station intervals with a proton magnetometer.

Many rocks formations contain magnetic minerals. Measurements of the magnetic field in the vicinity of these rock formations show departures from the undisturbed earth's magnetic field, called anomalies. By measuring the magnetic field it is possible to locate and delineate formations that are anomalous in terms of their magnetic properties.

Magnetite, ilmenite, pyrrhotite and maghemite are the most important naturally occurring magnetic minerals and, of the three, magnetite is by far the most common and occurs in massive iron ores, banded ironstones, in various concentrations in igneous and metamorphic rocks, distributed through some sedimentary rocks. Hematite, the most abundant iron mineral, has a very small susceptibility and many iron ore deposits do not produce significant magnetic anomalies. Presence of magnetic minerals in rocks cause deviations in the earth's magnetic field which forms the basis of the magnetic prospecting method.

Eight magnetic traverses were conducted.The aim of magnetic surveys is to investigate sub surface geology on the basis of anomalies in the earth's magnetic field resulting from the varying magnetic properties of underlying rocks. Different rock types have different magnetic susceptibilities, which may have remnant magnetism. The contrast in magnetic susceptibility and/or remnant magnetism gives rise to anomalies related to structures like intrusive dykes, faults, litho logical contacts and weathered/fractured bedrock.

Structures targeted by the magnetic survey include SW-NE striking dolerite dykes around the new PEP pit area as well as next to the Selati River.

5.2.3.1.1. Applications of Magnetic Method

- Geological surveys for positions of dolerite dykes, sills and fault zones; and
- Hydrogeological studies.

5.2.3.2. Electromagnetic Method

The Geonics EM-34 is used for rapid measurements of terrain conductivity with a maximum effective penetration depth of 60 meters and will be applied in the geophysical survey. The transmitter coil is energized with an alternating current. The time-varying primary magnetic field arising from the alternating current induces very small currents in the earth. These currents generate a secondary magnetic field, which is measured by the receiver coil, together with the primary magnetic field. The EM-34 system utilises a transmitter coil and a receiver coil at specific designed operating frequencies, coil separations and orientations to directly measure apparent terrain conductivity in mS/m.

The EM-34 has the two coils flexibly connected. The coil spacing is measured electronically, which can be 10, 20 or 40 metres to directly vary the effective exploration depths as indicated in Table 14.

Table 14: Investigation depths of EM-34 coil configurations

Coil Spacing (m)	Investigation Depth (m)	
	Vertical Coils	Horizontal Coils
10	7.5	15
20	15	30
40	30	60

With the horizontal coil orientation the EM-34 system is effective in locating near vertical conductive (fracture) zones, provided conductor width is less than the coil separation. The associated EM-34 anomaly is typically a negative peak response (relative to background conductivities) centered above the fracture and flanked with two positive peaks. Background crossover, between negative and positive peaks, is a function of coil separation and generally equals to inter coil spacing. The detectability of fracture zones depends on their width, the thickness and conductivity of the overburden layer, the quality of the groundwater and the depth of the ground water level. See figure 3 for data presentation example.

Eight traverses were surveyed by means of the Geonics EM-34. The electromagnetic method was used for rapid measurements of terrain conductivity in milliSiemens/m (mS/m) with a maximum effective penetration depth of 60 meters. Vertical and horizontal coil orientation was used with a 20 m and 40 m coil separation. The EM-34 is applied for its effectiveness to detect remanent and non magnetic dykes and to determine the dip of dykes or geological structures.

5.2.3.2.1. Applications of electromagnetic method

- Measuring of terrain conductivity;
- Groundwater pollution studies; and
- To determine position of none magnetically geological structures.

5.2.3.3. Earth Resistivity Imaging Method

The electrical resistivity varies between different geological materials, dependent mainly on variations in water content and dissolved ions in the groundwater. Resistivity investigations thus are used to identify zones with different electrical properties, which can then be referred to different geological strata. Resistivity is also called specific resistance, which is the inverse of conductivity or specific conductance. The most common minerals forming soils and rocks have very high resistivity in a dry condition, and the resistivity of soils and rocks is therefore normally a function of the amount and quality of water in pore spaces and fractures. The degree of connection between the cavities is also important. Consequently, the variation may be more limited within a confined geological area and variations in resistivity within a certain soil or rock type will reflect variations in physical properties. For example:, the lowest resistivities encountered for sandstones and limestone's mean that the pore spaces in the rock are saturated with water, whereas the highest values represent strongly consolidated sedimentary rock or dry rock above the groundwater surface. Sand, gravel and sedimentary rock may also have very low resistivities, provided the pore spaces are saturated with saline water.

Fresh crystalline rock is highly resistive, apart from certain ore minerals, but weathering commonly produces highly conductive clay-rich saprolite. The variations in characteristics within one type of geological material makes it necessary to calibrate resistivity data against geological documentation, from for example surface mapping, test pits or drilling. However, this applies to all geophysical methods.

The degree of water saturation will of course affect the resistivity, and the resistivity above the groundwater level will be higher than below if the material is the same. Consequently, the method can be used for determination of the depth to groundwater where a distinct groundwater table exists. However, if the content of fine-grained material is significant the water content above the groundwater surface, held by hygroscopic and capillary forces, may be large enough to dominate the electrical behaviour of the material. The resistivity of the pore water is determined by the concentrations of ions in solution, the type of ions and the temperature. The presence of clay minerals strongly affects the resistivity of sediments and weathered rock. The clay minerals may be regarded as electrically conductive particles, which can absorb and release ions and water molecules on its surface through an ion exchange process (Parasnis, 1986).

Field survey procedures

An Abem SAS 1000 terrameter and ES 464 switching unit will be used for the field survey. Four multi core cables and stainless steel pegs were used with the "roll-along" surveying method. Using a 10 m electrode separation requires a multi core cable length of 400 meters. Measurement of the resistivity of the ground is carried out by transmitting a controlled current (I) between two electrodes pushed into the ground, while measuring the potential (V) between two other electrodes. Direct current (DC) or a very low frequency alternating current is used, and the method is often called DC-resistivity. The resistance (R) is calculated using Ohm's law.

The electrode separation and survey protocol used, determines the depth of investigation. The measuring protocols commonly used include Schlumberger and Wenner sounding methods. The major difference between the two arrays is that the potential electrodes remain fixed in location during the Schlumberger array, whereas all four electrodes are moved during the Wenner array. The effects of near-surface lateral variations in resistivity are reduced during Schlumberger array. See Figure 39 for a 2d resistivity data presentation example.

A total of seven traverses were conducted with the Abem Lund 2D resistivity system. Traverse 7 which falls into the foot print area was excluded from the ERI traverses. The electrical resistivity varies between different geological materials, dependent mainly on variations in water content and dissolved ions in the groundwater. Resistivity investigations are thus used to identify zones with different electrical properties, which can then be referred to different geological strata. Resistivity is also called specific resistance, which is the inverse of conductivity or specific conductance. The most common minerals forming soils and rocks have very high resistivity in a dry condition, and the resistivity of soils and rocks is therefore normally a function of the amount and quality of water in pore spaces and fractures.

The electrode separation and survey protocol used, determines the depth of investigation. The measuring protocols used were Schlumberger array with an investigation depth of 80m, using 100 meter cables with 10 meter spacing intervals.

The ERI pseudo sections were plotted with the RES2DINV software package. The pseudo sections were presented in Excel, together with the EM and magnetic profiles. Figure 41 shows field setup of ERI survey at the NPM pit perimeter.

5.2.3.3.1. Applications of earth resistivity system

- To determine different resistivity values of host rock up to certain depths; and
- Hydrogeological investigations.

Figure 41: ERI at NPM Pit Perimeter

5.3. Evaluation of Geophysical Results

Geophysical data were evaluated by plotting the data on linear graphs which are presented in Appendix A. The graphs permit a comparison of all three geophysical methods used, with drill sites indicated on these traverses.

A total of 20 proposed drilling sites were selected from the geophysical results (Figure 40). Different dolerite dykes and anomaly types were targeted in order to obtain an understanding of the groundwater behavior associated with the various dykes. Both sides of dolerite dykes were also targeted in order to investigate whether dolerite dykes act as groundwater barriers (PEP1 and PEP2). Drilling sites were also selected in order to investigate groundwater connectivity alongside dyke strike directions at PEP2 and PEP3. Drill sites were selected on a negative magnetic anomaly dyke and PEP9 and PEP11 on a positive magnetic anomaly dyke.

Drilling depths of up to 180 m were anticipated at selected sites in order to determine if groundwater decreases or is absent at depth. The geological model obtained from Foskor indicates the dolerite dykes are near vertical; this was confirmed by exploration drilling preformed by Foskor.

Traverse 1: Four drilling sites were selected at geophysical stations PEP10 1/420 m, PEP9 1/720 m, PEP8 1/980 m and PEP11 1/1565 m, targeting the dolerite dyke contact zones. PEP10 and PEP9 targeted two different positive magnetic anomaly dykes, whereas PEP8 and PEP1 targeted two different negative magnetic anomaly dykes.

Traverse 2: Three drilling sites were selected at stations PEP7 2/580, PEP20 2/1040 and PEP2 2/1185. PEP7 targeted a deep weathering zone identified by means of the ERI. PEP20 targeted the contact zone of a positive magnetic anomaly dyke and PEP2 targeted the contact zone of a negative magnetic anomaly dyke.

Traverse 3: No drilling sites were selected on this traverse.

Traverse 4: Drilling sites PEP11 4/205 and PEP12 4/400 both targeted dolerite dyke contact zones of positive magnetic anomaly dykes.

Traverse 5: Four drilling sites were selected on this traverse positioned next to the Selati River to the south of the study area. PEP6 5/280 was selected on a fracture zone on the edge of a dolerite dyke. PEP5 5/660 was selected on deep weathering on a dolerite dyke contact zone. PEP3 5/1320 targeted a negative magnetic anomaly dyke contact zone, whereas PEP4 5/1570 targeted the edge of a small dolerite dyke.

Traverse 6: Three drilling sites were selected on this traverse to the north east of the study area, PEP19 6/105, PEP15 6/370 and PEP16 6/620. PEP19 were selected on a deep weathered and fractured zone identified by the ERI. PEP15 targeted a deep conductive zone identified on the ERI. PEP16 was selected on contact zone of a dolerite dyke.

Traverse 7: This traverse falls in the proposed PEP pit area and was surveyed with EM-34 and magnetic methods. A drill site and an alternative was selected, PEP17 7/50 and PEP17Alt 7/330 were both selected on minor EM fracture anomalies.

Traverse 8: Three drilling sites were selected on this geophysical traverse PEP18 8/330, PEP13 8/415 and PEP14 8/690. PEP18 targeted a deep conductive zone identified on the ERI. PEP13 targeted a deep conductive zone associated with a dolerite dyke contact zone. At PEP14 the geological target was a deep weathered zone identified by means of the ERI and EM methods.

Traverse 9: Two drilling sites were selected on this magnetically geophysical traverse at PEP9D 9/40 and PEP9S 9/100. These two sites targeted two adjacent dolerite dyke contact zones.

CHAPTER 6: Drilling

6.1. Objective

The objective of the drilling was to investigate groundwater occurrence in terms of quantity, quality and depth.

A total of 36 monitoring boreholes were drilled (Figure 42) consisting out of 17 pairs of deep and shallow boreholes which were planned to confirm the presence of a shallow/perched aquifer (24 m to 40 m below surface) in the weathered zone, and to investigate for the presence of a deeper aquifer in the fracture zones of the Phalaborwa Igneous Complex.

Figure 42: Positions on Newly Drilled Boreholes

6.2. Methodology

The drilling programme was conducted from 17 September 2009 to 20 November 2009, under the supervision of a hydrogeologist. The drilling was conducted by means of two rotary air percussion drilling rigs (Figure 43).

Figure 43: Air Percussion Drilling Rig at NSSP

Technical specifications for drilling of boreholes were prepared, to ensure that borehole construction was suitable and to capitalise on drilling data collection. The drilling specification of the shallow monitoring boreholes is indicated in Figure 44 and for deep monitoring boreholes in Figure 45.

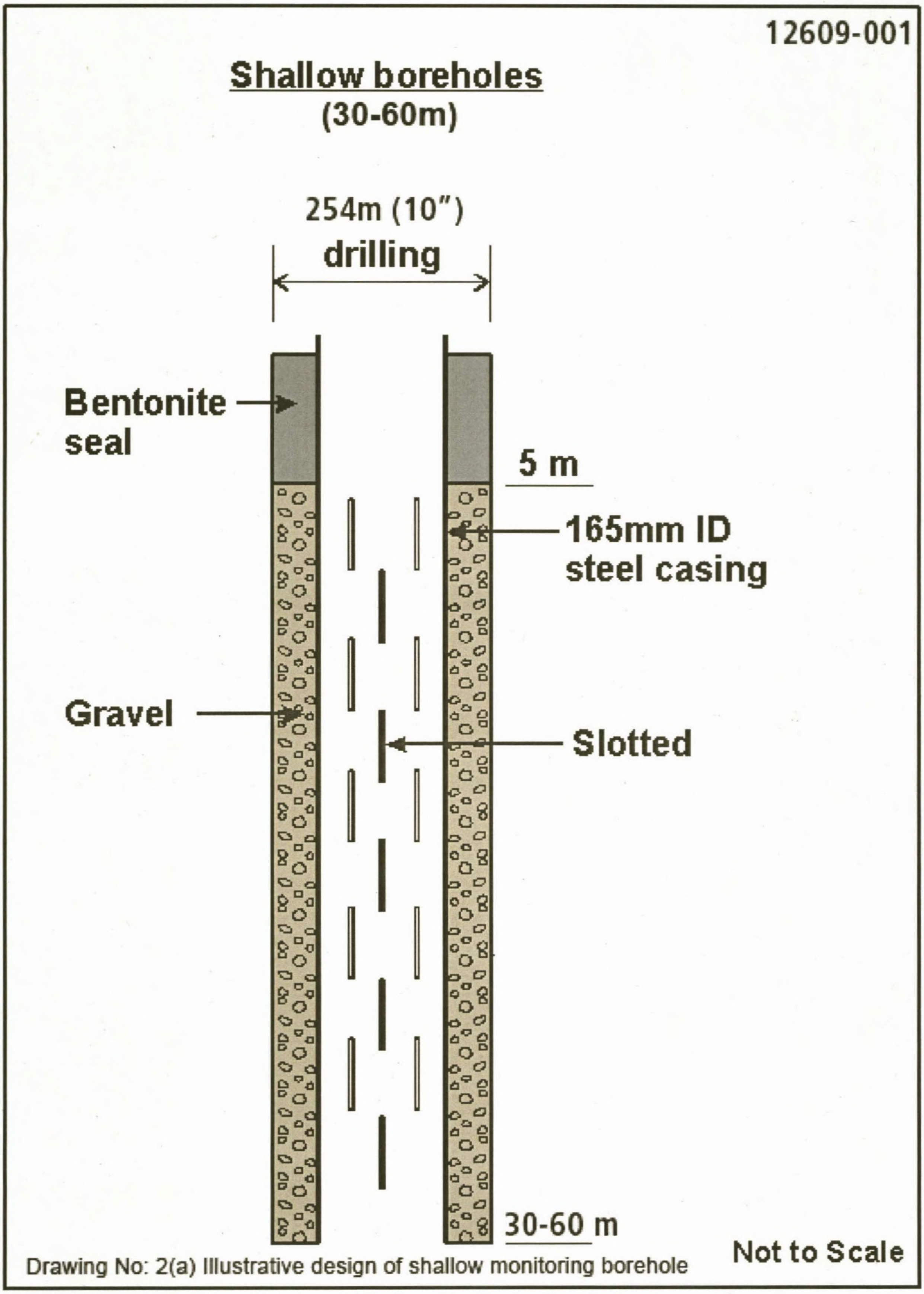


Figure 44: Technical Specification of Shallow Monitoring Borehole

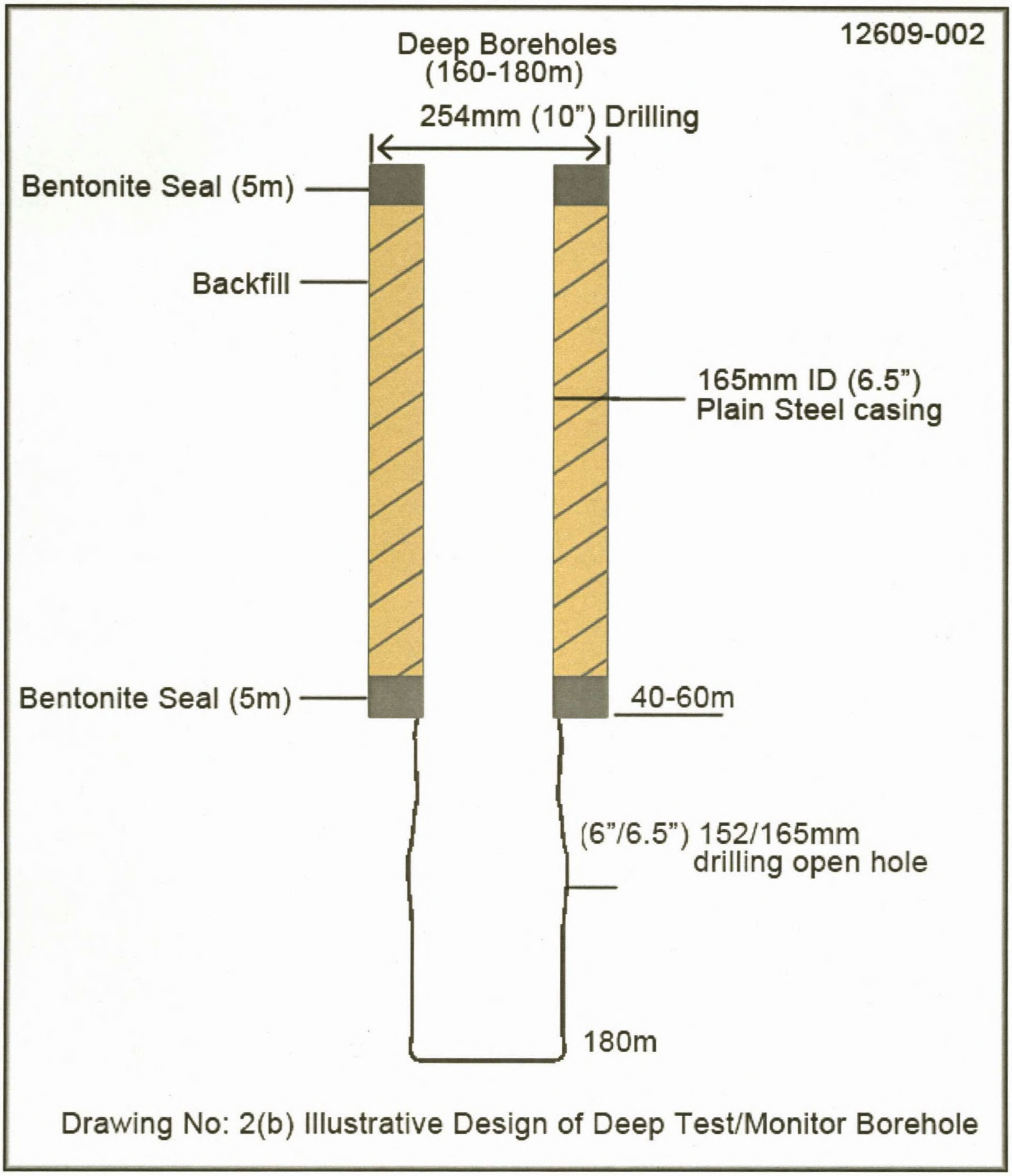


Figure 45: Technical Specification of Deep Monitoring Borehole

Sixteen pairs of boreholes (shallow and deep) were drilled on the proposed drilling sites, with two additional medium-depth boreholes, which were drilled at PEP10M and PEP8M where groundwater strikes were encountered at depths that could be used to obtain aquifer parameters form testing and/or monitoring. An additional pair of boreholes PEP17S/D was drilled on Traverse 5 next to the Selati River where a high yielding fracture zone was intersected. In total 36 testing/monitor boreholes were drilled. Borehole positions are indicated on Figure 42.

Shallow boreholes as illustrated in Figure 46 were drilled at 254 mm diameter and cased with 165 mm perforated steel casings. Shallow boreholes were gravel packed to stabilise the formation and allow groundwater flow into the boreholes.

The deep boreholes as illustrated in Figure 47 were drilled at 254 mm diameter up to depths exceeding the depths of the shallow monitoring boreholes, existing Foskor and PMC monitoring boreholes. Seals consisting out of a bentonite and cement mixture, ranging from 5 m to 6 m in thickness were effectively installed at the depth of these deep boreholes. The purpose of the bentonite seals were to case off of shallow water strikes in the deep boreholes and to establish if a deeper aquifer or groundwater occurrence exists and to minimise risk of cross contamination. Drilling was then continued at 165 mm diameter to investigate the occurrence of deeper groundwater.

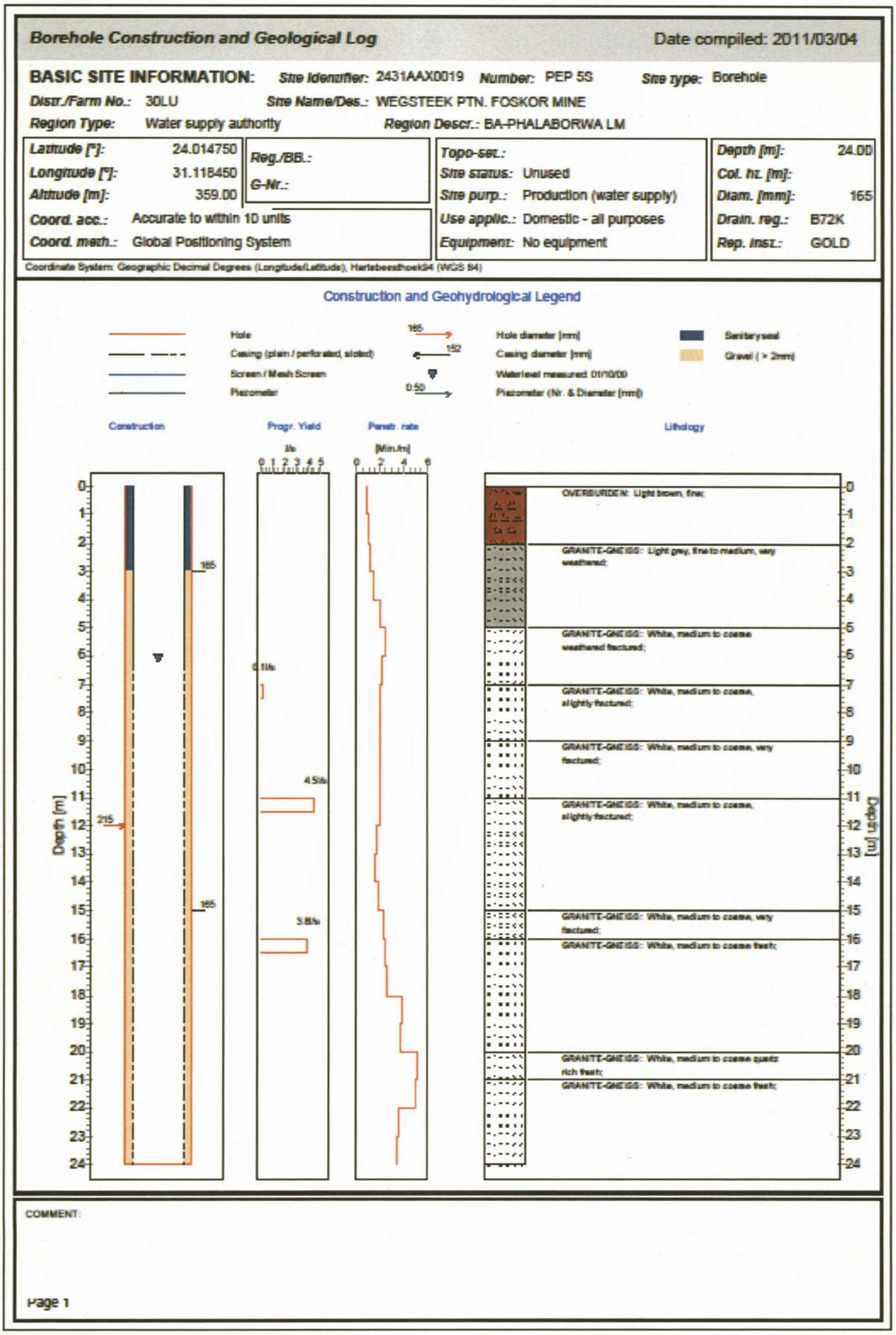
All boreholes were sealed at surface with a sanitation seal ranging from 2 m to 5 m, pending borehole construction to prevent surface pollution from entering the shallow/weathered aquifer.

Borehole development was conducted at all successful boreholes, the purpose being to increase the aquifer characteristics (permeability and storage) around the borehole from:

- Damages done to the formation during drilling;
- Improvement of the aquifer or gravel pack around the borehole; and
- Restoring the original hydraulic properties after deterioration caused by formation plugging by fine particles.

The bentonite seals were installed to seal off the weathered and fractured part of the aquifer and were very effective in sealing off the intersected water strikes. Eleven of the 17 deep boreholes drilled dry after the top part of the aquifer was sealed off and in most cases only seepage water entered these boreholes. The water levels in the deep boreholes recovered very slowly and some water levels were still in a process of recovering at the completion of the hydrogeological field investigation. This factor and the absence of deep water strikes indicate an absence of deep groundwater occurrence below 60m.

Detailed borehole logs are attached in a folder on a CD attached at the back of the thesis.



Borehole Construction and Geological Log Date compiled: 2011/03/04

BASIC SITE INFORMATION: *Site Identifier:* 2431AAX0019 *Number:* PEP 5S *Site type:* Borehole

Distr./Farm No.: 30LU *Site Name/Des.:* WEGSTEEK PTN. FOSKOR MINE

Region Type: Water supply authority *Region Descr.:* BA-PHALABORWA LM

Latitude [°]:	24.014750
Longitude [°]:	31.118450
Altitude [m]:	359.00
Coord. acc.:	Accurate to within 10 units
Coord. meth.:	Global Positioning System
Reg./BB.:	
G-Nr.:	
Topo-set.:	
Site status:	Unused
Site purp.:	Production (water supply)
Use applic.:	Domestic - all purposes
Equipment:	No equipment
Depth [m]:	24.00
Col. hz. [m]:	
Diam. [mm]:	165
Drain. reg.:	B72K
Rep. inst.:	GOLD

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

OVERBURDEN: Light brown, fine;

GRANITE-GNEISS: Light grey, fine to medium, very weathered;

GRANITE-GNEISS: White, medium to coarse weathered fractured;

GRANITE-GNEISS: White, medium to coarse, slightly fractured;

GRANITE-GNEISS: White, medium to coarse, very fractured;

GRANITE-GNEISS: White, medium to coarse, slightly fractured;

GRANITE-GNEISS: White, medium to coarse, very fractured;

GRANITE-GNEISS: White, medium to coarse fresh;

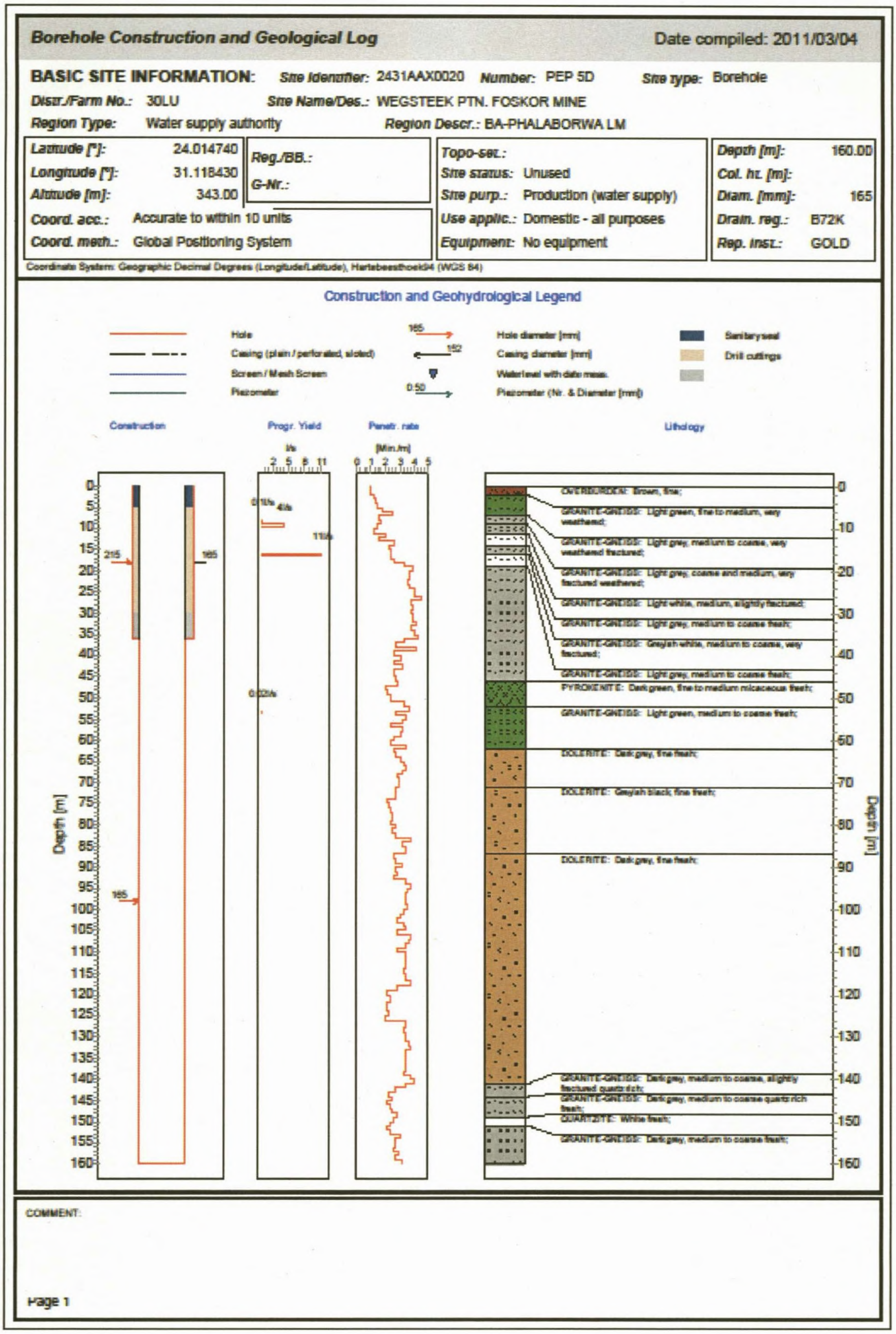
GRANITE-GNEISS: White, medium to coarse quartz rich fresh;

GRANITE-GNEISS: White, medium to coarse fresh;

COMMENT:

Page 1

Figure 46: Example of Shallow Monitoring Borehole Log



Borehole Construction and Geological Log Date compiled: 2011/03/04

BASIC SITE INFORMATION: *Site Identifier:* 2431AAX0020 *Number:* PEP 5D *Site type:* Borehole

Distr./Farm No.: 30LU *Site Name/Des.:* WEGSTEEK PTN. FOSKOR MINE

Region Type: Water supply authority *Region Descr.:* BA-PHALABORWA LM

Latitude [°]:	24.014740	*Reg./BB.:*		*Topo-set.:*		*Depth [m]:*	160.00
Longitude [°]:	31.118430	*G-Nr.:*		*Site status:*	Unused	*Col. ht. [m]:*	
Altitude [m]:	343.00			*Site purp.:*	Production (water supply)	*Diam. [mm]:*	165
Coord. acc.:	Accurate to within 10 units			*Use applic.:*	Domestic - all purposes	*Drain. reg.:*	B72K
Coord. meth.:	Global Positioning System			*Equipment:*	No equipment	*Rep. inst.:*	GOLD

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), Hartebeesthoek94 (WGS 84)

Construction and Geohydrological Legend

Hole
Casing (plain / perforated, slotted)
Screen / Mesh Screen
Piezometer
Hole diameter [mm]
Casing diameter [mm]
Waterlevel with date meas.
Piezometer (Nr. & Diameter [mm])
Sanitary seal
Drill cuttings

OVERBURDEN: Brown, fine;
GRANITE-GNEISS: Light green, fine to medium, very weathered;
GRANITE-GNEISS: Light grey, medium to coarse, very weathered fractured;
GRANITE-GNEISS: Light grey, coarse and medium, very fractured weathered;
GRANITE-GNEISS: Light white, medium, slightly fractured;
GRANITE-GNEISS: Light grey, medium to coarse fresh;
GRANITE-GNEISS: Greyish white, medium to coarse, very fractured;
GRANITE-GNEISS: Light grey, medium to coarse fresh;
PYROXENITE: Dark green, fine to medium micaceous fresh;
GRANITE-GNEISS: Light green, medium to coarse fresh;
DOLERITE: Dark grey, fine fresh;
DOLERITE: Greyish black, fine fresh;
DOLERITE: Dark grey, fine fresh;
GRANITE-GNEISS: Dark grey, medium to coarse, slightly fractured quartz rich;
GRANITE-GNEISS: Dark grey, medium to coarse quartz rich fresh;
QUARTZITE: White fresh;
GRANITE-GNEISS: Dark grey, medium to coarse fresh;

COMMENT:

Page 1

Figure 47: Example of Deep Monitoring Borehole Log

6.2.1.Drilling Results of NSPP

6.2.1.1. Shallow Monitoring Boreholes

Six of the 19 shallow monitoring boreholes had no water strikes with only groundwater seepage entering the boreholes. Yields intersected in other shallow monitoring boreholes were as follows:

- Seepage only (PEP1S, PEP2S, PEP3S, PEP4S, PEP7S and PEP9S) - six monitoring boreholes - 31.6%;
- <1l/s - six monitoring boreholes (PEP6S, PEP10S, PEP8S, PEP8M, PEP13S and PEP17S)- 31.6%;
- >1l/s to 2l/s - six monitoring boreholes (PEP10M, PEP11S, PEP12S, PEP14S, PEP15S and PEP16S)- 31.6%; and
- >2l/s - one monitoring boreholes (PEP5S) -5.2%.

Table 15 summarises the intersected blow yields of the shallow monitoring boreholes of the NSPP.

Table 15: Summarised Blow Yield of Shallow Monitoring Borehole of NSPP

Borehole Number	Final Blow yield (l/s)	Water strike depth (m)	Geology Intersected
Seepage only			
PEP1S	Seepage	Seepage	Pyroxenite
PEP2S	Seepage	Seepage	Pyroxenite
PEP3S	Dry	Dry	Granitic gneiss and dolerite
PEP4S	Dry	Dry	Granitic gneiss and dolerite
PEP7S	Dry	Dry	Granitic gneiss
PEP9S	Seepage	Seepage	Pyroxenite
Borehole Yields < 1l/s			
PEP6S	0.2	4(0.1),8(0.1)	Fractured Dolerite
PEP10S	0.35	11(0.3)	Granitic gneiss and dolerite
PEP8S	0.7	17(0.5)	Granitic gneiss
PEP8M	0.1	27(0.1)	Granitic gneiss
PEP13S	0.5	16(0.4)	Fractured Pyroxenite
PEP17S	0.4	14(0.25)	Granitic gneiss
Average Yield = 0.4l/s			
Borehole Yields .1l/s to 2l/s			
PEP10M	1.0	11(1.0)	Granitic gneiss and dolerite
PEP11S	2.0	29(2)	Pyroxenite and dolerite
PEP12S	1.05	31(0.1),39(1)	Pyroxenite and dolerite
PEP14S	1.0	11(1.0)	Fractured Pyroxenite
PEP15S	1.4	27(0.1),36(1.4)	Fractured Pyroxenite
PEP16S	1.7	17(1.7)	Fractured Pyroxenite
Average Yield = 1.4l/s			
Borehole Yields .> 2l/s			
PEP5S	8.3	7(0.1),11(4.5),16(3.8)	Granitic gneiss and dolerite
Average Yield = 8.3l/s			

The probabilities is based on the available data set, with the probability for intersecting groundwater in the shallow monitoring boreholes above 50 m is found to be 68.4% and for intersecting groundwater seepage 31.6%. The high yield at PEP5S of 8.3 l/s is an isolated area and should not to be considered as an average yield for the study area. The average borehole yield of the shallow monitoring boreholes ranges between 0.4 l/s to 1.4 l/s.

6.2.1.2. Deep Monitoring Boreholes

14 of the 17 deep monitoring boreholes drilled at NSPP drilled dry or had no water strikes after the shallow weathered part of the aquifer were sealed and cased off. Groundwater seepage however entered these boreholes. This is an indication that for the NSPP area most of the groundwater occurrence was found to be in the upper weathered and fractured part of the formation. Yields intersected in the deep monitoring boreholes were as follows:

- Seepage only - 14 monitoring boreholes - 82.4%;
- <1 l/s - three monitoring boreholes (PEP6D, PEP12D and PEP14D) - 17.6%;
- >1 l/s to 2 l/s - no intersections - 0%; and
- >2 l/s - no intersections -0%.

Table 16 summarises the intersected blow yields of the shallow monitoring boreholes of the NSPP.

Table 16 Summarised Blow Yield of Deep Monitoring Borehole of NSPP

Borehole Number	Final Blow yield (l/s)	Water strike depth (m)	Geology Intersected
Seepage only			
PEP1D	Seepage	Seepage	Pyroxenite
PEP2D	Seepage	Seepage	Pyroxenite
PEP3D	Dry	Dry	Granitic gneiss and dolerite
PEP4D	Dry	Dry	Granitic gneiss and dolerite
PEP5D	Seepage	Seepage	Granitic gneiss and dolerite
PEP7D	Seepage	Seepage	Granitic gneiss
PEP8D	Seepage	Seepage	Granitic gneiss
PEP9D	Seepage	Seepage	Pyroxenite
PEP10D	Seepage	Seepage	Granitic gneiss and dolerite
PEP11D	Seepage	Seepage	Pyroxenite and dolerite
PEP13D	Seepage	Seepage	Fractured Pyroxenite
PEP15D	Seepage	Seepage	Fractured Pyroxenite
PEP16D	Seepage	Seepage	Fractured Pyroxenite
PEP17D	Seepage	Seepage	Granitic gneiss
Borehole Yields < 1l/s			
PEP6D	0.7	57(0.02),129(0.6)	Fractured Dolerite
PEP12D	0.8	60(0.8)	Pyroxenite and dolerite
PEP14D	0.5	69(0.5)	Fractured Pyroxenite
Average Yield = 0.7l/s			
Borehole Yields .1l/s to 2l/s			
None	No Intersections	No Intersections	-
Borehole Yields .> 2l/s			
None	No Intersections	No Intersections	-

Figure 48 show the distribution of the blow yields encountered in the NSPP area. The average yield of the deep monitoring boreholes is 0.7l/s.

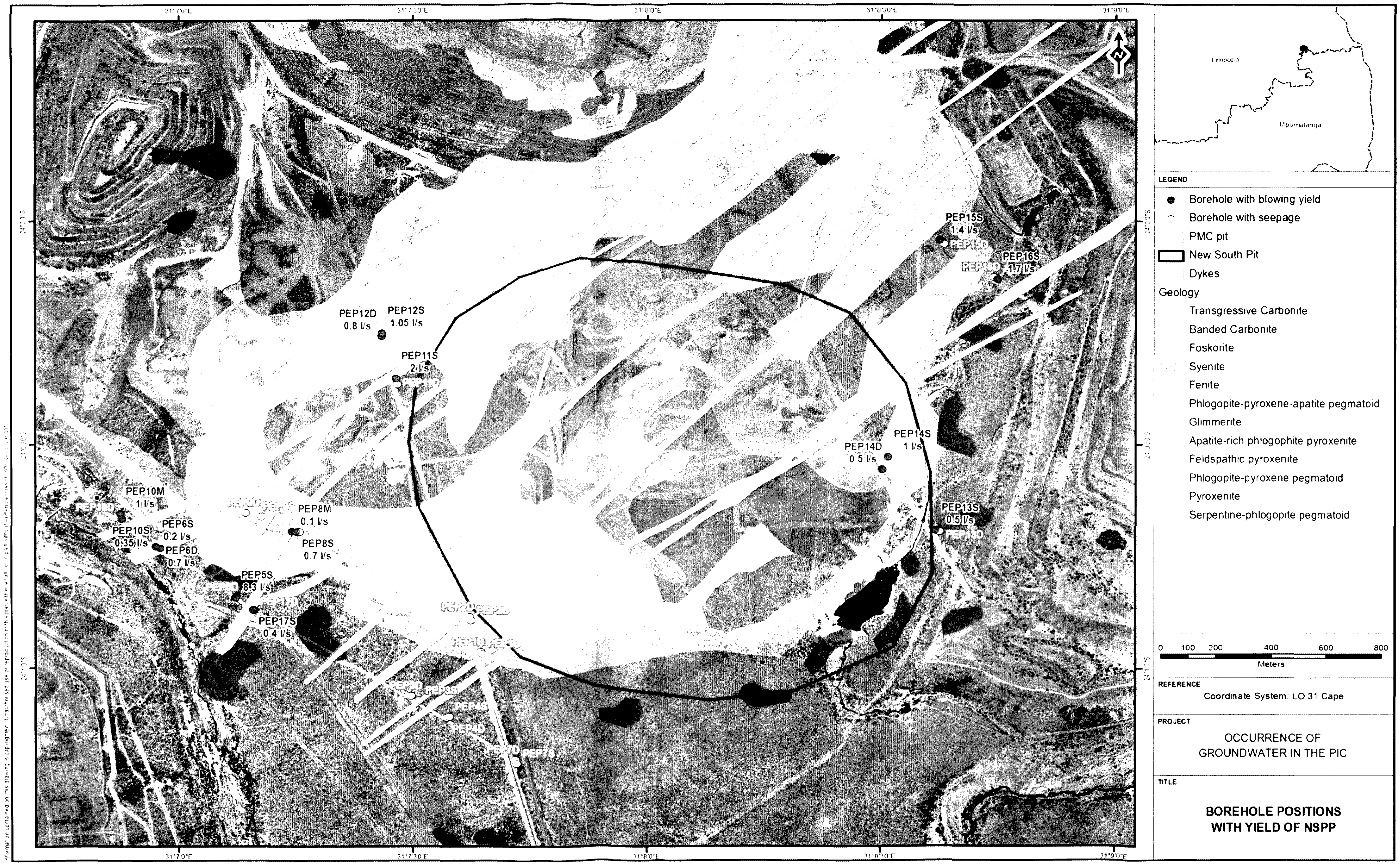


Figure 48: Borehole Positions with Yield of NSPP

The probability of intersecting groundwater in the deep monitoring boreholes below 50 m is 17.6% (assuming there was no leakage at PEP14D and PEP12D) and for intersecting groundwater seepage 82.4%. These probabilities are based on the available data set.

Leakage of bentonite seals is expected at boreholes PEP14D and PEP12D as a result of mine blasting activities. At these boreholes the water levels for the deep and shallow boreholes are at the same level, and interaction (drawdown) occurred during test pumping of shallow boreholes in the corresponding deep boreholes. Test pumping of these two deep boreholes confirmed the absence of deeper fracture zones.

Groundwater was intersected in only one deep borehole PEP6D (129 m-0.6 l/s) with certainty after the upper part of aquifer was sealed off. The drilling results obtained in this investigation gave a 5.8% (assuming leakage at PEP14D and PEP12D) probability for groundwater occurrence below the weathered and fractured zone. Boreholes PEP2D (146 m) and PEP17D (51 m) showed some dampness at depth.

6.2.2. Dolerite Dykes Intercepted

The dolerite dykes that were targeted for groundwater occurrence and that were intercepted during the drilling phase are summarised below in Table 17. At drill site PEP1 and PEP2 the dolerite dykes are assumed to be near vertical, since dolerite was not intersected during drilling.

From the drilling results obtained regarding the dolerite dyke intersections, five (29%) of the intersected 17 upper dolerite dyke contact zones had water strikes. These water strikes however, were all above 50m and were located in the weathered and fractured formations. All 17 of the lower dolerite contact zones intersected were dry.

Table 17: Summarised Interpretation of Dolerite Dykes Intersected

Borehole number	Inferred Dolerite dyke Dip(°)	Inferred Direction of Dip	Upper Contact Zone Yield (l/s)	Depth Intersected (m)	Lower Contact Zone Yield (l/s)	Depth Intersected (m)
PEP3S	85°	North West	Dry	26	Not intersected	Not intersected
PEP3D	85°	North West	Dry	130	Not intersected	Not intersected
PEP3D1	85°	North West	Dry	0-11	Not intersected	Not intersected
PEP4D	90°	Vertical	Dry	122	Not intersected	Not intersected
PEP4D1	90°	Vertical	Dry	0-16	Not intersected	Not intersected
PEP5D	70°	North West	Dry	62	Dry	141
PEP6S	82°	South East	0.1	0-24	Not intersected	Not intersected
PEP6D	82°	South East	0.2	20	Dry	104
PEP8D	85°	North West	Dry	4	Dry	78
PEP9D	90°	Vertical	Dry	122-123	Not intersected	Not intersected
PEP10S	85°	North West	0.3	9.0	Not intersected	Not intersected
PEP10M	85°	North West	Dry	34	Not intersected	Not intersected
PEP10D	85°	North West	Dry	46	Dry	91
PEP11S	80°	South East	2.0	32	Not intersected	Not intersected
PEP11D	80°	South East	Dry	153	Not intersected	Not intersected
PEP12S	83°	South East	1.0	38	Not intersected	Not intersected
PEP12D	83°	South East	Dry	137	Not intersected	Not intersected

6.2.3. Conclusion of drilling results of NSPP

Most groundwater strikes were limited and relative shallow with deep contact zones generally dry. Drilling of the NSPP area has confirmed that most groundwater was occurring within the upper weathered and fractured zone (50 m) of the formation as confirmed by the results of the shallow monitoring boreholes. These results correspond with the findings of case study I where the reported water strikes where from 16 to 48 m. Case study II also confirms the presence of weathered and fractured aquifer systems.

The shallow monitoring boreholes for this study area had 68.4% of the boreholes intersecting groundwater and 31.6% of the boreholes intersecting groundwater seepage only.

The 17.6% of the deep monitoring boreholes had water strikes (<1 l/s) and an 82.4% of the deep monitoring boreholes had groundwater seepage.

Drilling results of the NSPP are summarised in Table 18, and individual drill sites is discussed on a folder written on a CD attached to the thesis.

Table 18: Summarised Drilling Results at NSPP

BH No	Completion Date	Latitude	Longitude	BH Diameter Final ID	Depth (m)	Casing 165mm ID	Depth of solid casing in Deep BH	Water strikes sealed of in Deep BH (l/s)	Water Strike (l/s)	Geology Intersected	Final Blow Yield (l/s)	SWL (mbgl)
PEP1S	19/9/2009	24.01684	31.12720	165	40	40	-	None	37(damp)	Pyroxenite	Seepage	19.27
PEP1D	23/9/2009	24.01677	31.12717	165	180	48	48	26(0.1)	Dry	Pyroxenite	Seepage	53.67
PEP2S	17/9/2009	24.01560	31.12683	165	42	33	-	None	Dry	Pyroxenite	Seepage	22.74
PEP2D	22/9/2009	24.01546	31.12678	165	180	72	72	25(damp)	146(damp)	Pyroxenite	Seepage	22.3
PEP3S	1/10/2009	24.01859	31.12499	165	36	36	-	None	Dry	Granitic gneiss and dolerite	Dry	Backfilled
PEP3D	3/10/2009	24.01842	31.12469	165	142	42	42	None	Dry	Granitic gneiss and dolerite	Seepage	>100
PEP4S	3/10/2009	24.01920	31.12606	165	41	41	-	None	Dry	Granitic gneiss and dolerite	Dry	Backfilled
PEP4D	5/10/2009	24.01922	31.12597	165	141	56	56	None	Dry	Granitic gneiss and dolerite	Seepage	>100
PEP5S	29/9/2009	24.01475	31.11845	165	24	24	-	None	7(0.1),11(4.5),16(3.8)	Fractured Granitic gneiss	8.3	5.6
PEP5D	7/10/2009	24.01474	31.11843	165	160	36	36	8(0.1),9(4),16(11)	53(0.02)	Granitic gneiss and dolerite	Seepage	6.63
PEP6S	18/09/2009	24.01285	31.1156	165	24	24	-	None	4(0.1),8(0.1)	Fractured dolerite	0.2	5.34
PEP6D	1/10/2009	24.01291	31.11576	165	156	39	39	7(0.2)	57(0.02),129(0.6)	Dolerite and granitic gneiss	0.7	2.77
PEP7S	29/9/2009	24.02093	31.12844	165	34	34	-	None	Dry	Granitic gneiss	Dry	Dry
PEP7D	30/9/2009	24.02078	31.12839	165	121	40	40	Dry	Dry	Granitic gneiss	Seepage	18.18
PEP8S	15/10/2009	24.01231	31.12059	165	31	31	-	None	17(0.5)	Granitic gneiss	0.7	6.14
PEP8M	17/10/2009	24.01229	31.12044	165	41	18	-	None	27(0.1)	Granitic gneiss	0.1	10.12
PEP8D	24/10/2009	24.01230	31.12070	165	180	48	48	21(damp),26(damp)	Dry	Granitic gneiss	Seepage	>100
PEP9S	24/10/2009	24.01173	31.11937	165	44	44	-	None	Seepage	Pyroxenite	Seepage	30.55
PEP9D	26/10/2009	24.01158	31.11879	165	180	51	51	Dry	Dry	Pyroxenite	Seepage	>100
PEP10S	5/10/2009	24.01181	31.11438	165	26	26	-	None	11(0.3)	Granitic gneiss and dolerite	0.35	6.48
PEP10M	6/10/2009	24.01163	31.11432	165	40	20	-	None	11(1.0)	Granitic gneiss and dolerite	1.0	3.4
PEP10D	9/10/2009	24.01175	31.11419	165	151	51	51	18(3.2)	137(0.01)	Granitic gneiss and dolerite	Seepage	4.57
PEP11S	14/10/2009	24.00659	31.12414	165	42	42	-	None	29(2)	Pyroxenite and dolerite	2.0	19.5
PEP11D	22/10/2009	24.00681	31.12419	165	176	50	50	39(0.2)	Dry	Pyroxenite and dolerite	Seepage	>100
PEP12S	10/10/2009	24.00489	31.12365	165	48	48	-	None	31(0.1),39(1)	Pyroxenite and dolerite	1.05	13.63
PEP12D	19/10/2009	24.00500	31.12363	165	151	56	56	21(0.1),41(0.8)	60(0.8)	Pyroxenite and dolerite	0.8	14.73
PEP13S	16/10/2009	24.01224	31.14338	165	54	54	-	None	16(0.4)	Fractured Pyroxenite	0.5	7.8
PEP13D	5/11/2009	24.01229	31.14352	165	170	66	66	16(0.7)	Dry	Pyroxenite	Seepage	>100
PEP14S	10/10/2009	24.00950	31.14167	165	54	54	-	None	11(1.0)	Fractured Pyroxenite	1.0	4.35
PEP14D	24/10/2009	24.00924	31.14173	165	180	66	66	21(0.9)	69(0.5)	Pyroxenite	0.5	4.63
PEP15S	19/10/2009	24.00141	31.14351	165	56	56	-	None	27(0.1),36(1.4)	Fractured Pyroxenite	1.4	14.05
PEP15D	23/10/2009	24.00155	31.14365	165	180	66	66	41(1.5)	Dry	Pyroxenite	Seepage	18.12
PEP16S	17/10/2009	24.00286	31.14554	165	56	56	-	None	17(1.7)	Fractured Pyroxenite	1.7	5.86
PEP16D	21/10/209	24.00277	31.14543	165	180	64	64	17(0.1)	Dry	Pyroxenite	Seepage	7.93
PEP17S	6/10/2009	24.01521	31.11907	165	26	26	-	None	14(0.25)	Granitic gneiss	0.4	6.72
PEP17D	10/10/2009	24.01520	31.11910	165	150	32	32	14(damp)	51(damp)	Granitic gneiss	Seepage	8.59

6.3. Drilling NPM

6.3.1. Objective

The objective of the drilling was to investigate groundwater occurrence in the area of the NPM in terms of quantity, quality and depth. A total of 26 monitoring boreholes were drilled comprising out of 10 pairs of shallow and deep monitoring boreholes, two additional deep (NPM1D and NPM11D) and four additional shallow (NPM13S, NPM14S, NPM15S and NPM16S) monitoring boreholes.

The pairs of deep and shallow monitoring boreholes were planned to confirm the presence of a shallow/perched aquifer (18 m to 60 m below surface) in the weathered zone of the NPM area, and for the presence of a deeper aquifer in the fracture zones of the Phalaborwa Igneous Complex.

A deep monitoring borehole (NPM1D) was drilled on the pit wall targeting a fault zone with a north south striking direction. A second deep monitoring borehole was drilled in the pit centre (NPM11D) to obtain confirmation of any deeper groundwater strikes in the pyroxenite formation.

The drilling results was included as part of this thesis to obtain a better understanding of the occurrence of groundwater in the NPM area.

6.3.2. Methodology

The drilling was conducted by means of two rotary air percussion drill rigs. The drilling specification followed was the same as those followed during the PEP project, which entailed the drilling of shallow monitoring boreholes ranging from 18 m to 60 m and deep monitoring boreholes of 180 m.

6.3.2.1. Shallow Monitoring Boreholes

The shallow boreholes were drilled at 254 mm diameter and cased with 165 mm perforated steel casings. Shallow boreholes were gravel packed to stabilise formation and allow groundwater flow into the boreholes.

6.3.2.2. Deep Monitoring Boreholes

The deep boreholes were drilled at 254 mm diameter up to depths exceeding the depths of shallow and existing Foskor monitoring boreholes. Bentonite and cement seals of ranging from 5 to 6 m in thickness were effectively installed at the depth of these deep boreholes. Drilling was then continued at 165 mm diameter to investigate the occurrence of deeper groundwater.

Shallow water strikes were cased off in the deep boreholes to establish if a deeper aquifer or groundwater occurrence exists and to minimise risk of cross contamination.

Monitoring borehole NPM16S which intersected a wide open fracture at 50 m in the granite were completed by means of Odex drilling and cased with 194mm (ID) steel casing.

6.3.3. Drilling Results

The borehole positions and final blow yields of monitoring boreholes for the NPM area is indicated in Figure 49.

6.3.3.1. Shallow Monitoring Boreholes

Eight of the 14 shallow monitoring boreholes drilled had no water strikes with only groundwater seepage entering these boreholes. From the results of this area 43% of the shallow monitoring boreholes had water strikes in the upper (58 m) weathered and fractured zone of the formation. Yields intersected in the shallow monitoring boreholes were as followed:

- Seepage only - eight monitoring boreholes - 57,1%;
- <1 l/s - two monitoring boreholes (NPM7S and NPM9S) - 14,3%;
- >1 l/s to 2 l/s - two monitoring boreholes (NPM6S and NPM14S) - 14,3%; and
- >2 l/s - two monitoring boreholes (NPM4S and NPM16S)-14,3%.

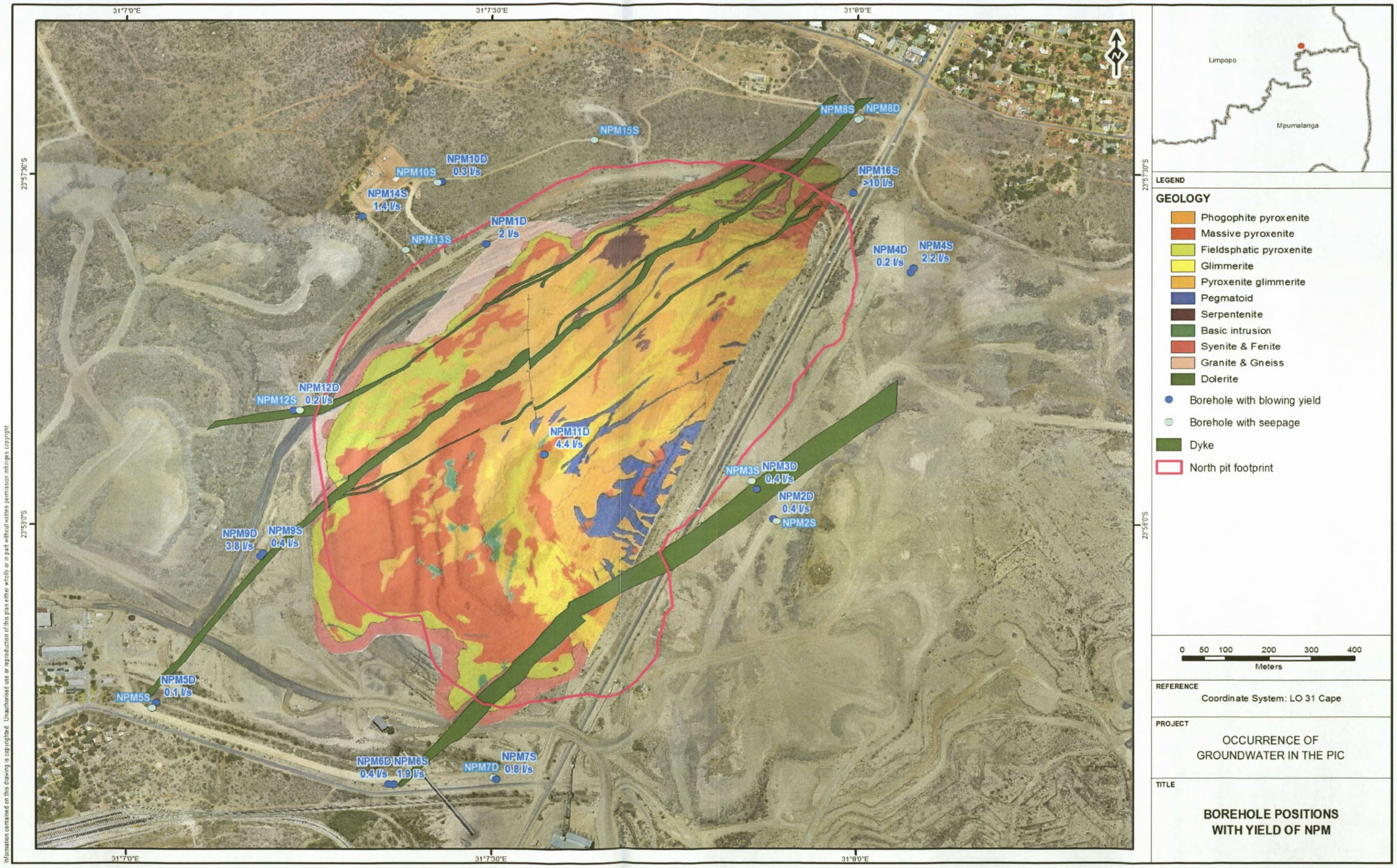


Figure 49: Borehole Positions with Yields of NPM

Table 19 summarises the intersected blow yields of the shallow monitoring boreholes drilled at the NPM.

Table 19: Summarised Intersected Yields of Shallow Monitoring Boreholes at NPM

Borehole Number	Final Blow yield (l/s)	Water strike depth (m)	Geology Intersected
Seepage only			
NPM2S	Seepage	Seepage	Pyroxenite
NPM3S	Seepage	Seepage	Pyroxenite
NPM5S	Seepage	Seepage	Granite and Dolerite
NPM8S	Seepage	Seepage	Dolerite
NPM10S	Seepage	Seepage	Dolerite
NPM12S	Seepage	Seepage	Granite
NPM13S	Seepage	Seepage	Granite and Dolerite
NPM15S	Seepage	Seepage	Granite and Dolerite
Borehole Yields < 1l/s			
NPM7S	0.8	49	Granite and Dolerite
NPM9S	0.4	8	Granite
Average Yield = 0.6l/s			
Borehole Yields .1l/s to 2l/s			
NPM6S	1.9	26	Granite and Dolerite
NPM14S	1.4	24	Granite
Average Yield = 1.65l/s			
Borehole Yields .> 2l/s			
NPM4S	2.2	58	Pyroxenite
NPM16S	>10	50	Pyroxenite and Dolerite
Average Yield = 6.1/s			

The probabilities is based on the available data set, with the results of the NPM area giving a probability of intersecting groundwater in the upper weathered and fractured zone above 58 m as 42.9% and for intersecting groundwater seepage as 57.1%. This is less than the 68.4% of intersections of the NSPP area. The average yield of the shallow monitoring boreholes obtained at the NPM area range between 0.6 to 1.8 l/s. The high yield intersected at NPM16S is an isolated fracture zone and not sustainable.

6.3.3.2. Deep monitoring boreholes

Twelve deep monitoring boreholes were drilled including NPM11D in the pit centre. As this borehole intersected blasting fractures and not natural fractures it was left out of intersected water strike percentage calculations. These blasting fractures are filled with groundwater and will be present in the pit centre as long as blasting continuous.

Borehole PM11D had a final blow yield of >2 l/s resulting from blasting fractures being filled with groundwater.

The yields intersected in the other 11 deep monitoring boreholes were as follows:

- Seepage only - two monitoring boreholes(NPM7D and NPM8D) - 18.2%;
- <1 l/s- seven monitoring boreholes - 63.6%;
- >1 l/s to 2 l/s - one monitoring boreholes (NPM2D) - 9.1%; and
- >2 l/s - one monitoring boreholes NPM9D -9.1%, and

The drilling results of the NPM area gave a probability of intersecting groundwater in the deep fractured to fresh zone below 58 m as 81.8% and 18.2%.intersected groundwater seepage only.

Table 20 summarises the intersected blow yields of the deep monitoring boreholes drilled at the NPM.

Table 20: Summarised Intersected Yields of Deep Monitoring Boreholes at NPM

Borehole Number	Final Blow yield (l/s)	Water strike depth (m)	Geology Intersected
	Seepage only		
NPM7D	Seepage	Seepage	Granite and Dolerite
NPM8D	Seepage	Seepage	Granite and Dolerite
	Borehole Yields < 1l/s		
NPM2D	0.4	139(0.1),166(0.3)	Pyroxenite and Dolerite
NPM3D	0.4	80	Pyroxenite
NPM4D	0.9	91	Pyroxenite
NPM5D	0.1	76	Granite and Dolerite
NPM6D	0.4	61(0.1), 140(0.3)	Granite and Dolerite
NPM10D	0.3	88	Granite and Dolerite
NPM12D	0.2	70	Granite and Dolerite
	Average Yield = 0.4l/s		
	Borehole Yields .1l/s to 2l/s		
NPM1D	2.0	150(0.4)156(0.6)	Granite
	Average Yield = 2.0l/s		
	Borehole Yields .> 2l/s		
NPM9D	2.2	69(0.5), 105(3.4)	Granite
	Average Yield = 2.2/s		
	Blasting Fractures Filled with Groundwater		
NPM11D	4.4	Blasting Fractures	Pyroxenite
	Average Yield = 4.4/s		

6.3.3.3. Discussion

The drilling results of the NPM confirm the presence of three aquifer zones as identified during the study at the NSSP consisting out of:

- Upper weathered aquifer zone (15 to 32 m);
- Fractured permeable aquifer horizon (24 to 58 m); and
- Fresh to slightly fractured aquifer zone.
- The average weathering depth of the granite at the NPM is 15 m and the fracturing zone is 24 m. The average weathering depth of the pyroxenite is 32 m and the fractured pyroxenite 56 to 58 m. The average dolerite dykes weathering is 12 m and the fractured zone is 23m f

Nine of the 11 deep monitoring boreholes drilled at the NPM intersected groundwater below the fractured aquifer zone of 50 m as defined during the study at the NSPP. At NPM11D groundwater occur in +/- 6 m of blasting fractures at the pit bottom. These drilling results gave an 81.8% probability for groundwater occurrence below the weathered and fractured zone for the NPM area, which is much higher as results (17.6%) obtained at the NSPP area. The probabilities are based on the available data set.

The average blow yield obtained at the monitoring boreholes of the deep fractured to fresh zone at the NPM area range from 0.4 to 2.2 l/s.

Drilling Results of NPM are summarised in Table 21, with complete borehole logs in a folder on a CD attached to the back of the thesis.

Table 21: Summarised Drilling Results of NPM

BH No	Completion Date	Latitude	Longitude	BH Diameter Final ID	Depth (m)	Casing 165mm ID Depth (m)	Depth of solid casing in Deep BH	Water strikes sealed of in Deep BH (l/s)	Water Strike (l/s)	Geology Intersected	Final Blow Yield (l/s)	SWL (mbgl)
NPM1D	23/3/2011	23.96070	31.12461	165	180	26.0	26	None	150(0.4)156(0.6)	Granite	2	90.82
NPM2S	9/3/2011	23.96730	31.13126	165	48	48.0	-		Seepage	Pyroxenite	Seepage	14.98
NPM2D	9/3/2011	23.96724	31.13119	165	180	72.0	72	None	139(0.1),166(0.3)	Pyroxenite and Dolerite	0.4	15.88
NPM3S	14/3/2011	23.96634	31.13070	165	48	48.0	-		seepage	Pyroxenite	Seepage	17.46
NPM3D	12/3/2011	23.96653	31.13081	165	180	66.0	66	27(0.3)	80(0.4)	Pyroxenite	0.4	17.2
NPM4S	9/3/2011	23.96127	31.13437	165	66	66.0	-		58(0.5)	Pyroxenite	2.2	27.39
NPM4D	14/3/2011	23.96137	31.13431	165	180	72.0	72	47(0.2),58(1.0)	91(0.2)	Pyroxenite	0.2	26.22
NPM5S	21/3/2011	23.97175	31.11701	165	42	42.0	-		Seepage	Granite and Dolerite	Seepage	19.4
NPM5D	24/3/2011	23.97162	31.11709	165	180	48.0	48		76(0.1)	Granite and Dolerite	0.1	20.45
NPM6S	18/3/2011	23.97355	31.12241	165	42	42.0	-		26(0.5)	Granite and Dolerite	1.9	5.82
NPM6D	13/3/2011	23.97355	31.12253	165	180	54.0	54	11(1.4), 38(2.0)	61(0.1), 140(0.3)	Granite and Dolerite	0.4	14.94
NPM7S	17/11/2011	23.97344	31.12486	165	54	54.0	-		49(0.6)	Granite and Dolerite	0.8	19.88
NPM7D	21/3/2011	23.97340	31.12480	165	180	60.0	60	47(0.3)	Dry	Granite and Dolerite	Dry	24.39
NPM8S	26/3/2011	23.95775	31.13310	165	36	36.0	-		Seepage	Dolerite	Seepage	16.58
NPM8D	30/3/2011	23.95772	31.13314	165	180	42.0	42		Dry	Granite and Dolerite	Dry	15.70
NPM9S	17/3/2011	23.96807	31.11953	165	18	18.0	-		8(0.4)	Granite	0.4	2.95
NPM9D	19/3/011	23.96814	31.11948	165	180	29.0	29	12(0.2)	69(0.5),105(3.4)	Granite	3.8	29.97
NPM10S	24/3/2011	23.95924	31.12350	165	32	32.0	-		Seepage	Dolerite	Seepage	13.99
NPM10D	28/3/2011	23.95922	31.12360	165	180	40.0	40	None	88(0.3)	Granite and Dolerite	0.3	14.11
NPM11D	26/3/2009	23.96571	31.12593	165	180	6.0	6	3(1.3)	4(1.3)35(2.6)	Pyroxenite	4.4	1.2
NPM12S	11/4/2011	23.96467	31.12037	165	24	24.0	-		Seepage	Granite	Seepage	22.63
NPM12D	13/4/2011	23.96467	31.12023	165	180	30.0	30	None	70(0.2)	Granite and Dolerite	0.2	23.36
NPM13S	13/4/2011	23.96084	31.12278	165	30	30.0	-		Seepage	Granite and Dolerite	Seepage	21.12
NPM14S	15/4/2011	23.96005	31.12179	165	30	30.0	-		24(0.9)	Granite	1.4	5.96
NPM15S	18/4/2011	23.95824	31.12706	165	38	30.0	-		Seepage	Granite and Dolorite	Seepage	44.3
NPM16S	6/5/2011	23.95945	31.13303	165	71	55(191mm)	37		50- 56(+/-10l/s)	Pyroxenite	>10	48.57

6.3.3.4. Intercepted Dolerite Dykes at NPM

At the NPM study area the following water strike results were obtained at the 15 monitoring boreholes which intersected dolerite dykes:

- At NPM16S the upper dolerite dyke contact intersected had groundwater, all other upper dolerite contact zones intersected drilled dry;
- Lower dolerite dyke contact zones intersected - nine out eleven intersected drilled dry with only monitoring borehole NPM6D which had a water strike of 2.0 l/s and
- Eight of the boreholes (53%) had water strikes either within the dolerite dyke or close to the contact zones of the dolerite dyke (Figure 50); and
- These drilling results give a 53% probability for the occurrence of groundwater in boreholes targeting dolerite dykes for the NPM area.

Table 22 summarise the drilling results of intercepted dolerite dykes.

Table 22: Drilling Results of Intersected Dolerite Dykes at NPM

Borehole number	Upper Contact Zone Yield (l/s)	Upper Contact Depth Intersected (m)	Lower Contact Zone Yield (l/s)	Lower Contact Depth Intersected (m)	WS with in dolerite dyke (l/s)	Final Blow Yield (l/s)
NPM2D	Dry	129	Dry	174	0.1 at 139m,0.3 at 166m	0.4
NPM5S	Dry	2,18,22	Dry	17,19,23	None	Seepage
NPM5D	Dry	51	Dry	110	0.1 at 76m	0.1
NPM6S	Dry	32	Dry	34		1.9(26m)
NPM6D	Dry	2	2	38	1.4 at 11m	0.4
NPM7S	Dry	21,40,49	Dry	28,46	0.6 at 49m	0.8
NPM7D	Dry	9,33,40,58,88	Dry	23,37,57,60,158	0.3l/s at 47m	Dry
NPM8S	Dry	1	-	Not Intersected		Seepage
NPM8D	Dry	70,98,124,134	Dry	72,101,131,174		Seepage
NPM10S	Dry	1	-	Not Intersected		Seepage
NPM10D	Dry	2,81	Dry,	36,142	0.3 at 88m	0.3
NPM12D	Dry	34,84,92,100	Dry	76,91,93,106	0.2 at 70m	0.2
NPM13S	Dry	5	-	Not Intersected		Seepage
NPM15S	Dry	4	-	Not Intersected		Seepage
NPM16S	>10	50	Dry	56		>10

Figure 50: Drilling of NPM6D in Fractured Dolerite

6.3.4. Conclusion of drilling results of NPM

More groundwater strikes were encountered at the NPM area with 42.9% of the shallow monitoring intersecting water strikes above 58 m and 81.1% of the deep monitoring boreholes had water strikes below 58 m. This success percentage of the deep monitoring boreholes excludes the blasting fractures intersected at NPM11D in the pit.

The dolerite dyke contact zones were generally dry although there is a 53% probability of intersecting groundwater at the sides or within the dykes.

Drilling has confirmed that the highest yields is in the upper 58 m of the formations, although high yield have been intersected in NPM1D (Fault zone and NPM9D - deep fracturing).

The difference in groundwater occurrence between the two areas (NSPP and NPM) is probably related to:

- The NPM pit which is currently developed to approximately 160 mbgl (compared to approximately 60 mbgl at the NSPP) and a dewatering cone has developed around the NPM pit. This dewatering cone will initially affect the upper weathered and fractured zone around the NPM which give rises to less water strikes in this zone (43%) compared to water strikes in the same region at the NSPP (68%). This statement is supported by the fact that existing shallow monitoring boreholes of 30m deep close to the NPM pit has dried up;

- The NSPP pit area is more extensively intruded by north east to south west striking dolerite dykes, and these dykes are impermeable at depth and tend to compartmentalize the formation. This could be a reason for encountering more water strikes at depth at the NPM (82%) to 18% at the NSPP; and
- Differences in crystallization temperatures, crystallization times and geological compositions will also play a role.

CHAPTER 7: Aquifer Testing

7.1. Objective

Pump tests was performed on 22 newly drilled boreholes to gain an understanding of the aquifer hydraulics. These hydraulic parameters determined from the test data provide essential inputs into understanding the hydrogeology of the study area.

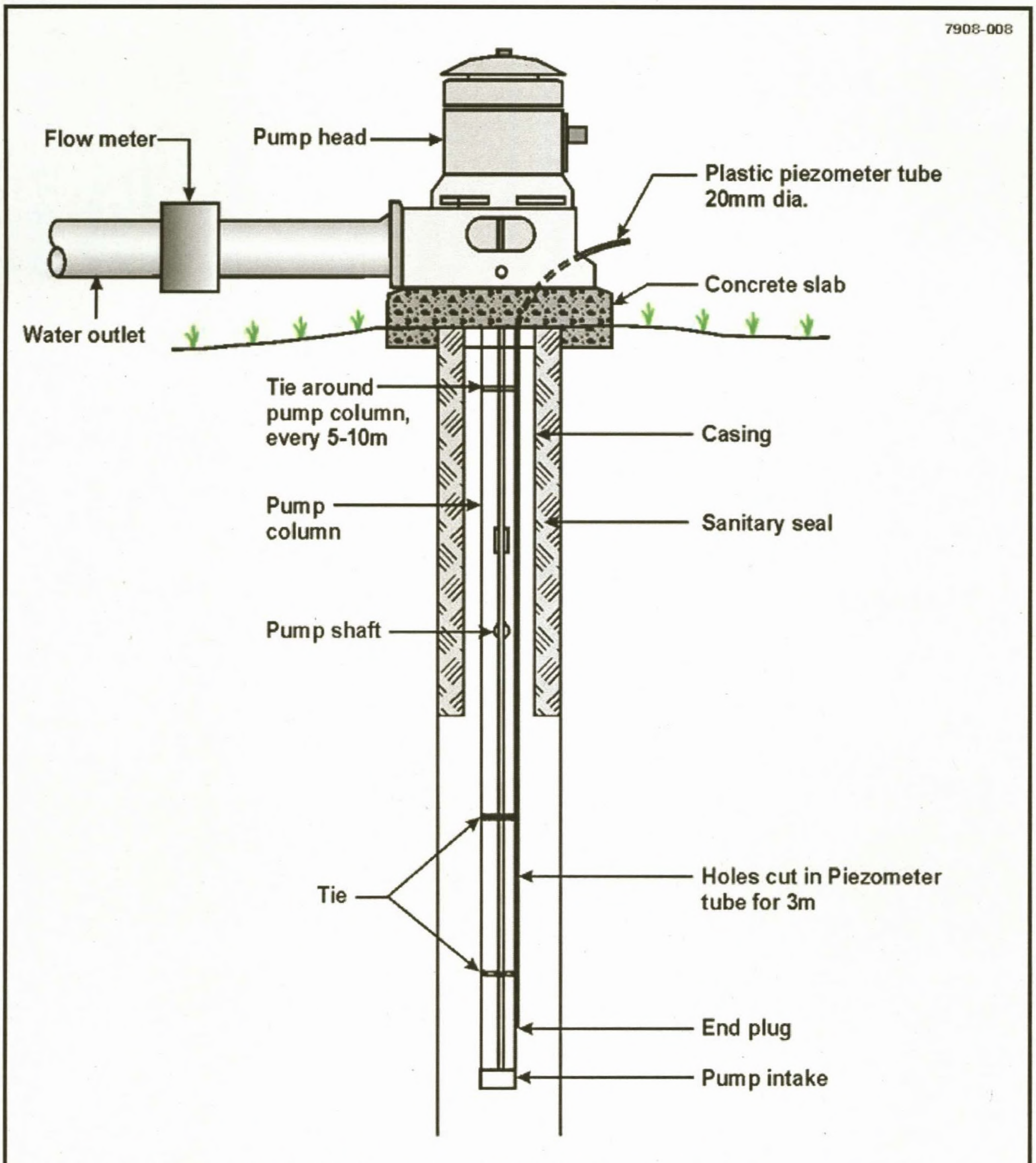
If the emphasis of the CDT is on hydraulic parameter estimation, a long-duration Constant Discharge Test at a low rate must be conducted, if the emphasis however is on sustainable yield estimation, a short duration test, stressing the boreholes must be conducted to try and reach the main fracture position within eight hours of the CDT.

The first approach on hydraulic parameter estimation was followed during the study.

7.2. Methodology

Technical specifications for test pumping of boreholes were prepared to ensure that testing equipment is suitable for testing programme and to capitalize on testing data collection.

Positive displacement rotary pumps or mono pumps (Figure 51) were used, as these pumps are the most suitable to maintain a constant yield during a CDT. Centrifugal pumps have a varying flow depending on pressure or head, whereas the positive displacement pumps has more or less a constant flow regardless of pressure.



Drawing no. 2 : Pump head with piezometer tube attached to pump column

Figure 51: Positive Displacement or Mono Pump

Testing sites were demarcated (Figure 52) and lay flats were positioned from 100 to 200m distance from the tested borehole.

Figure 52: Pumping Test Rig

Pump testing consisted out of a step drawdown test (SDT) followed by a constant discharge test (CDT), and a water level recovery test. Each SDT comprised three to four 60-minute steps at increasing pumping rates. The aim of the SDT is to determine the pumping rate for the CDT. The CDT is conducted to determine the hydraulic parameters of the aquifer and identify possible aquifer boundaries. CDT was conducted for periods of between 12 and 68 hours, after which the recovery was measured. The CDT pumping rates were set at yields determined from the SDT to be sustainable for the planned duration of the test. Pumping rates varied from 0.1 l/s to 25 l/s.

Some low-yielding boreholes were submitted direct to a CDT at a low yield of 0.1 l/s to 0.2 l/s, until pump inlet was reached where after recovery were measured. The purpose of these low pumping rates was to obtain more accurate hydraulic parameters for the aquifer, as to slug testing.

Test pumping yields were measured volumetrically as indicated in Figure 53. This method involved the using of different sizes of containers for different yields, during which the time to fill is measured and the yield is calculated as:

Yield = Volume (l)/Time(s)

= l/s

Flow meters are commonly used for boreholes with high yields, where the use of containers is unpractical.

Figure 53: Volumetric Yield Measurement

Water-level recovery measurements were taken for the same period as pumping during the SDT and CDT or to 95% recovery of the original water level.

Recovery % is calculated by means of the following formula:

Draw down after recovery (m)/Draw down after CDT *100 -100

= %

The recovery of the boreholes provides an independent measure of the transmissivity of the aquifer. The residual drawdown is plotted against t/t' (time since pumping started over time since pumping ended). Recovery data give an indication of the assured yield.

Water levels were monitored in shallow, deep boreholes and two existing PMC boreholes (NE5 and NE8) during the CDT to determine whether the shallow and deep aquifer systems are linked.

Water level recorders (divers) were also use to monitor changes in water levels in observation boreholes. These graphs are listed in Appendix C.

A summary of the test pumping performed is presented in Table 23.

7.3. Slug Testing

Slug tests were conducted on three low-yielding boreholes. The other deep boreholes could not be slug tested because of slow-rising water levels after top part of aquifer were cased off. Slug tests (Figure 54) provide a rapid means of assessing the in-situ hydraulic conductivity in boreholes with insufficient yields to undertake pumping tests. The test involves measuring the water-level response in a borehole to a rapid displacement of water. The displacement was induced through the introduction of a slug below the rest water level. The rate of recession of the water level displacement provides an indication of the hydraulic conductivity of the borehole. The water level responses were measured using an electronic water level data recorder.

Figure 54: Slug Testing

Table 23: Summary of Pump Tests Preformed at NSPP

Borehole no.	Completion date	Borehole depth(m)	Blow Yield (l/s)	Pump Installation depth(m)	Static Water Level (mbgl)	SDT (l/s)	Recovery after SDT (m)	CDT (hr)	CDT (l/s)	D/D after CDT (m)	Recovery after CDT (hours)	Draw down After recovery (m)
PEP1S	19/10/2009	40	Seepage	32	19.27	None	None	4.2	0.15	12.99	4.2	1.19
PEP1D	17/10/2009	180	Seepage	150	53.67	None	None	13	0.14	102.89	13	88.74
PEP2S	16/10/2009	42	Seepage	38.5	22.74	None	None	0.66	0.15	15.48	0.66	15
PEP2D	13/10/2009	180	Seepage	152.5	22.3	None	None	10	0.14	-	-	-
PEP5S	22/10/2009	24	8.3	21	5.6	5,8,12,20,25,34	0.28	68.3	25	13.57	68.3	2.5
PEP5D	17/11/2009	160	Seepage	-	6.63	-	-	Slug test	-	-	-	-
PEP6S	10/10/2009	24	0.2	23.5	5.34	None	None	3.4	0.2	17.01	3.4	0.02
PEP6D	6/11/2009	156	0.7	146.5	2.77	0.2,0.4,0.8,1.6	23.68	24	0.5	81.61	24	19.61
PEP7D	15/10/2009	121	Seepage	121	18.18	None	None	2.5	0.14	91.59	2.5	68.52
PEP8S	22/10/2009	31	0.7	29.5	6.14	0.2,0.4,0.8,1.6	0.65	24	0.55	8.11	20	0.76
PEP9S	8/11/2009	44	Seepage	41.5	30.55	None	None	0.25	0.1	9.85	1	9.85
PEP10S	24/10/2009	26	0.35	23.5	6.48	0.5,0.7,1	0.18	12	0.32	1.04	12	0.05
PEP10M	13/10/2009	40	1.0	38	3.34	0.5,1.4,2.5,4	1.32	16.6	2.02	32.66	13.3	0.0
PEP10D	27/10/2009	151	Seepage	146.5	4.57	None	None	11.6	0.1	134.50	11.6	45.12
PEP11S	13/11/2009	42	2.0	38.5	19.5	0.5,1,2.3,4	0.02	24	1.66	9.07	12	0.22
PEP12S	24/10/2009	48	1.05	44.5	13.63	0.5.1.2	1.18	48	1.0	11.39	30	0.32
PEP12D	22/10/2009	151	0.8	146.5	14.73	0.2,0.4,0.8,1.6,3.4	0.92	24	1.0	83.81	24	0.12
PEP13S	18/11/2009	54	0.5	47.5	7.8	0.5,1,2.0,4	0.14	24	1.7	4.57	24	0.05
PEP14S	14/11/2009	54	1.0	50.5	4.35	0.5,1,2	0.41	24	1.05	10.18	24	0.03
PEP14D	22/10/2009	180	0.5	108	4.63	0.2,0.5,1	58.08	5	0.55	99.93	3.3	48.22
PEP15S	7/11/2009	56	1.4	47.7	14.05	0.5,1,2.3,4	0.21	48	1.75	14.37	12	0.99
PEP16S	12/11/2009	56	1.7	46.5	5.86	0.5,1,2.3,4	0.35	48	2.55	11.35	28.3	0.33
PEP16D	17/11/2009	180	Seepage	-	7.93	-	-	Slug test	-	-	-	-
PEP17S	29/10/2009	26	0.4	22.2	6.72	0.2,0.4	0.29	6.7	0.7	15.45	5	2.11
PEP17D	17/11/2009	150	Seepage	-	8.59	-	-	Slug test	-	-	-	-

An estimate of a borehole yield which is submitted to a slug test can be read from the graph of yield versus recession time (Figure 55), which was compiled by the Institute of Groundwater Studies (IGS). The higher the borehole yields the quicker the response or recession time.

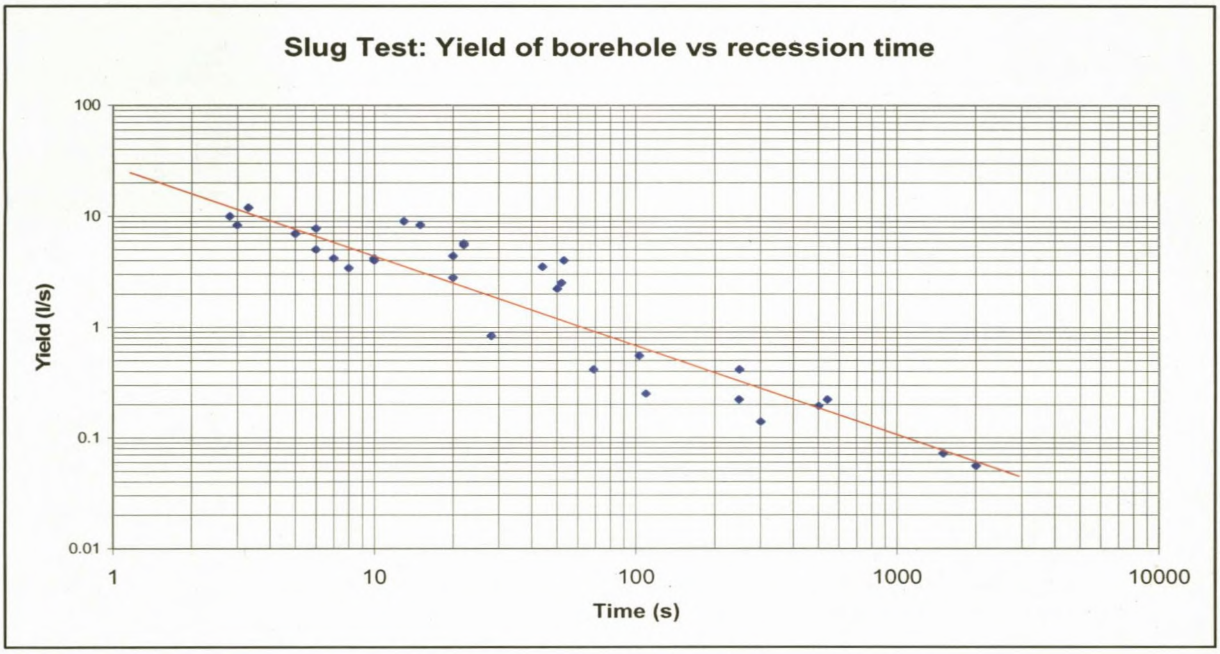


Figure 55: Slug Testing - Yield versus Recession Time Graph (from IGS)

Test pumping was performed on 22 newly drilled boreholes to gain an understanding of the aquifer hydraulics. These hydraulic parameters determined from the test data provide essential inputs into the numerical flow and transport model required for the impact assessment.

7.4. Evaluation of Pump Testing Results

Pump testing results were interpreted by means of *WHI Aquifer Test version 3 software, by Waterloo Hydrogeologic Inc.* The pump testing results are summarised in Table 24 and pump testing graphs are listed in Appendix C. Observation boreholes monitored during CDT are listed in Table 25: with calculated S values. The software uses of the XY borehole coordinates, borehole parameters and pumps test data of tested and observation boreholes to calculate S values.

The test pumping results indicate and confirm the presence of a weathered-fractured aquifer at shallow depth. On the plotted test pumping graphs, the hydraulic response of the aquifer shows a steady initial drawdown of the water level, with a sharp increasing (dewatering) trend as the water level exceeds the depth of the weathered-fractured zone of the aquifer.

Table 24: Summarised Pump Test Results of NSPP

Borehole Number	Static Water level (mbgl)	Pump Test Duration(Hr)	Test Yield (l/s)	Hydraulic conductivity(k) Slug in (m/day)	Hydraulic conductivity(k) Slug out (m/day)	Transmissivity Pumping (T) (m^2/day)	Transmissivity Recovery (T) (m^2/day)	Storativity (S)	Aquifer Classification
PEP1S	19.27	4.2	0.15			*1.07*	*0.443*		Weathered Pyroxenite
PEP1D	53.67	13	0.14			*0.0266*	*0.351*	$2.9x10^{-4}$	Pyroxenite – Fresh to slightly fractured
PEP2S	22.74	0.66	0.15			*0.119*	*Not recovered*		Weathered Pyroxenite
PEP2D	22.3	10	0.14			*0.0293*	*0.139*	$1.14X10^{-4}$	Pyroxenite – Fresh to slightly fractured
PEP5S	5.6	68.3	25			*834*	*739*	$1.03x10^{-4}$	Fractured Granitic gneiss
PEP5D	6.63	Slug test	-	0.00724	0.00417				Granitic gneiss and dolerite
PEP6S	5.34	3.4	0.2			*2.64*	*0.319*		Fractured dolerite
PEP6D	2.77	24	0.5			*0.277*	*0.393*		Dolerite and granitic gneiss Fresh to slightly fractured
PEP7D	18.18	2.5	0.14			*0.0293*	*0.123*		Granitic gneiss Fresh to slightly fractured
PEP8S	6.14	24	0.55			*17.7*	*25.4*	$5.37X10^{-3}$	Fractured Granitic gneiss
PEP9S	30.55	0.25	0.1			*0.185*	*Not recovered*		Pyroxenite Fresh to slightly fractured
PEP10S	6.48	12	0.32			17.1	13.8	$1.3x10^{-2}$	Fractured Granitic gneiss and dolerite
PEP10M	3.34	16.6	2.02			*2.71*	*1.99*	$1.17x10^{-2}$	Fractured Granitic gneiss and dolerite
PEP10D	4.57	11.6	0.1			*0.0475*	*0.050*	$1.89X10^{4}$	Granitic gneiss and dolerite Fresh to slightly fractured
PEP11S	19.5	24	1.66			*40.5*	*59.4*		Fractured Pyroxenite and dolerite
PEP12S	13.63	48	1.0			*12.1*	*38.6*		Fractured Pyroxenite and dolerite
PEP12D	14.73	24	1.0			*3.22*	*4.75*	$5.71X10^{-3}$	Fractured Pyroxenite and dolerite
PEP13S	7.8	24	1.7			*527*	*134*		Fractured pyroxenite
PEP14S	4.35	24	1.05			*23.5*	*45.4*	$1.45X10^{-3}$	Fractured pyroxenite
PEP14D	4.63	5	0.55			*0.226*	*0.291*		Pyroxenite Fresh to slightly fractured
PEP15S	14.05	48	1.75			*21.4*	*32.8*		Fractured pyroxenite
PEP16S	5.86	48	2.55			*60.7*	*52.5*		Fractured pyroxenite
PEP16D	7.93	Slug test	-	0.0249	0.0146				Pyroxenite Fresh to slightly fractured
PEP17S	6.72	6.7	0.7			*1.38*	*1.05*		Fractured Granitic gneiss
PEP17D	8.59	Slug test	-	0.00228	0.00068				Granitic gneiss Fresh to slightly fractured

Table 25: Observation Boreholes with Calculated S Values during CDT (Aquifer Test -Cooper Jacob Method)

Tested Borehole	Observation Borehole	Draw down (m)	CDT (min)	Storativity - S	Method measured
PEP17S	PEP17D	0.08	400	-	Hand
PEP17S	PEP5S	No DD	400	-	Hand
PEP17S	PEP5D	No DD	400	-	Hand
PEP10D	PEP10M	0.02	700	$1.89X10^{-4}$	Hand
PEP10D	PEP10S	0.02	700	$1.89X10^{-4}$	Hand
PEP10D	PEP6S	No DD	700	-	Diver
PEP10D	PEP6D	No DD	700	-	Diver
PEP12S	PEP12D	0.42	2880	-	Hand
PEP12S	PEP11S	No DD	2880	-	Hand
PEP12D	PEP12S	0.17	1440	$5.71X10^{-3}$	Hand
PEP12D	PEP11S	0.01	1440	-	Hand
PEP12D	PEP11D	No DD	1440	-	Diver
PEP5S	PEP5D	5.42	3900	-	Hand
PEP5S	PEP17S	2.65	4000	$1.03x10^{-4}$	Hand
PEP5S	PEP17D	1.96	4000	-	Hand
PEP5S	PEP6S	0.118	4100	$1.6x10^{-4}$	Hand
PEP5S	PEP6D	0.114	4100	-	Hand
PEP5S	KGM-B32	No DD	4100	-	Diver
PEP5S	PEP8S	No DD	4100	-	Hand
PEP5S	PEP8D	No DD	4100	-	Diver
PEP5S	KGM-B5	No DD	4100	-	Diver
PEP5S	KGM-B7	No DD	4100	-	Diver
PEP5S	PEP3D	No DD	4100	-	Diver
PEP5S	PEP4D	No DD	4100	-	Diver
PEP10S	PEP10M	0.16	720	$1.3x10^{-2}$	Hand
PEP10S	PEP10D	0.66	720	-	Hand
PEP6D	PEP6S	0.02	1440	-	Hand
PEP2D	PEP2S	0.19	600	$1.14X10^{-4}$	Hand
PEP2D	PEP1S	No DD	600	-	Diver
PEP2D	PEP1D	No DD	600	-	Diver
PEP2D	KGM-B33	No DD	600	-	Diver
PEP1D	PEP1S	0.32	250	$2.9x10^{-4}$	Hand
PEP2S	PEP2D	No DD	800	-	Hand
PEP15S	NE8	0.2169	2880	-	Diver
PEP15S	PEP14S	No DD	2880	-	Diver
PEP15S	PEP16S	0.072	2880	$4.79x10^{-3}$	Diver
PEP15S	PEP16D	0.066	2880	-	Diver
PEP15S	PEP15D	No DD	2880	-	Diver
PEP7D	PEP1S	No DD	150	-	Diver
PEP7D	PEP1D	No DD	150	-	Diver
PEP10M	PEP10S	0.93	500	$1.17x10^{-2}$	Hand
PEP10M	PEP10D	8.29	500	-	Hand
PEP10M	PEP6S	No DD	500	-	Diver
PEP10M	PEP6D	No DD	500	-	Diver
PEP8S	PEP8M	0.0765	1440	$5.37X10^{-3}$	Hand
PEP8S	PEP9S	No DD	1440	-	Hand
PEP16S	NE8	No DD	2700	-	Diver
PEP16S	PEP16D	2.53	2700	-	Hand
PEP16S	PEP15S	No DD	2700	-	Diver
PEP16S	PEP15D	No DD	2700	-	Diver
PEP6S	PEP6D	0.02	200	-	Hand
PEP11S	PEP12D	No DD	200	-	Diver

7.4.1. CDT Results

The 22 tested borehole yields of the NSPP is summarised in Table 26. Low yields were experienced in the shallow weathered aquifer with the average yield is 0.15 l/s.

The yields in the deep fractured permeable aquifer zone range from as low as 0.1 l/s to 25l/s. The average pumped yield obtained for the fractured aquifer zone is 0.9 1l/s (excluding PEP5S of 25 l/s).

The average pump tested yield for the slightly fractured to fresh aquifer system is 0.5 l/s.

Table 26: Tested Borehole Yield in Different Aquifer Zones of the NSPP

Borehole No.	Tested Yield (l/s)	Aquifer Classification	Water Strike (mbgl)
Weathered Aquifer Zone			
PEP1S	0.15	Weathered Pyroxenite	37
PEP2S	0.15	Weathered Pyroxenite	seepage
Average Yield	**0.15**		
Fractured Aquifer Zone			
PEP10S	0.32	Fractured Granitic gneiss and dolorite	11
PEP10M	2.02	Fractured Granitic gneiss and dolorite	11
PEP11S	1.66	Fractured Pyroxenite and dolorite	29
PEP12S	1.0	Fractured Pyroxenite and dolorite	31,39
PEP12D	1.0	Fractured Pyroxenite and dolorite	60
PEP13S	1.7	Fractured pyroxenite	16
PEP14S	1.05	Fractured pyroxenite	11
PEP14D	0.55	Pyroxenite Fresh to slightly fractured	69
PEP15S	1.75	Fractured pyroxenite	27,36
PEP16S	2.55	Fractured pyroxenite	17
PEP17S	0.7	Fractured Granitic gneiss	14
PEP1D	0.14	Pyroxenite – Fresh to slightly fractured	Seepage
PEP2D	0.14	Pyroxenite – Fresh to slightly fractured	146
PEP5S	*25.0*	*Fractured Granitic gneiss*	*7,11,16*
PEP6S	0.2	Fractured dolorite	4,8
PEP7D	0.14	Granitic gneiss Fresh to slightly fractured	Seepage
PEP8S	0.55	Fractured Granitic gneiss	17
PEP9S	0.1	Pyroxenite Fresh to slightly fractured	41
Average Yield	**0.9**		
Slightly Fractured to Fresh			
PEP6D	0.5	Dolorite and granitic gneiss Fresh to slightly fractured	57,129
PEP10D	0.1	Granitic gneiss and dolorite Fresh to slightly fractured	137
Average Yield	**0.5**		

7.5. NPM Aquifer Testing

The objective of the aquifer testing at the NPM was to:

- To gain an understanding of the aquifer hydraulics; and
- To determine aquifer parameters.

7.5.1. Pump Testing Specification and Procedures

Technical specifications for pump testing of boreholes were prepared by a hydrogeologist to ensure that the testing equipment fielded was suitable for testing and to capitalize on testing data collection. Test pumping was performed on 13 newly drilled boreholes and details are summarised in Table 27.

Pump testing consisted out of a step drawdown test (SDT) followed by a constant discharge test (CDT), and a water level recovery test. Each SDT comprised three to four 60-minute steps at increasing pumping rates. The aim of the SDT is to assess the performance of the borehole under different pumping yields and determine the pumping rate for the CDT.

The CDT is conducted to determine the hydraulic parameters of the aquifer and identify possible aquifer boundaries. The CDT was conducted for periods of between 12 and 48 hours, after which the water level recovery was measured. The CDT pumping rates were set at yields determined from the SDT to be sustainable for the planned duration of the test. Pumping rates varied from 0.2 l/s to 15 l/s. Pumping yields were measured volumetrically.

Water-level recovery measurements were taken for the same period as pumping during the SDT and CDT or to 95% recovery of the original water level. The recovery of the boreholes provides an independent measure of the Transmissivity of the aquifer. Water levels were monitored in shallow and deep boreholes during the CDT to determine whether the shallow and deep aquifer systems are linked.

Table 27: Summarised Pump Testing Details of NPM

Borehole no.	Completion date	Borehole depth(m)	Blow Yield (l/s)	Pump Installation depth(m)	Static Water Level (mbgl)	Type of Test	SDT (l/s)	Recovery after SDT (m)	CDT (hr)	CDT (l/s)	D/D after CDT (m)	Recovery after CDT (hours)	Draw down After recovery (m)
NPM1D	18/4/2011	180	2	174	90.82	CDT	0.39,1.14,2.02,4.01,7.12	0.29	48	2.73	27.90	48	3.21
NPM2S	28/3/2011	48	Seepage	Slug	14.98	Slug	-						
NPM2D	30/3/2011	180	0.4	153	15.88	CDT	0.2,0.45,0.81,1.4	11.52	12	0.21	51.32	12	2.96
NPM3S	24/3/2011	48	Seepage	Slug	17.46	Slug	-						
NPM3D	6/5/2011	180	0.4	141	17.2	CDT	0.45,0.91,1.82	13.14	12	0.37	73.95	12	1.07
NPM4S	27/4/2011	66	2.2	62	27.39	CDT	0.53,1.1,2.12	0.06	48	1.12	29.44	38	0.94
NPM4D	30/3/2011	180	0.2	Slug	26.22	Slug	-						
NPM5S	30/3/2011	42	Seepage	Slug	19.4	Slug	-						
NPM5D	10/5/2011	180	0.1	Slug	20.45	Slug	-						
NPM6S	10/4/2011	42	1.9	39	5.82	Slug	0.55,1.13,2.21,4.46	0.35	48	1.7	10.90	48	0.92
NPM6D	20/4/2011	180	0.4	141	14.94	CDT	0.23,0.46,1.02	18.62	8	0.41	139.39	8	28.40
NPM7S	25/3/2011	54	0.8	53	19.88	CDT	0.29,0.66,0.91,1.64	1.96	12	0.62	25.8	12	3.0
NPM7D	10/5/2011	180	Seepage	Slug	24.39	Slug	-						
NPM8S	12/4/2011	36	Seepage	Slug	16.58	Slug	-						
NPM8D	14/4/2011	180	Dry	Slug	15.70	Slug	-						
NPM9S	29/3/2011	18	0.4	15	2.95	CDT	0.31,0.71	0.5	10	0.3	10.96	12	0.73
NPM9D	6/4/2011	180	3.8	141	29.97	CDT	1,2.4,5.21,10.43	0.52	48	4.81	34.93	48	0.54
NPM10S	13/4/2011	32	Seepage	Slug	13.99	Slug	-						
NPM10D	12/4/2011	180	0.3	155	14.11	CDT	0.2,0.45,0.92,1.56	5.01	12	0.2	21.74	12	0.6
NPM11D	27/3/2011	180	4.4	141	1.2	CDT	1.98,4.42,8.65,10.46	0.33	12.3	5.65	138.96	9	0.62
NPM12S	Not Tested	24	Seepage	Not Tested	22.63	Not Tested	-						
NPM12D	19/4/2011	180	0.2	Slug	23.36	Slug	-						
NPM13S	10/5/2011	30	Seepage	Slug	21.12	Slug	-						
NPM14S	5/5/2011	30	1.4	27	5.96	CDT	0.36,0.8,1.68	0.19	48	0.82	8.76	48	0.53
NPM15S	Not Tested	44	Seepage	Not Tested	44.3	Not Tested	-						
NPM16S	10/5/2011	71	>10	66	48.57	CDT	1.9,4,7.8/9,15.5,19	0.45/1.82	2/6.3	15/5.4	15.43/15.48	4/12	2.81/3.88

7.5.2. Pump Testing Results

Pump Testing results of the NPM were interpreted by means of *WHI Aquifer Test version 3 software, by Waterloo Hydrogeologic Inc.* The pump testing results of the NPM are summarised in Table 28.

Only seven S (Storativity) values could be calculated for the NPM area because of long distances and dolerite dykes between testing boreholes.

The test pumping results indicate and confirm the presence of a weathered-fractured aquifer at shallow depth.

NPM16 which intersected a large open fracture are localised and contain approximately 100.9 m^3 of groundwater. The fracture zone was pumped dry to pump inlet situated below the fracture and was pumped for 15.02 l/s within 6720 s. Inflow rate of groundwater into the cavity is approximately 5 l/s (81.7% recovery over 4hours).

The test pumping results and water levels of the NPM confirm that the shallow and deeper aquifer zones are linked. Inter action was confirmed during pump testing between the deep and shallow monitoring boreholes at NPM2S/D, NPM3S/D, NPM4S/D, NPM6S/D and NPM10S/D (Table 29).

Table 28: Summarised Pump Testing Results of NPM

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	Type of Test	Constant Draw Down Duration(Hr)	Test Yield (l/s)	Transmissivity Pumping (T) (m^2/day)	Transmissivity Recovery (T) (m^2/day)	Storativity (S)	Geology Intersected and Aquifer Classification
NPM1D	180	90.82	CDT	48	2.73	6.08	6.16		Granite-DFA
NPM2D	180	15.88	CDT	12	0.21	$3.39X10^{-1}$	$7.41X10^{-2}$	$3.13X10^{-6}$	Pyroxenite and Dolerite-DFA
NPM3D	180	17.2	CDT	12	0.37	$1.91X10^{-1}$	$1.99X10^{-1}$	$1.36 X10^{-5}$	Pyroxenite-DFA
NPM4S	66	27.39	CDT	48	1.12	2.65	1.65	$7.65X10^{-5}$	Pyroxenite-F
NPM6S	42	5.82	CDT	48	1.7	$1.12X10^{+1}$	$1.15X10^{+1}$	$4.48X10^{-6}$	Granite and Dolerite-F
NPM6D	180	14.94	CDT	8	0.41	$3.19X10^{-1}$	$4.91X10^{-2}$	$4.04X10^{-6}$	Granite and Dolerite-DFA
NPM7S	54	19.88	CDT	12	0.62	1.25	$4.7X10^{-1}$	$2.87X10^{-5}$	Granite and Dolerite-F
NPM9S	18	2.95	CDT	10	0.3	6.21	1.04		Granite-F
NPM9D	180	29.97	CDT	48	4.81	$8.61X10^{-2}$	$7.47X10^{-2}$		Granite-DFA
NPM10D	180	14.11	CDT	12	0.2	$4.62X10^{-1}$	$1.66X10^{-1}$	$2.32X10^{-5}$	Granite and Dolerite-DFA
NPM11D	180	1.2	CDT	12.3	5.65	$1.08X10^{+2}$	$1.01X10^{+2}$		Pyroxenite-BF
NPM12S	24	22.63	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Granite-W
NPM14S	30	5.96	CDT	48	0.82	7.32	7.36		Granite-F
NPM15S	45	44.3	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Granite and Dolorite-F
NPM16S	71	48.57	CDT	2/6.3	15/5.4	$1.48X10^{+2}$	$1.23X10+^{2}$		Pyroxenite and Dolerite-F

Table 29: Observation boreholes at NPM

Tested Borehole	Observation Borehole	Draw down (m)	CDT (min)	Storativity (S)	Method measured
NPM1D	NPM11D	0.0	2880		Diver
	NPM14S	0.0	2880		Hand
	NPM13S	0.0	2880		Hand
	NPM10S/D	0.0	2880		Hand
NPM2D	NPM2S	0.07	720	$3.13X10^{-5}$	Hand
	NPM3S/D	0.0	720		Hand
	NPM4S/D	0.0	720		Diver
NPM3D	NPM3S	0.52	720	$1.36\ X10^{-5}$	Hand
	NPM2S/D	0.0	720		Hand
NPM4S	NPM4D	1.83	2880	$7.65X10^{-5}$	Hand
	NPM3S	0.0	2880		Hand
	NPM2S	0.0	2880		Hand
	NPM8S	0.0	2880		Diver
NPM6S	NPM6D	2.13	2880	$4.37X10^{-6}$	Hand
	NPM7S	0.14	2880	$4.54X10^{-6}$	Hand
	NPM5S	0.0	2880		Hand
NPM6D	NPM6S	0.08	480	$4.04X10^{-6}$	Hand
	NPM7S/D	0.0	480		Hand
NPM7S	NPM6S	0.07	720	$2.87X10^{-5}$	Hand
	NPM6D	0.0	720		Hand
NPM9S	None	None	None	None	None
NPM9D	NPM9S	0.0	2880		Handr
NPM10D	NPM10S	0.84	720	$2.33X10^{-5}$	Hand
	NPM8S	0.0	720		Diver
	NPM1D	0.0	720		Diver
NPM11D	NPM6S	0.0	740		Diver
	NPM9S	0.0	740		Diver
	NPM1D	0.0	740		Diver
NPM14S	NPM13S	0.0	2880		Hand
	NPM10S/D	0.0	2880		Hand
NPM16S	NPM8S/D	0.0	2880		Hand
	NPM1D	0.0	380		Diver
	NPM4S/D	0.0	380		Hand

7.5.3. Slug Testing

Slug tests were conducted on 11 low-yielding boreholes at the NPM. Monitoring boreholes NPM12S (1.37 m) and NPM15S (0.7 m) were not submitted to slug test as the available water in the boreholes were not sufficient to perform slug test on.

The slug test results of the NPM is summarised in Table 30:

Table 30: Summarised Slug Testing Results of the NPM

Borehole Number	**Borehole Depth (m)**	**Static Water level (mbgl)**	**Hydraulic conductivity(k) Slug in (m/day)**	**Hydraulic conductivity(k) Slug out (m/day)**	**Geology Intersected and Aquifer Classification**
NPM2S	48	14.98	$2.25X10^{-3}$	$8.21X10^{-3}$	Pyroxenite-W
NPM3S	48	17.46	$8.31X10^{-3}$	$8.80X10^{-3}$	Pyroxenite-W
NPM4D	180	26.22	$2.82X10^{-2}$	$5.50X10^{-2}$	Pyroxenite-DFA
NPM5S	42	19.4	$2.25X10^{-2}$	$2.14X10^{-2}$	Granite and Dolerite-W
NPM5D	180	20.45	$7.82X10^{-9}$	$9.11X10^{-9}$	Granite and Dolerite-DFA
NPM7D	180	24.39	$1.7X10^{-9}$	$3.37X10^{-8}$	Granite and Dolerite-F
NPM8S	36	16.58	$1.46X10^{-3}$	$1.53X10^{-3}$	Dolerite-W
NPM8D	180	15.70	$3.25X10^{-9}$	$2.16X10^{-9}$	Granite and Dolerite-F
NPM10S	32	13.99	$8.88X10^{-2}$	$9.37X10^{-2}$	Dolerite-W
NPM12D	180	23.36	$1.09X10^{-3}$	$1.92X10^{-3}$	Granite and Dolerite-F
NPM13S	30	21.12	$8.15X10^{-7}$	$5.83X10^{-7}$	Granite and Dolerite-W

CHAPTER 8: Groundwater Chemistry

8.1. Groundwater Sampling

8.1.1.Objective and Methodology

The objective of the groundwater sampling was to assess and determine the baseline groundwater quality for the new PEP area. Water samples were collected from 27 boreholes and were sent to UIS laboratory, an accredited laboratory in Centurion for analysis. Analytical Certificates are on a cd attached at the back of the thesis. Samples were analysed for the following:

- pH, EC, TDS, SO_4, Ca, Mg, K, Na, NO_3 as N, alkalinity as $CaCO_3$; and
- ICP scans for metals such as Fe, Mn, and Al.

This data is used to confirm together with existing data a baseline groundwater quality for the area of investigation, against which future impacts can be measured.

8.1.2. Sampling Procedure

Monitoring boreholes which were submitted to CDT were sampled during the constant draw down test to obtain a groundwater sample that is representative of the surrounding geological formation. Monitoring boreholes that were not submitted to test pumping were sampled with disposable bailers (Figure 56).

Figure 56: Disposable Bailer

Groundwater sampling was undertaken in accordance with South African standards. The water samples consist out of 1 litre hydrochemistry samples and acidified filtered water samples.

Samples were stored in a cooler box with ice packs and were maintained in a cool state until delivery to the laboratory within the required holding times. Field parameter measurements were taken at time of sampling of Temp, pH and EC.

8.1.3. Field Parameter Measurements

Hand held field measurements were taken of pH, EC and temperature of all sampled boreholes and are summarised below in Table 31.

Table 31: Field Measurements

Borehole number	pH	EC (mS/m)	Temp ° Celsius	Sample Method
PEP 17D	8.91	165	24.4	Bailer sample
PEP 17S	7.09	476	24.5	CDT
PEP 16S	6.84	539	30.7	CDT
PEP 15S	7.12	339	25.1	CDT
PEP 14S	7.28	568	20.6	CDT
PEP 13S	7.04	613	19.4	CDT
PEP 12D	7.08	459	27.6	CDT
PEP 12S	7.0	239	26.6	CDT
PEP 11S	7.27	210	28	CDT
PEP 10D	7.42	189	26.2	CDT
PEP 10M	6.94	167	28.1	CDT
PEP 10S	6.88	296	27.7	CDT
PEP 8S	6.96	331	33.1	CDT
PEP 7D	7.45	126	26.5	CDT
PEP 6D	7.44	108	25.3	CDT
PEP 6S	6.95	383	30.7	CDT
PEP 5S	7.15	340	26.2	CDT
PEP 5D	8.6	301	23.7	Bailer sample
PEP 2D	7.85	146	28.2	CDT
PEP 2S	8.64	114	26.6	CDT
PEP 1D	8.38	90	27.5	CDT
PEP 1S	7.25	108	28.2	CDT
PEP 11D	10.03	127	27.4	Bailer sample
PEP 15D	9.23	296	25.1	Bailer sample
PEP 14D	7.35	529	28.5	CDT
PEP 9S	8.31	90	20.0	CDT
PEP 16D	8.35	503	24.7	Bailer sample

The pH values of most of the groundwater samples measured with hand held instruments are all near neutral to alkaline. The field measurements of the bailed samples pH are all alkaline and of a higher order because of stagnant groundwater in boreholes (8.3 to 10.03), to the pH of the pumped boreholes (6.8 to 8.64).

The pH of groundwater is highly related to the geology composition of the host formation and is predominantly to the weathered section which is more permeable. The neutralization of hydrogen ions in groundwater results in an increase in pH and is referred to as an alkalinisation process. These overall alkaline pH values measured are probably caused by alkaline elements such as Ca, Mg and Na which are leached from the host formation.

Relative high EC values were measured ranging from 90mS/m to 613mS/m. The high EC values are an indication that the groundwater quality is probably affected by the mining activities.

8.2. Evaluation of Analytical results

Table 32 presents the analytical results from the groundwater at Foskor - Phalaborwa. Analytical results are compared to the SANS 241 (2006) Class I drinking water quality guidelines. Highlighted values in red exceed the Class I guidelines upper limit for drinking water standards and green the maximum allowable limit.

Elevated concentrations of calcium, magnesium and sodium have been reported for most of the samples and can be related to the geology. The Phalaborwa complex represents the remains of an alkaline volcano that was once active 2047 Millions years ago, (Wilson and Anhaueusser, 1998). Previous studies have reported plagioclase and clay minerals as the main mineral occurrences on the mine site (Moukodi, 2008). As a result, Ca, Mg and Na are expected to occur naturally in the groundwater in elevated concentrations.

Elevated sulphate concentrations result from the neutralisation of sulphide-bearing waste deposits like the waste rock and the copper sulphide tailings dam in the vicinity of the site. These two waste facilities are located up-gradient from the site and the Selati River (a tributary to the Olifants River).

The pH of the water is near-neutral to alkaline and metal concentrations (Fe, Mn, Al) are within the SANS 241 Class I water quality guidelines (SANS 2006). The near neutral to alkaline pH of the groundwater relates to the presence of alkaline elements such as Ca, Mg and Na. Elevated nitrates can be attributed to explosives residual from the mine blasting activities on site.

Table 32: Summarised Hydrochemistry Results of Sampled Boreholes

Sample ID	pH	TDS(mg/l)	EC(mS/m)	Ca(mg/l)	Mg(mg/l)	Na(mg/l)	K(mg/l)	SO$_4$(mg/l)	Cl(mg/l)	HCO$_3$(mg/l)	Al(mg/l)	Mn(mg/l)	Fe(mg/l)	NO$_3$(mg/l)
PEP 17D	8.8	920	151	12	111	138	23	357	208	205	0.05	0.05	0.05	0
PEP 17S	7.9	1160	176	102	133	122	32	339	200	388	0.05	0.05	0.05	26
PEP 16S	7.3	5930	804	383	513	419	62	3010	379	396	0.05	0.29	0.13	78
PEP 15S	8.0	3710	547	203	379	262	67	1770	335	387	0.05	0.07	0.05	14
PEP 14S	8.1	5500	791	304	714	451	123	3130	432	396	0.05	0.05	0.14	96
PEP 13S	7.9	6230	855	613	506	351	47	3150	381	350	0.05	0.05	0.08	127
PEP 12D	7.4	4340	649	311	437	160	57	1860	456	320	0.05	0.05	0.05	210
PEP 12S	7.7	4090	616	354	435	151	51	2090	404	284	0.05	0.05	0.05	0
PEP 11S	7.9	1530	175	73	153	124	45	449	159	432	0.05	0.05	0.05	20
PEP 10D	7.5	1060	156	91	36	205	7	230	354	101	0.05	0.10	0.57	0
PEP 10M	7.4	1910	365	170	131	204	12	795	229	309	0.05	0.11	0.35	2
PEP 10S	7.3	2480	400	253	196	164	11	1120	233	277	0.05	0.05	0.05	22
PEP 8S	7.7	2630	414	143	255	179	50	807	368	373	0.05	0.05	0.05	64
PEP 7D	7.9	714	114	50	39	149	11	61	94	446	0.05	0.16	0.15	2
PEP 6D	7.9	598	81	63	32	85	7	28	126	290	0.05	0.18	0.06	0
PEP 6S	7.7	3480	487	312	281	144	29	1390	286	297	0.05	0.07	0.08	82
PEP 5S	7.1	732	106	140	1	120	24	76	383	20	0.05	0.05	0.12	0
PEP 5D	8.4	2370	405	89	345	226	67	1270	358	109	0.05	0.05	0.20	216
PEP 2D	8.2	520	85	35	30	73	33	78	86	229	0.05	0.05	0.05	3
PEP 2S	8.2	812	132	52	96	79	43	199	96	383	0.05	0.13	0.14	17
PEP 1D	7.6	2930	423	214	264	154	43	1070	300	332	0.05	0.05	0.05	66
PEP 1S	7.8	712	104	62	66	44	40	91	62	371	0.21	0.34	0.13	10
PEP 11D	10	632	102	10	1	214	46	104	133	98	0.05	0.09	0.05	10
PEP 15D	8.3	2140	367	206	48	248	91	383	676	20	0.05	0.05	0.05	0
PEP 14D	8.0	4960	729	272	457	473	122	2750	429	343	0.05	0.05	0.36	67
PEP 9S	7.8	514	90	47	35	67	21	97	103	190	0.05	0.05	0.08	3
PEP 16D	8.2	4500	705	175	439	333	106	2490	465	77	0.05	0.05	0.35	40
SANS Class I	4.5 -10	1000	150	150	70	200	50	400	200	ng	0.3	0.1	0.2	10
Max Allowable		2400	370	300	100	400	100	600	600	na	0.5	1.0	2.0	20

8.2.1. Sulphate (SO_4)

Sulphide minerals have been mined in the area for several decades. These minerals (Covellite (CuS) and Chalcocite (Cu_2S)) occur in a carbonatite pipe, host of carbonated minerals such as calcite ($CaCO_3$). The reaction of the sulphide-bearing minerals and the carbonates release aqueous forms of sulphate as:

$$Cu_2S + CaCO_3 + O_2 + H_2O \rightarrow 2Cu^{2+} + Ca^{2+}{}_{(aq)} + SO_4^{2-}{}_{(aq)} + H_2CO_3 + 4e^-$$

$$CuS + CaCO_3 + {}^3/_2\, O_2 + H_2O \rightarrow Cu^{2+} + Ca^{2+} + SO_4^{2-} + H_2CO_3 + 2e^-$$

Where H_2CO_3 is carbon dioxide dissolved in water, (Moukodi, 2008).

Furthermore, the production of wet process phosphoric acid produces hydrated calcium sulphate (gypsum) as follows:

$$3\ H_2SO_4 + Ca_3\ (PO_4)_2 + 6\ H_2O \rightarrow 2\ H_3PO_4 + 3\ CaSO_4.2H_2O.$$

These processes can be accountable for the elevated concentrations of sulphate in the groundwater. Sulphate (SO_4), Ca, Mg and Na contribute to the Total Dissolved Solids (TDS).

8.2.2. Piper and expanded Durov Diagrams

The groundwater chemistry was plotted on Piper and expanded Durov diagrams to visually display and correlate the chemistry and different types of water. This approach is followed to determine if there is a difference in the quality of the two aquifer zones, and if both aquifers have been impacted by contamination from mining activities at the site.

Piper diagrams were used to graphically represent the relative percentages of anions and cations constituents of the groundwater of the sampled boreholes Figure 57. The cation percentages are plotted in the left triangle and the anion percentages in the right triangle. A projection of these cation and anion presentations onto the central block defines the type of water.

The *Expanded Durov diagram* (Figure 58) also represents the relative percentages of anions and cations in water samples. The cation percentages are plotted in the top part of the diagram and the anion percentages in the left part. A projection of these cation and anion percentages onto the central area presents the chemical signature of the major ion composition of the water related to various environments.

From the results of the Piper and expanded Durov diagrams two types of water dominate:

- Calcium magnesium sulphate type (Ca-Mg-SO_4); and

- Sodium magnesium bicarbonate type (Na-Mg-HCO_3).

The majority of the groundwater is a Ca-Mg-SO4 type, with magnesium being the dominant cation and sulphate the dominant anion and is evident on both diagrams. This plotting position on the piper diagram is typical of water being affected from mine pollution and from opencast mine water on the expanded Durov diagram. The calcium magnesium sulphate type of water-(Ca,Mg)SO_4 is present for both deep and shallow and indicates that both aquifers have already been impacted by the elevated sulphate originating from mining activities.

The second type of sodium magnesium bicarbonate (Na-Mg-HCO_3).is more present in the shallow aquifer than in the deep aquifer. However, this type is associated with the geological formation.

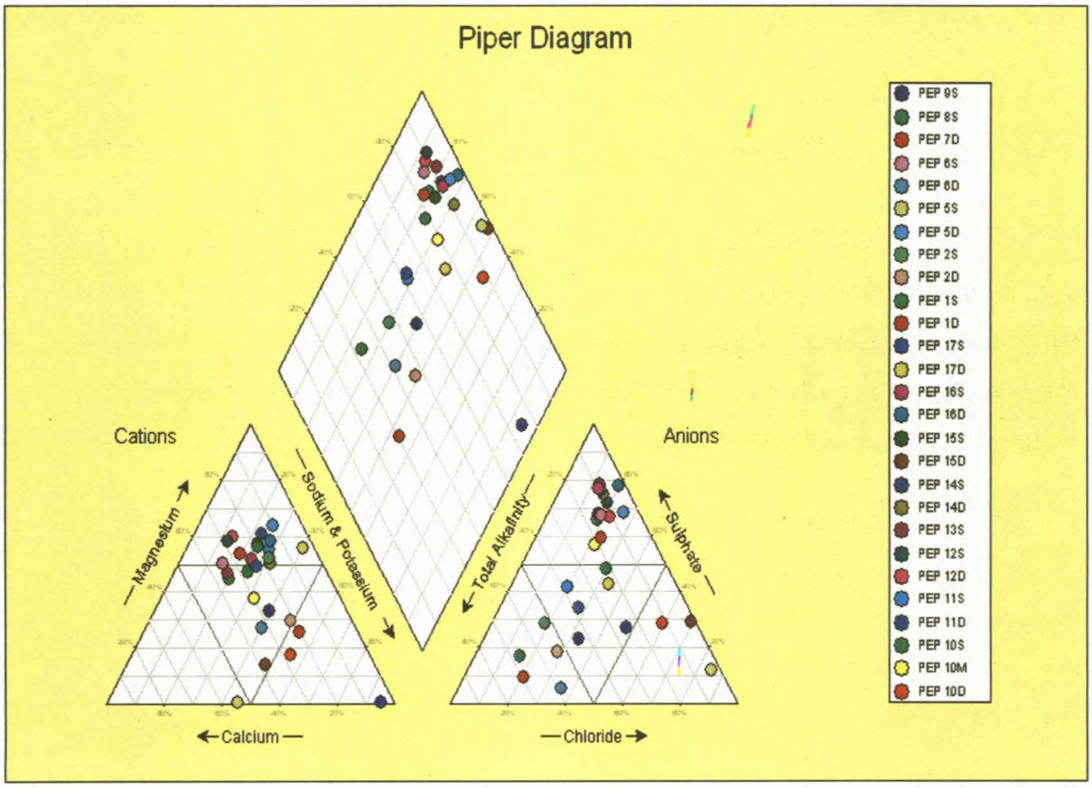


Figure 57: Piper Diagram of the Groundwater of Sampled Boreholes.

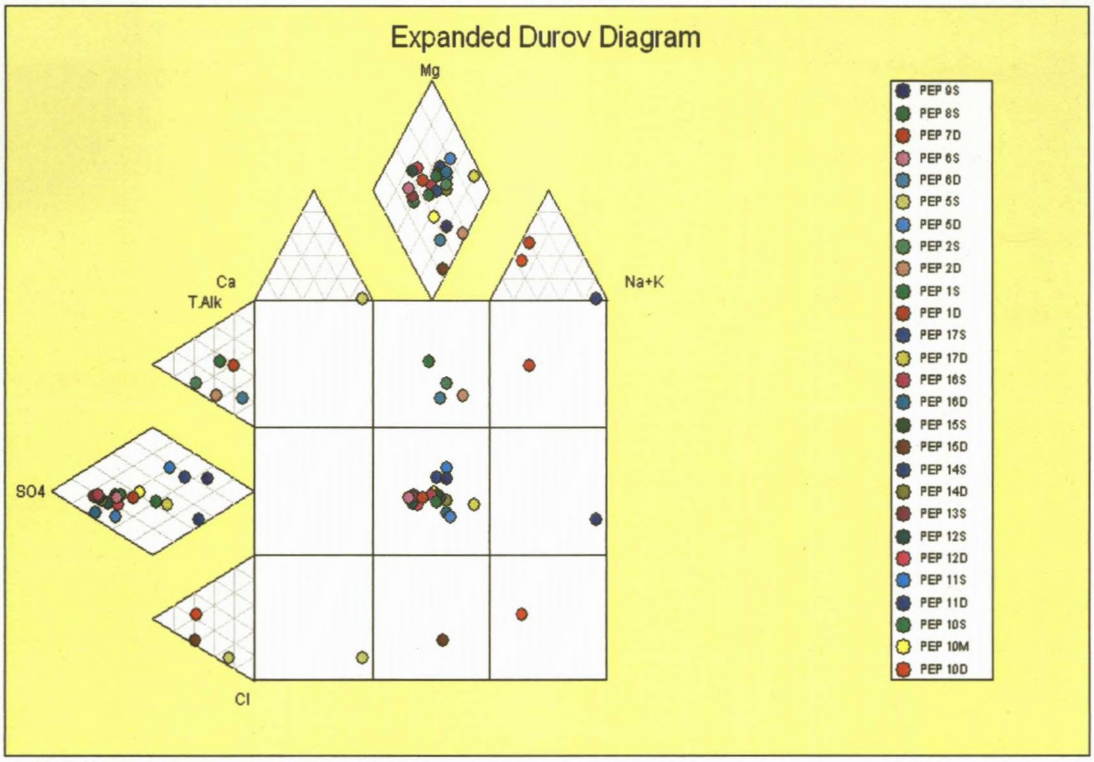


Figure 58: Expanded Durov Diagram

8.2.3. Sulphate Distribution

Figure 59 shows the distribution of sulphate concentrations at the NSPP area at Foskor. The areas with the highest concentrations are located immediately down gradient of the Waste Rock dump. This correlates with the chemical processes explained in the section above. The figure also confirms that deep and shallow ground water has been impacted with elevated sulphate concentrations.

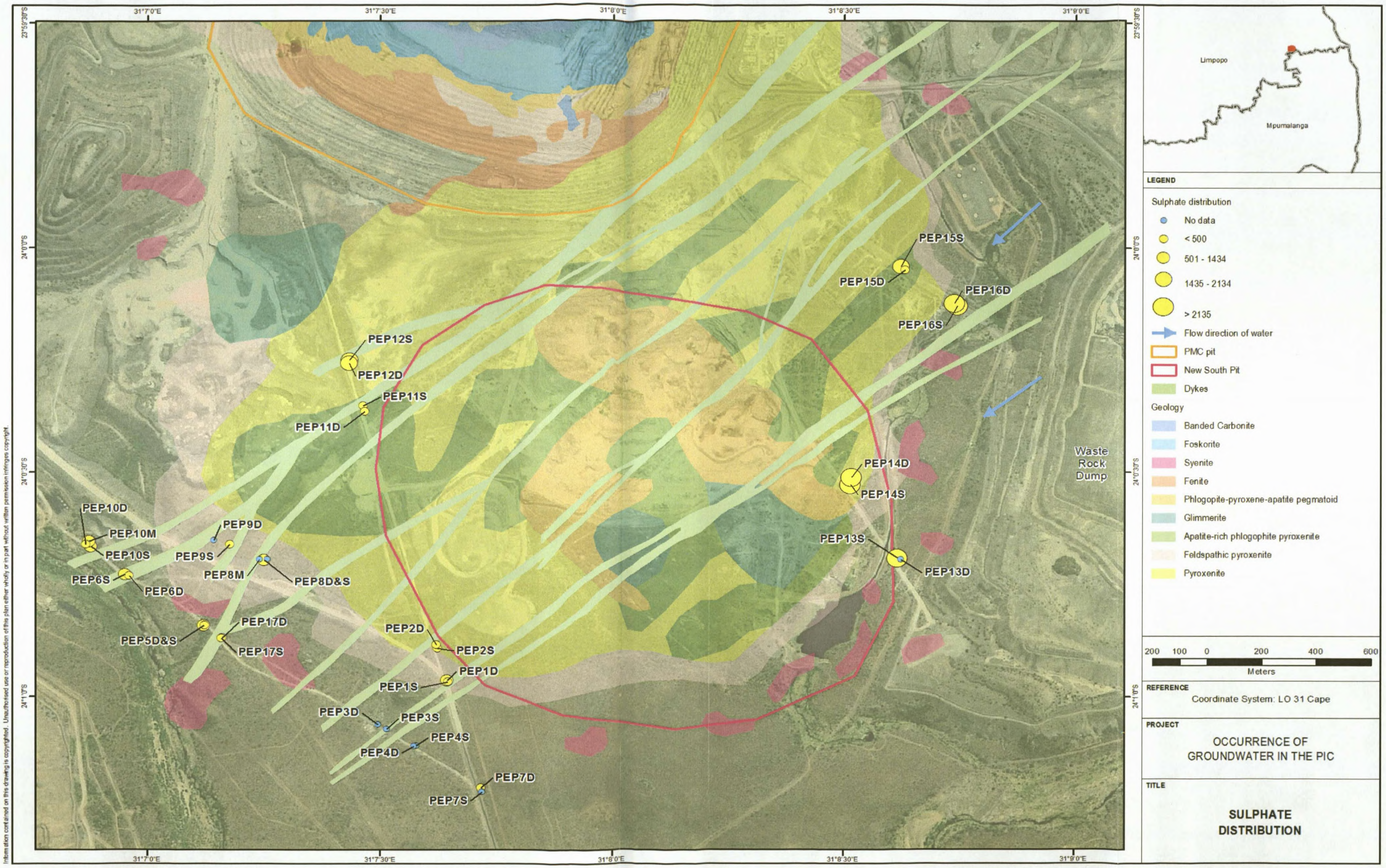


Figure 59: Sulphate Distribution

8.2.4. TDS Distribution

Figure 60 shows the distribution of TDS concentrations at the NSPP area at Foskor. The areas with the highest concentrations are located to the east of the study area. Ca, Mg, K and Na contribute to the high TDS values. The high TDS values correlate with the elevated sulphate concentrations down gradient of the Waste Rock dump.

8.2.5. pH Distribution

Figure 61 shows the distribution of pH concentrations at the NSPP area at Foskor. The alkaline elements Ca, Mg and Na contribute to the alkaline nature of the groundwater, with the highest pH value at PEP11D.

8.2.6. Cl Distribution

Figure 62 shows the distribution of Cl concentrations at the NSPP area at Foskor. The areas with the highest concentrations are located within the NSPP area, in the pyroxenite formation and the lowest values is to the south west in the granitic gneiss formation.

8.2.7. NO_3 Distribution

Figure 63 shows the distribution of nitrate concentrations at the NSPP area at Foskor. The high concentrations of nitrate are attributed to explosives residual from the mine blasting activities. There is no distinct nitrate distribution but areas with higher borehole yields tend to have higher concentrations. This relationship is probably from nitrate being easier dissolved and transported by higher yielding boreholes.

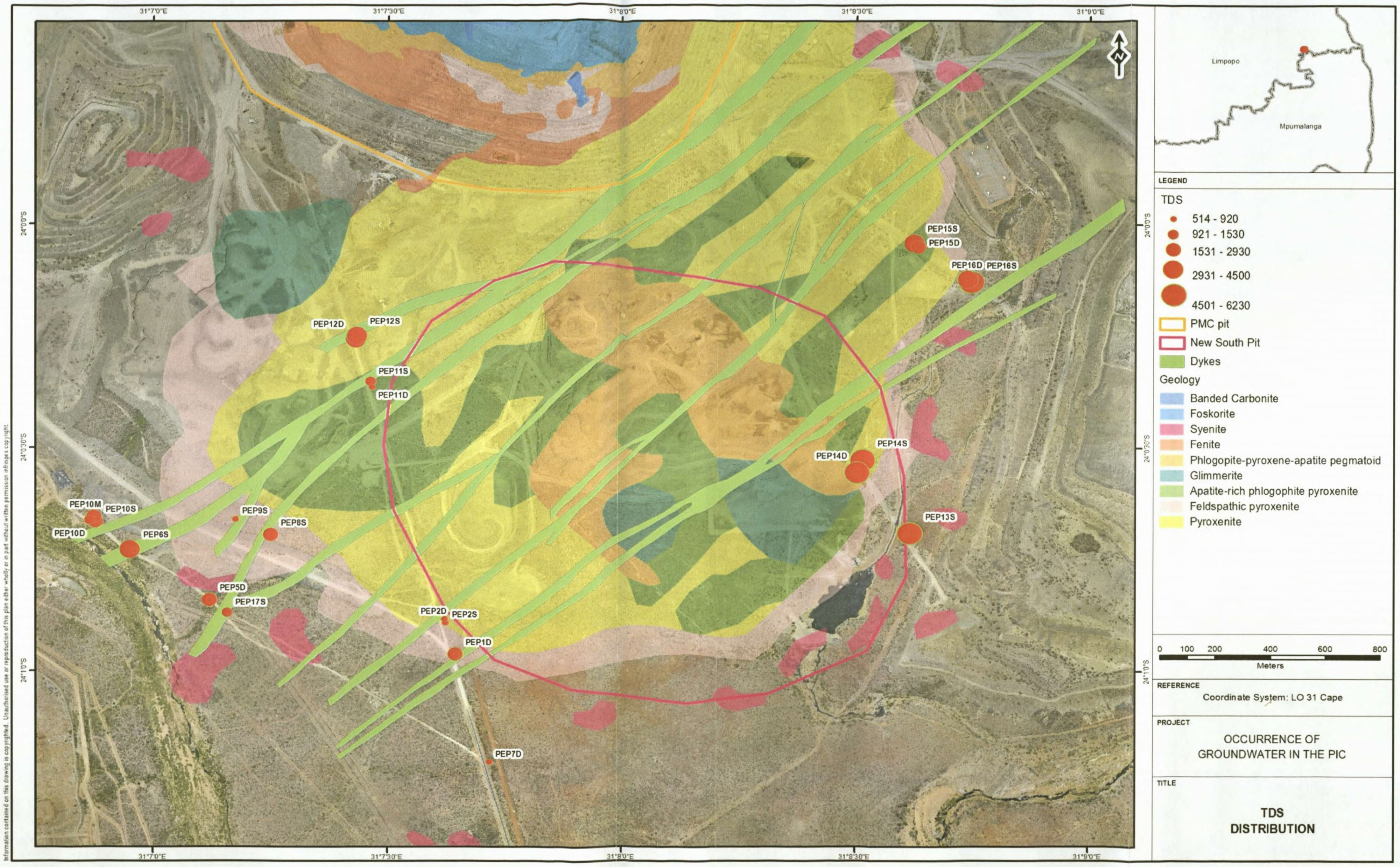


Figure 60: TDS Distribution

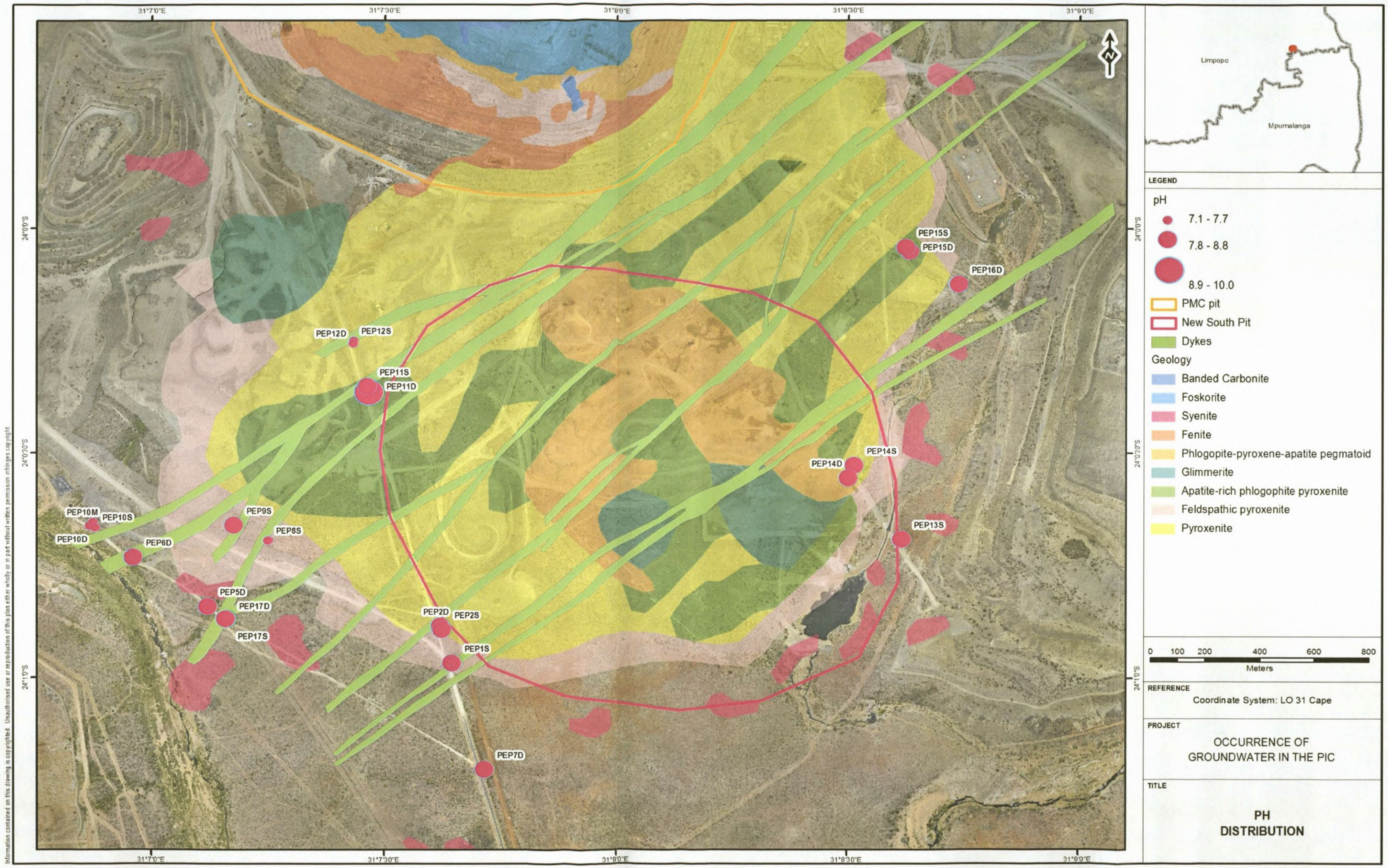


Figure 61: pH Distribution

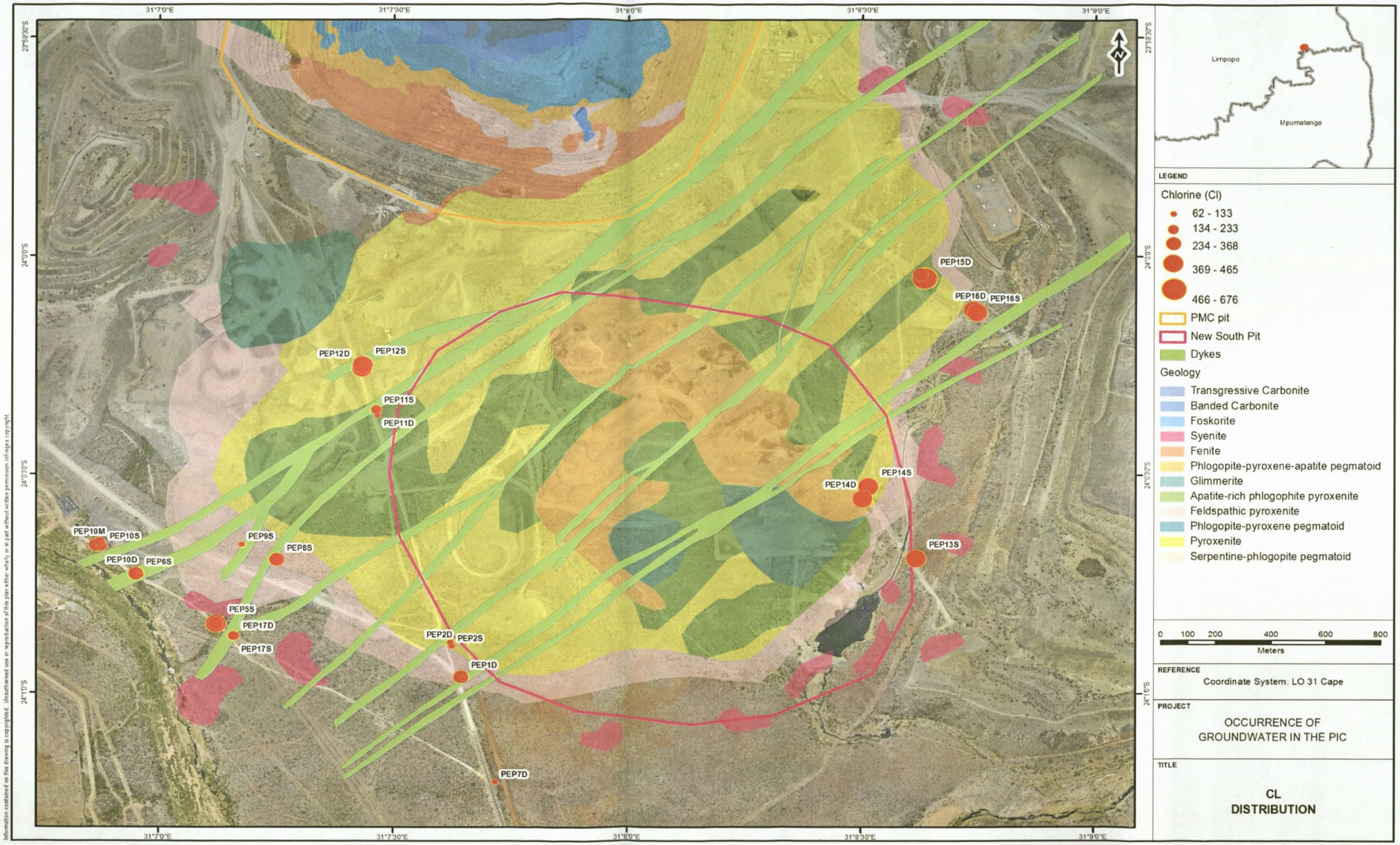


Figure 62: Cl Distribution

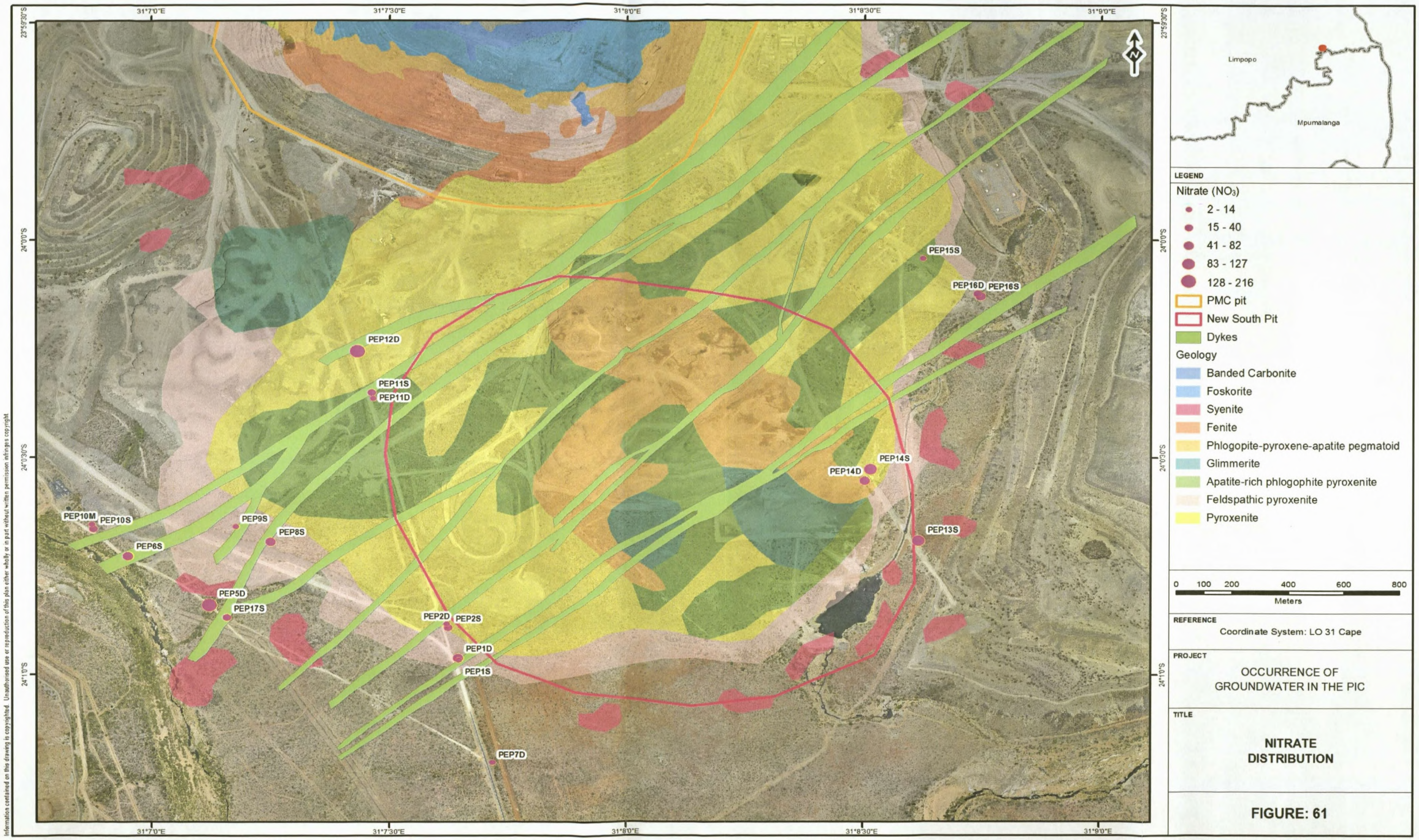


Figure 63: Nitrate Distribution

CHAPTER 9: Conceptual Model

A conceptual model is a simplified version of the reality or real word problem, using assumptions.

It is an interpretation of the characteristics and dynamics of an aquifer system which is based on an examination of all available hydrogeological data for a modelled area. This includes the external configuration of the system, location and rates of recharge and discharge, location and hydraulic characteristics of natural boundaries, and the directions of groundwater flow throughout the aquifer system.

A conceptual model forms the basis of understanding a groundwater problem.

9.1. Objective

The objective of the conceptual model for the NSPP area was to construct a geological and hydrogeological model of the study area to gain an understanding of the groundwater situation surrounding the pit area. This was obtained by using borehole logs to create geological cross sections, dolerite dyke positions, groundwater flow direction and pump testing data.

9.2. Geological Cross Sections

Two cross sections, representative of the geology were drawn across the investigation area. These cross sections are developed from constructing a borehole log profile of boreholes drilled during the field investigation phase. The compiled borehole log profile is listed in Annexure B together with detailed borehole logs. The positions of the cross sections are indicated on the conceptual model (Figure 66).

The cross sections together with the conceptual model constructed during the phase I study (Golder Report No. 10113/11436/2/G) were utilised to compile updated conceptual model for the new PEP investigation area.

- Cross section A -B: Figure 64 is a cross section through the granitic/gneiss next to the Selati River.
- Cross section C-B: Figure 65 is a cross section of the pyroxenite, in a south west to north-west direction on the road bordering the new PEP pit.

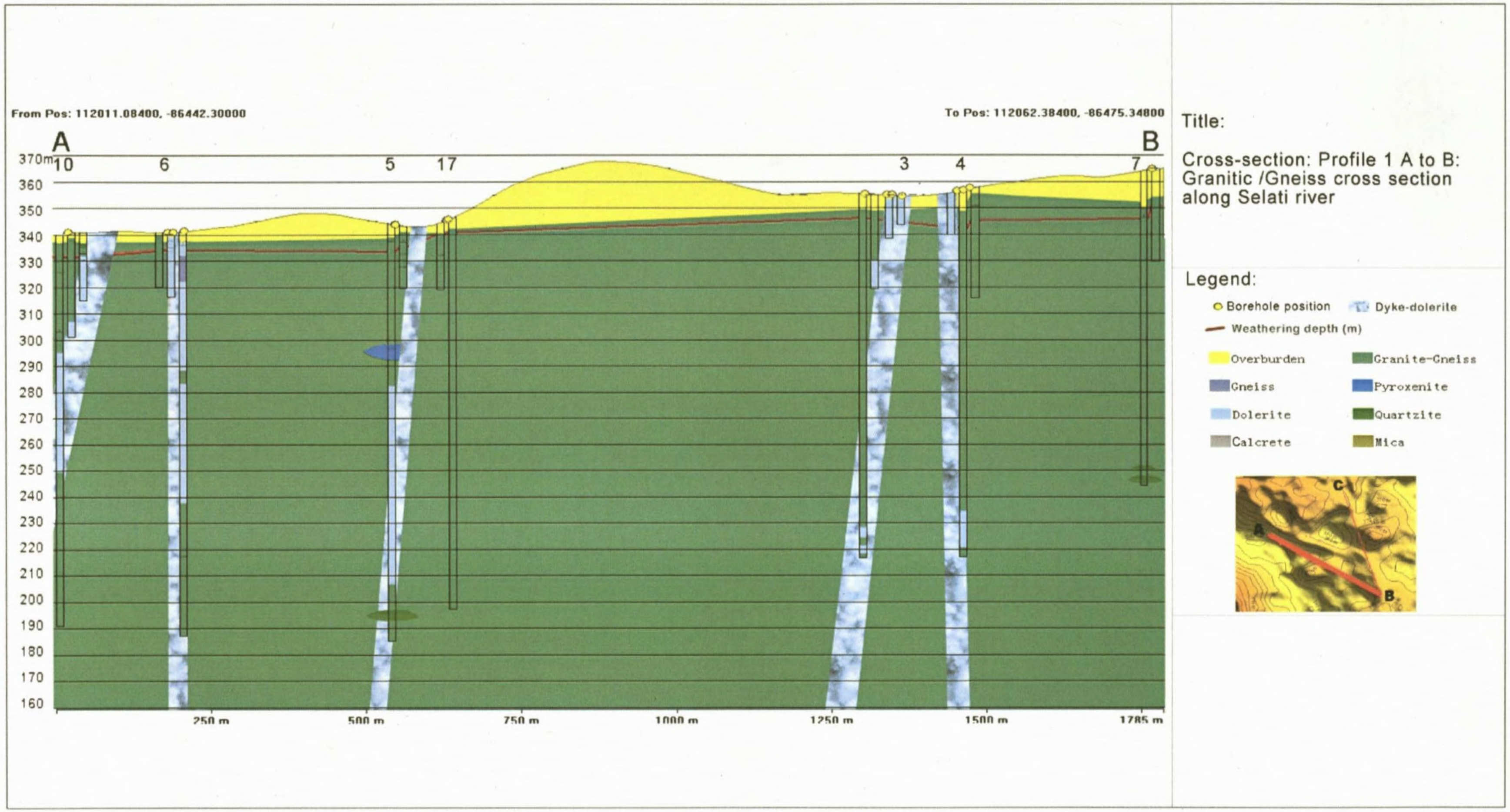


Figure 64: Cross Section through Granitic-gneiss

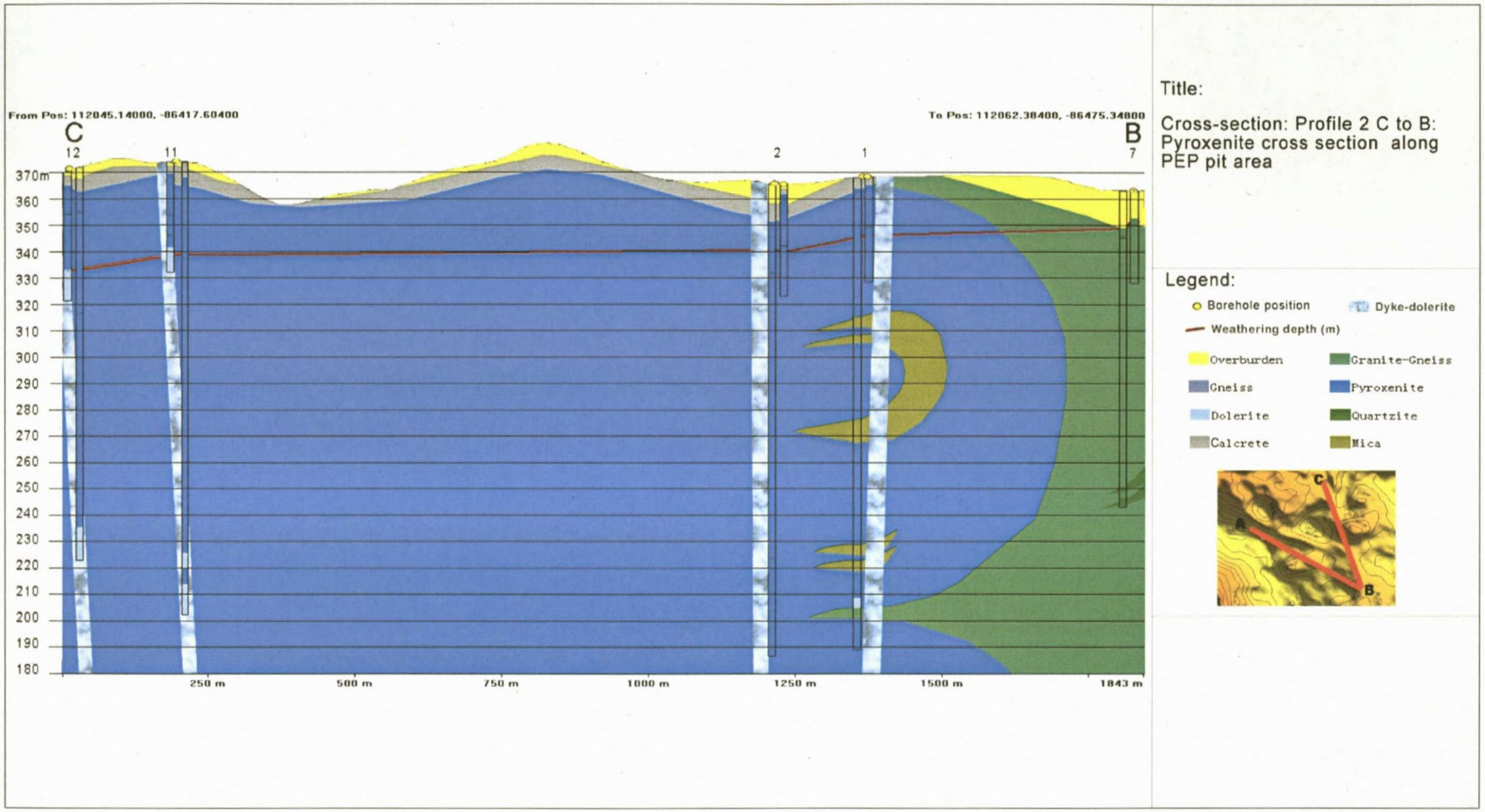


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Figure 65: Cross Section through Pyroxenite

9.3. Conceptual Model of NSPP

The conceptual model was developed from data gathered during the field investigation phase. The conceptual model forms the basis for the understanding of the groundwater occurrence and flow mechanisms of the investigation area, and is use as basis for a numerical groundwater model.

The conceptual model developed for the PEP investigation area is presented as two figures:

- A cross section conceptual model constructed of the area of investigation, showing the positions of the cross section intersections (Figure 66); and a constructed conceptual model of the area of investigation (Figure 67).

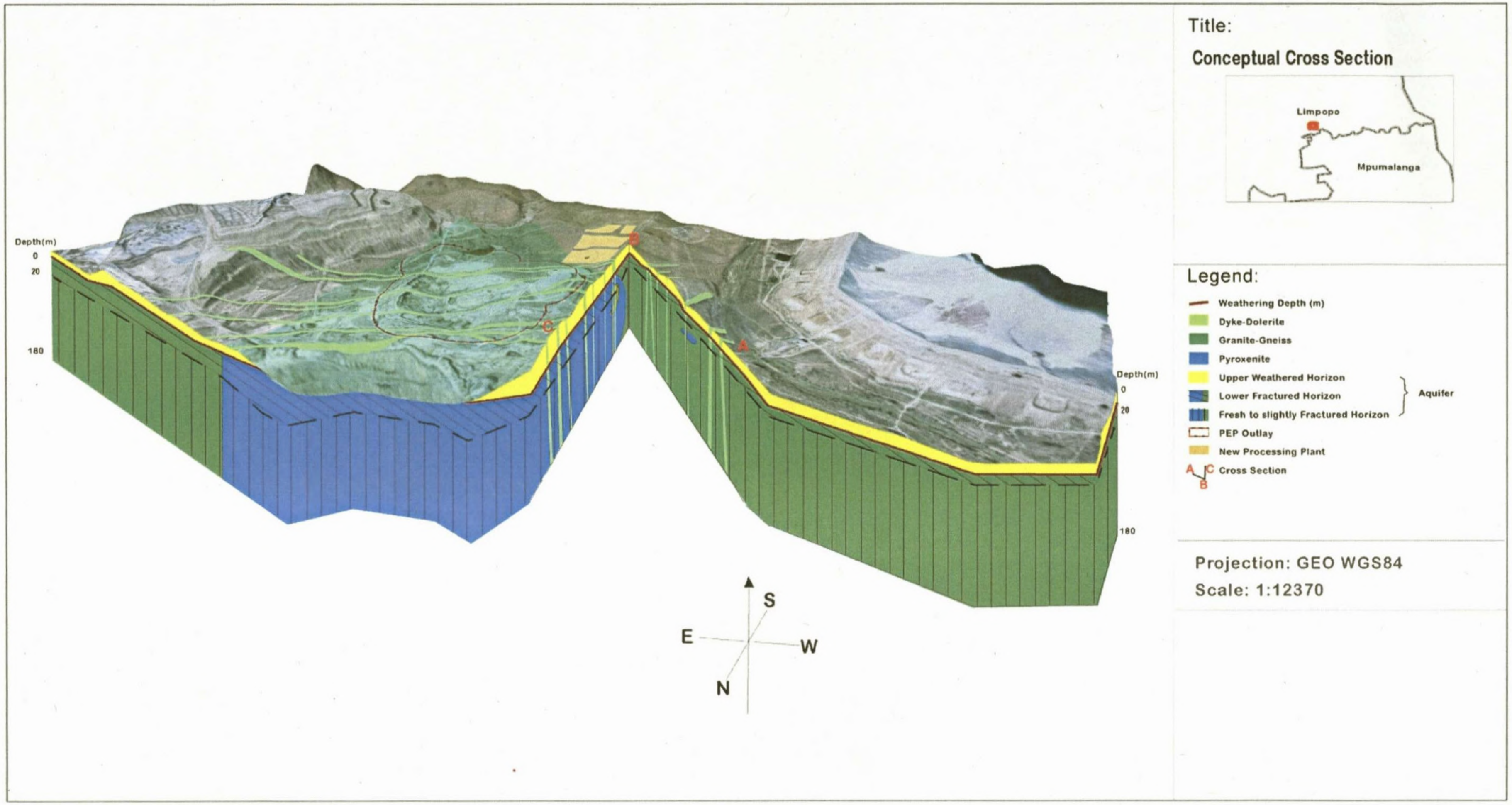

Figure 66: Cross Section Conceptual Model

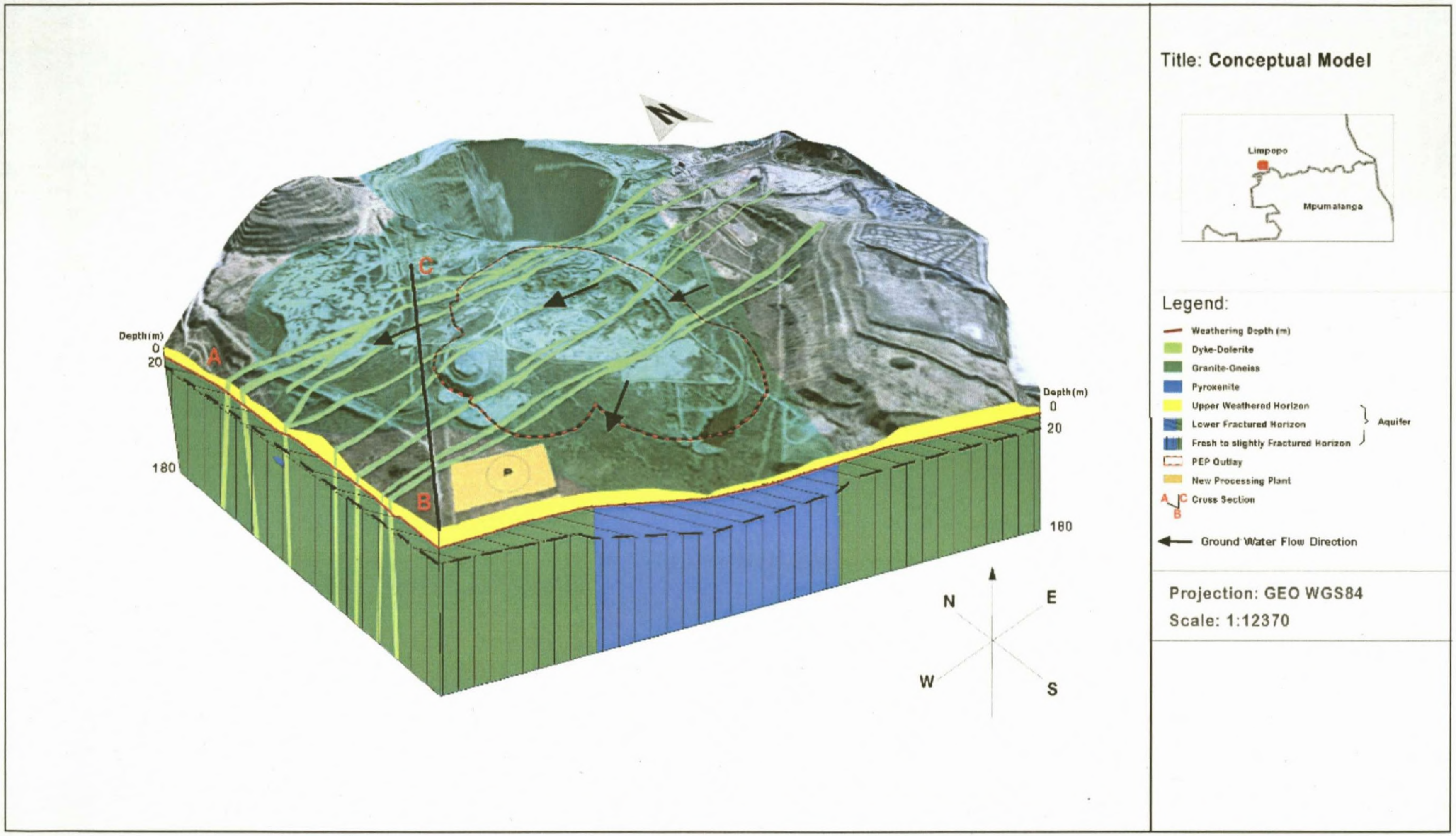

Figure 67: Conceptual Model

9.3.1. Groundwater Recharge

Groundwater recharge may be defined as the addition of water to the saturated zone, either from surface water, rainfall or the lateral migration of groundwater from adjacent aquifers. It involves the downward percolation of water or soil moisture, which eventually reaches the groundwater table, thereby forming an additional source to an already existing groundwater reservoir.

The chloride method for recharge which is based on rainfall was used for the study area. Recharge from rainfall is a highly complex process in which numerous factors and their interaction play a role.

The more important aspects affecting recharge from rainfall according to Vegter (1995) are:

- The amount, type, intensity, duration and temporal distribution of rainfall;
- Climate - potential evaporation;
- Surface slope and type of vegetation cover - storm water runoff, interception and transpiration losses;
- Infiltration capacity of the materials at the surface be it rock or soil and subsoil, the presence of so-called macrospores and fractured rock is of major importance and capillary movement; and
- The moisture retention capacity of the aeration or unsaturated zone and temporal fluctuations of moisture.

According to the published hydrogeological maps (DWAF 1996) the average recharge for the PIC study area is 5 mm to 10 mm per annum.

Using the Chloride method = average Cl in rainfall (mg/l)/average Cl in groundwater (mg/l)

= 1.0/192(Harmonic Mean)

= 0.5%

The Harmonic Mean of chloride values (Table 33) was calculated from the analytical results of the newly drilled shallow monitoring boreholes analysed during this study.

Table 33: Chloride Values of Shallow Monitoring Boreholes

Borehole No.	PEP 9S	PEP 8S	PEP 6S	PEP 5S	PEP 2S	PEP 1S	PEP 17S	PEP 16S	PEP 15S	PEP 14S	PEP 13S	PEP 12S	PEP 11S	PEP 10S	PEP 10M
Chloride mg/l	103	368	286	383	96.2	61.8	200	379	335	432	381	404	159	233	229
Geology	P	GG	GG	GG	P	P	GG	P	P	P	P	P	P	GG	GG
Yield l/s	0.1	0.55	0.2	25	0.15	0.15	0.7	2.55	1.75	1.05	1.7	1	1.66	0.32	2.02
Harmonic Mean of Cl values						192.1									

Note: GG - Granitic/Gneiss, P - Pyroxenite

Recharge = 0.5% of the MAP 513 mm = 2.6 mm per annum. This is lower than the recharge indicated on the published hydrogeological maps (DWAF 1996). This is however, more indicative of the site specific conditions and probably from a very low rainfall season in 2009 in the area with recharge being below average.

9.3.2. Geology

The geology consists of pyroxenite underlying the PEP pit area, bordered by granitic-gneiss formation. The top part of the aquifer consists of a weathered horizon of 8 (granitic -gneiss) to 30m (pyroxenite) at surface, with a permeable fractured aquifer horizon below it. The lower part of the conceptual model consists of a fresh to slightly fractured impermeable zone.

9.3.3. Dolerite Dykes

Dolerite dykes with a characteristic SW-NE direction of strike laterally extend through the investigation area and have the following influence on the area of investigation:

- The dolerite dykes control the groundwater flow;
- These sub vertical dolerite dykes are impermeable at depth but are weathered near surface;
- Cross flow over dolerite dykes is possible near surface in weathered sections of dolerite dykes where the water table is above this level;
- Along the dolerite dyke intrusions highly permeable fractures zones exists in the host rocks, which are responsible for higher flow on contact zones and at shallow depth; and
- These dolerite dykes are impermeable at depth, and are responsible for forming compartments in the host rocks. The compartmentalization is evident from the deep water level in the PMC pit, neighboured by the shallow water levels at the PEP pit and surrounding area.

9.3.4. Aquifer Zones

The drilling and testing results enable a semi confined aquifer system to be identified which is divided in to three aquifer zones:

- Upper weathered aquifer zone;
- Fractured permeable aquifer horizon; and
- Fresh to slightly fractured aquifer zone.
- These three aquifer zones are present in the two types of host rock, namely pyroxenite and granitic-gneiss, with different weathering and fracturing depths respectively and are discussed accordingly.

9.3.5. Pyroxenite

The weathering and fracturing depths in the pyroxenite are deeper than the surrounding granitic-gneiss formation. The groundwater flow in the pyroxenite formation is in the weathered and fractured zones with low flow at depth.

- Upper Weathered Aquifer Zone
- The average weathering depth in the pyroxenite formation is 30 m (ranging from 24 m to as deep as 38 m). Water strikes encountered in this zone were low yielding and with the deepest water strike encountered at 38 m (PEP1S).
- The Transmissivity (T) values obtained for the shallow boreholes representing the weathered aquifer in the pyroxenite aquifer zone range between 0.12 m^2/d (PEP2S) to 1.07 m^2/d (PEP1S).
- The Storage coefficient (S) for the upper weathered horizon is 0.0003.

Fractured Permeable Aquifer Zone

- In the fractured permeable aquifer zone below the weathered zone, water strikes were the most prominent. The fracturing depth in the pyroxenite range between 11 m to 50 m.
- The Transmissivity (T) values obtained for shallow boreholes representing the fractured horizon below the weathered section for the pyroxenite range between from 3.22 m^2/d (PEP12D) to 527 m^2/d (PEP13S). Without taking the extreme T value (PEP13S) into account, the average T value for the pyroxenite 26.9 m^2/d.

- The Storage coefficient (S) for the fractured aquifer horizon in the pyroxenite range between 0.001(PEP17S) to 0.005 (PEP15S)

Fresh to Slightly Fractured Aquifer Zone

- This zone is located below 50m and only seepage was encountered in the deep boreholes intersecting the pyroxenite.
- The Transmissivity (T) values obtained from the deep boreholes representing the deep fresh to slightly fractured aquifer horizon range between 0.03 m^2/d (PEP1D) to 0.23 m^2/d (PEP14D) for the pyroxenite aquifer zone.
- The Storage coefficient (S) for this horizon is 0.0001(PEP2D) to 0.0003 (PEP1D) in the pyroxenite.

9.3.6. Granitic-gneiss

The flow in this formation is in the weathered/fractured horizon, with very low groundwater flow at depth.

Upper Weathered Aquifer Zone

- The average weathering depth in the in the granitic-gneiss formation is 8 m and ranges from 4 m to as deep as 15 m. Water strikes encountered in the exploration boreholes are characterised by very low yields.
- No water strikes were encountered in the fractured zone of the granitic-gneiss and therefore no T value were calculated for this aquifer zone.
- The Storage coefficient (S) calculated for the upper weathered horizon is 0.0003.

Fractured Permeable Aquifer Zone

- Water strikes were the most prominent in the fractured permeable aquifer horizon below the weathered zone. The fracturing depth of the granitic-gneiss range from 6 m to 20 m compared to the pyroxenite 11 m to 50 m.
- The Transmissivity (T) values obtained for shallow boreholes representing the fractured horizon below the weathered section range between 1.38 m^2/d (PEP17S) to 834 m^2/d (PEP5S) in the granitic-gneiss. Without taking the two extremes (PEP5S and PEP13S) into account, the average T value for the granitic-gneiss is 9.7 m^2/d

with an average T value of 18.45 m^2/d for the combined fractured horizon of pyroxenite and granitic-gneiss.

- The storage coefficient (S) for the fractured horizon below the weathering ranges between 0.0001 (PEP5S) to 0.013 (PEP10S/M) in the granitic-gneiss.

Fresh to Slightly Fractured Aquifer Zone

- In this impermeable layer of fresh to slightly fractured granitic-gneiss below 50 m, only one water strike was recorded at 126 m (PEP6D of 0.6 l/s).
- The Transmissivity (T) values obtained for the deep boreholes representing the deep fresh to slightly fractured aquifer horizon ranging between 0.03 m^2/d (PEP1D) and 0.23 m^2/d (PEP14D) and are representative for both the granitic-gneiss and for the pyroxenite aquifer zones.
- The Storage coefficient (S) for this horizon is 0.0001 (PEP10D) in the granitic-gneiss.

Aquifer parameters for both pyroxenite and granite-gneiss are summarised in Table 34.

Table 34: Average Aquifer Parameter Values

Aquifer zone	Dolerite Dyke		Contact zone		Pyroxenite		Granitic-gneiss	
	S	T (m^2/d)	S	T (m^2/d)	S	T (m^2/d)	S	T (m^2/d)
Weathered zone		-		-		0.4		-
Fractured zone		1.2		105		52.5		250
Fresh zone		< 0.01		0.4		0.25		0.19

9.4. Piezometric Contours and Groundwater Flow Direction

From the hydrogeological data obtained from Foskor's bi-annually monitoring reports for 2009 and the data obtained from this study in 2009 for the new PEP area, a piezometric contour map was constructed to determine the general groundwater flow direction for the NSPP area.

The main purpose of the piezometric contour map is to:

- Indicate groundwater flow direction;
- Indicate depth of water table below surface;
- Indicate the hydraulic gradient;
- Time series maps also indicate changes in groundwater storage; and

- Determine impact direction of mining contamination of groundwater and surface water.

The Selati River acts as an effluent river system with groundwater being discharged to the river.

A good correlation of 90% (Figure 68) was obtained between the topographic elevation and water levels. It can thus be assumed that the groundwater level will mimic the topography. The piezometric contour map was compiled from measured water levels during 2009 and extrapolating these values across the study area, using Bayesian interpolation.

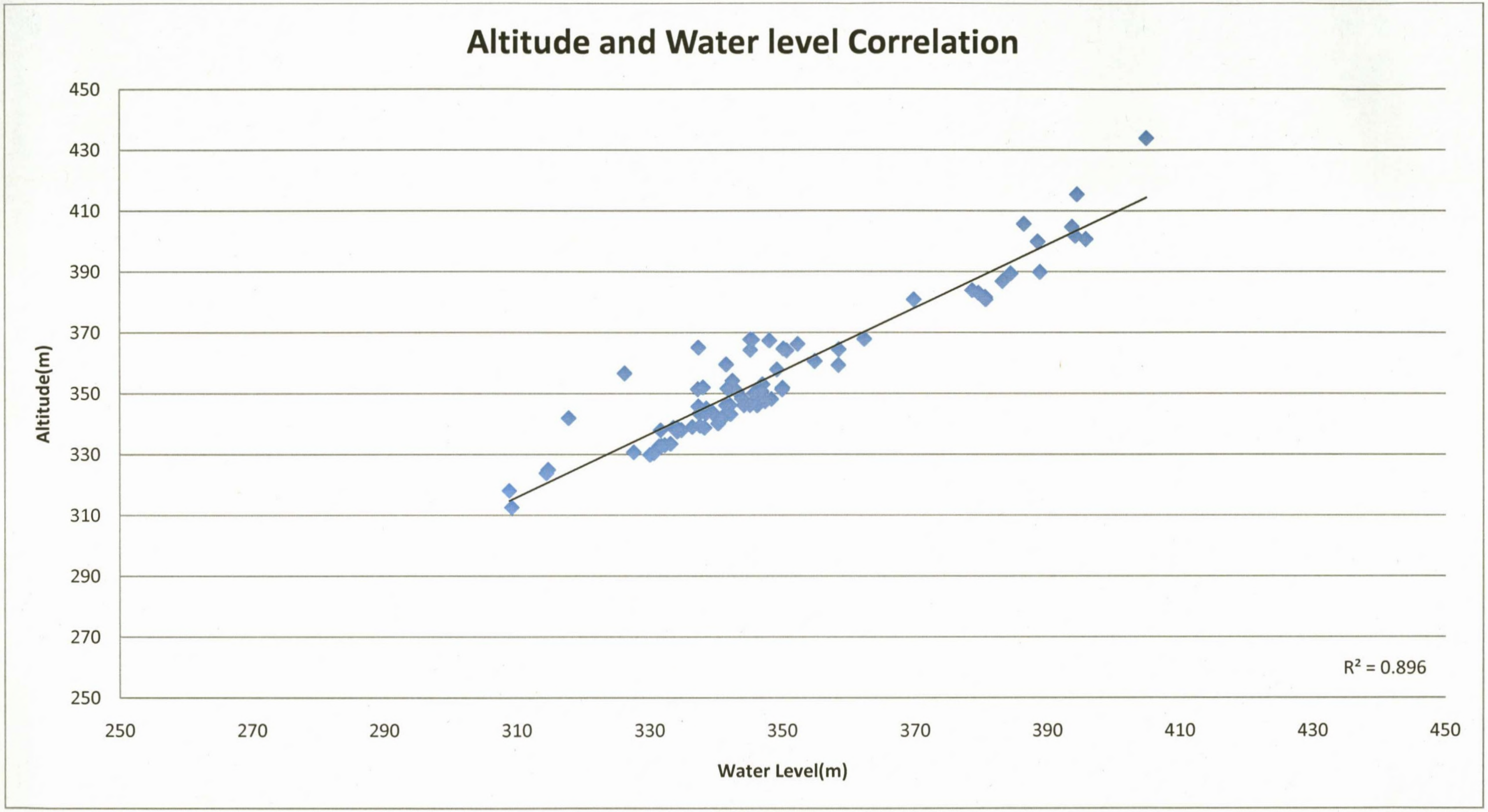

Figure 68: Altitude and Water Level Comparison

9.4.1. Groundwater Flow Direction

- The piezometric map (Figure 69) indicates that the groundwater flow direction is largely controlled by the dolerite dykes, because dolerite dykes are impermeable at depth, and are responsible for forming compartments in the host rocks. The groundwater flow in the NPM pit area and the PMC pit are towards the pit excavations but primarily to the south and towards the Selati River.

In general the groundwater flow direction in the area of the PIC is towards the Selati River. The hydraulic gradient is low (2%) at approximately 10m drop in groundwater levels for every 500 m distance at surface (1:0.02). The hydraulic gradient around the pit areas will be steep caused by the dewatering from these areas.

Hydraulic gradient is calculated by the gradient of slope:

Piezometric interval (m)/equivalent map distance in (m) *100

10/500 * 100 = 2%

The groundwater flow south of the Selati River mimics the topography and is towards the north east towards the Selati River.

Groundwater Flow Velocity

The groundwater flow velocity is calculated as follows:

V = i * k /porosity

= 0.02 * 0.00897 (Average k value obtained)/ 0.45(Average porosity of Igneous rocks)

=0.000398667 m/d = 3.4 x 10^{-4} m/d

Where v = Groundwater velocity, i = Groundwater gradient.

Figure 69: Groundwater Piezometric Map

9.5. NPM Conceptual Model

A simplified conceptual model of the NPM was developed from drilling and pump testing data gathered during the field investigation of the NPM during the beginning of 2011. The conceptual model forms the basis for the understanding of the aquifer parameters, groundwater occurrence and flow mechanisms of the NPM area. The conceptual model is represented as two images namely:

- A view from south east of the study area (Figure 70); and
- A view from north west of the study area (Figure 71).
- The conceptual model of the NPM area is discussed in the sections below:

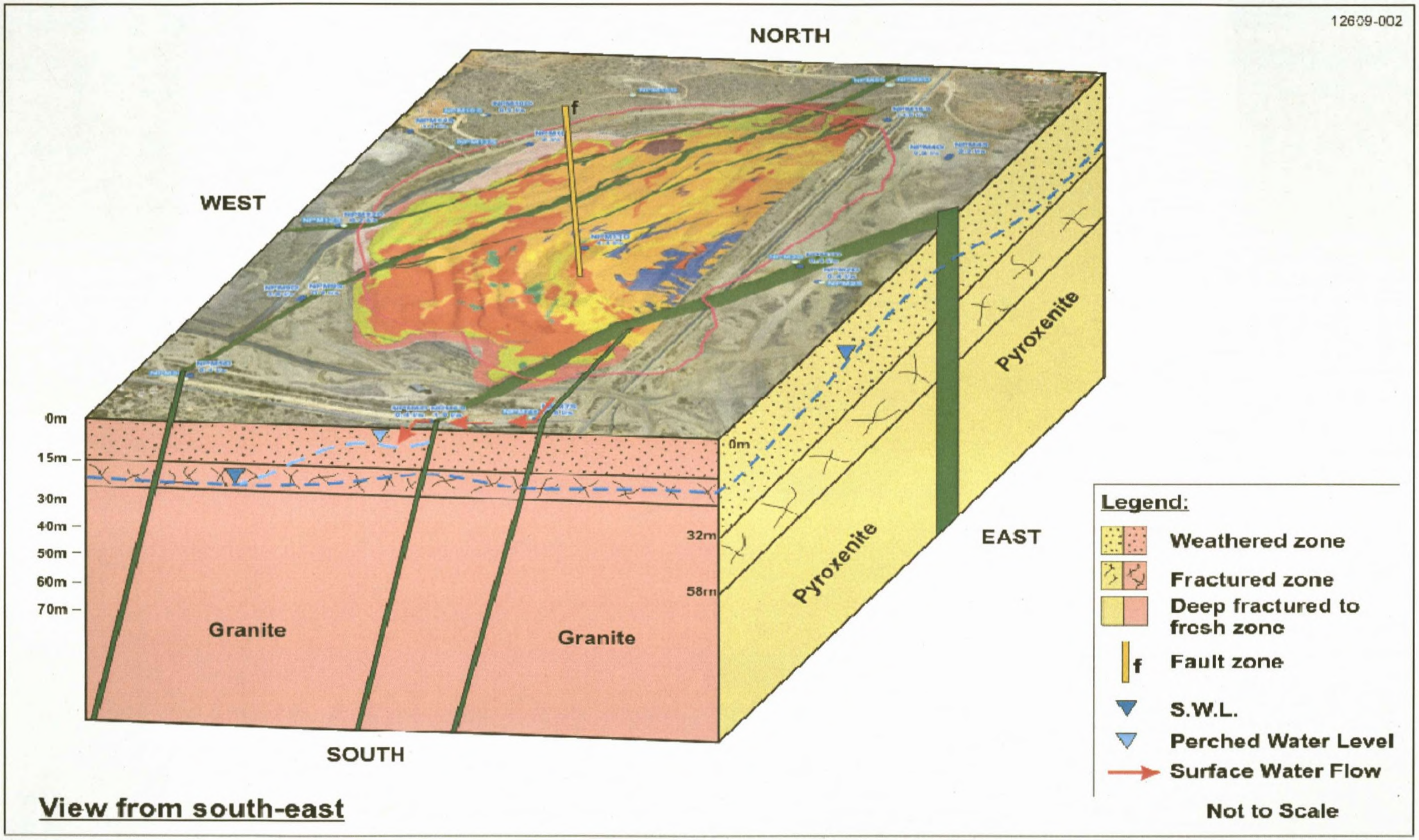

Figure 70: South -East view of NPM Conceptual Model

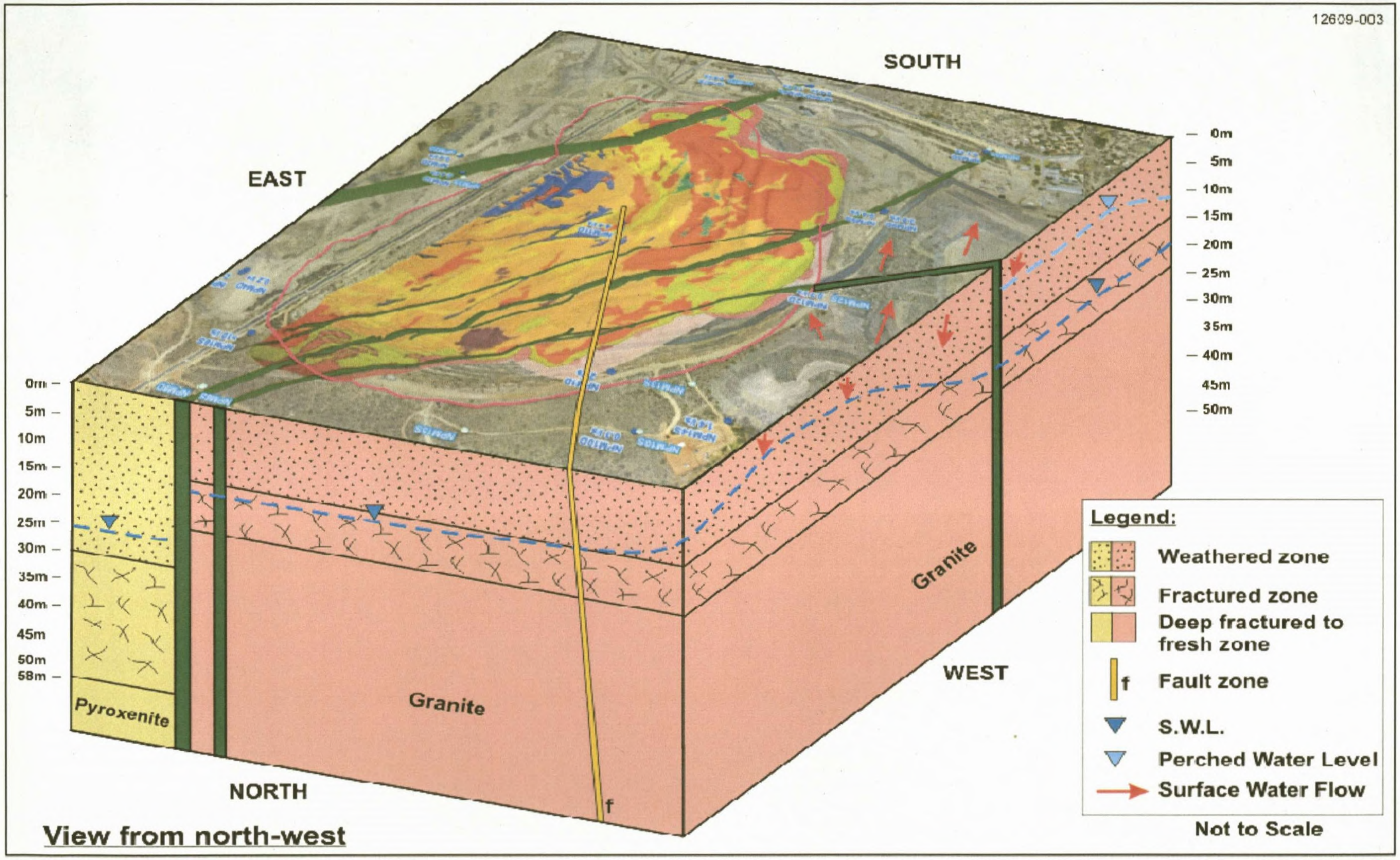

Figure 71: North Western section of NPM Conceptual Model

9.5.1. Geology

The geology of the NPM investigation area consists of pyroxenite underlying the NPM pit area, bordered by granite formation. The top part of the aquifer consists of a weathered horizon (15 to 32 m) at surface, with a permeable fractured aquifer horizon (24 to 58 m) below it. The lower part of the conceptual model consists of a fractured to fresh zone.

The two host rocks consisting of pyroxenite and granite have different weathering and fracturing depths respectively and are discussed accordingly. The average aquifer parameters are summarised in Table 35 and graphically represented in Figure 72.

9.5.2. Aquifer System and Zones

A semi confined aquifer system consisting out of three aquifer zones were identified in the pyroxenite and surrounding granite formation during the drilling and the test pumping of the monitoring boreholes namely:

- Upper weathered aquifer zone (15 to 32 m);
- Fractured permeable aquifer horizon (24 to 58 m); and
- Deep fractured to fresh aquifer zone below 58 m.
- These three aquifer zones were also identified at the NSPP with deep drilling.

Table 35: NPM Aquifer Parameters

Aquifer zone	Pyroxenite			Granite			Dolerite Dyke and Granite Contact zone			Dolerite Dyke and Pyroxenite Contact zone			Dolerite		
	S	T (m^2/d)	K(m/d)	S	T (m^2/d)	K(m/d)	S	T (m^2/d)	K(m/d)	S	T (m^2/d)	K(m/d)	S	T (m^2/d)	K(m/d)
Weathered zone	-	-	$6.89x10^{-3}$						$1.09x10^{-2}$			-			$9.1x10^{-2}$
Fractured zone	$7.65X10^{-5}$	2.15			5.48		$1.65x10^{5}$	6.105			135.5				
Deep Fractured to Fresh zone	$3.36X10^{-5}$	0.195			3.1		$2.33x10^{5}$	0.249			0.207				
Blasting Fractures in pit centre		105		No Blasting Fractures											
Fault zone	No info				6.12		No info								

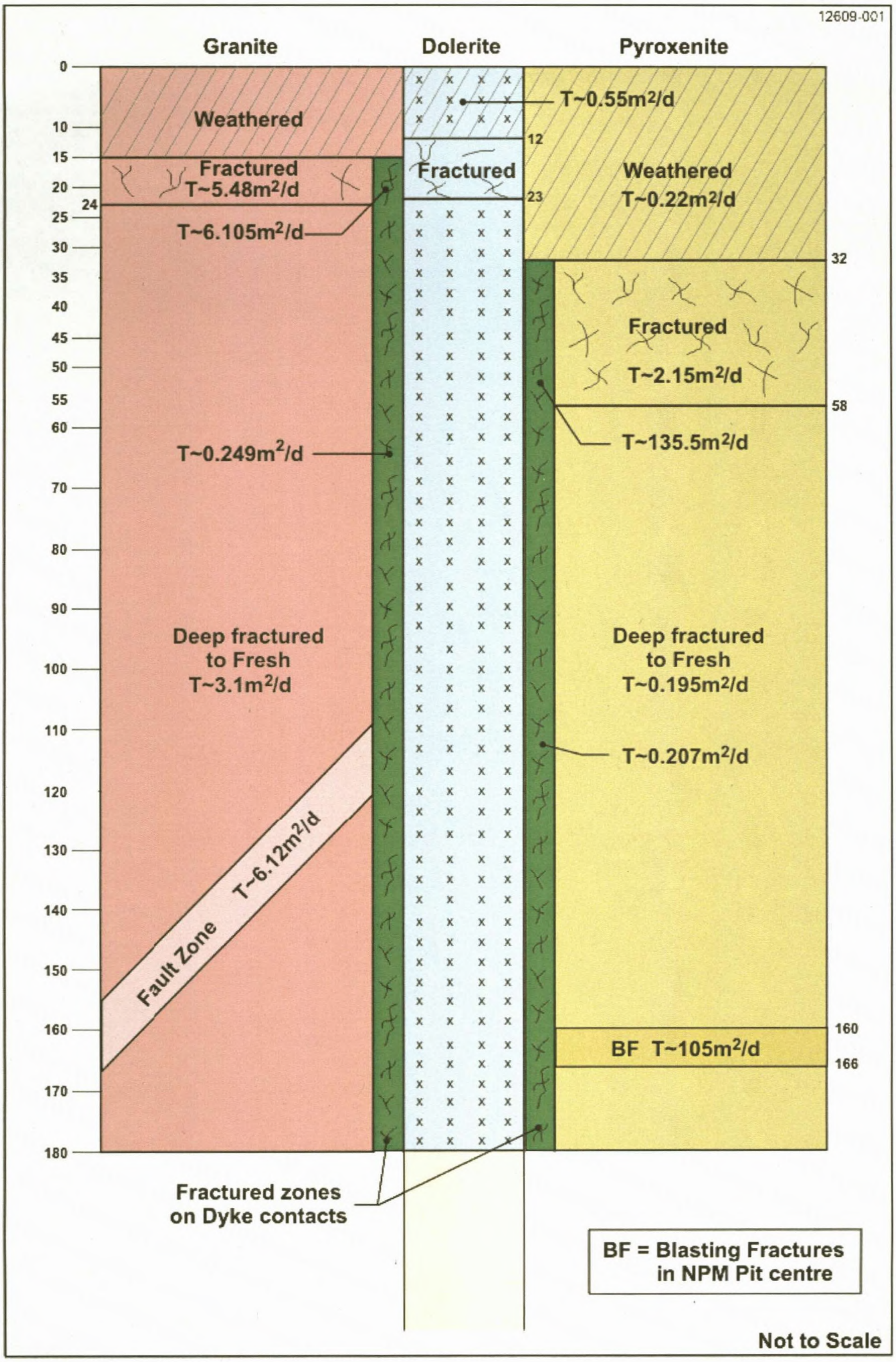

Figure 72: NPM Aquifer Parameters

9.5.3. Pyroxenite

The weathering and fracturing depths encountered in the pyroxenite are deeper than the surrounding granite formation and is outlined below:

9.5.3.1. Weathered Pyroxenite Zone

The average weathering depth of the pyroxenite at the NPM Is 32 m compared with 30 m at the NSPP.

The hydraulic conductivity values (k) values obtained for the shallow boreholes representing the weathered aquifer in the pyroxenite aquifer zone range between $2.25X10^{-3}$ to $8.8X10^{-3}$ m/d.

No Storage coefficient (S) was calculated for the weathered pyroxenite horizon.

9.5.3.2. Fractured Pyroxenite

The average depth of the fractured pyroxenite aquifer zone is 58 m at the NPM compared to 50 m at the NSPP.

The Transmissivity (T) values obtained for the fractured aquifer zone in the pyroxenite below the weathered section range between 1.65 to 2.65 m^2/d.

- The Storage coefficient (S) for the upper weathered horizon is $7.65X10^{-5}$.

9.5.3.3. Deep Fractured to Fresh Pyroxenite Zone

The deep fractured to fresh zone is located below 58 m and several water strikes were encountered in the deep boreholes intersecting the pyroxenite

The Transmissivity (T) values obtained from the deep boreholes representing the deep fractured to fresh aquifer horizon range between $1.91X10^{-1}$ to $1.99X10^{-1}$ m^2/d.

The Storage coefficient (S) for the deep fractured to fresh horizon is $3.63X10^{-5}$.

9.5.3.4. Blasting Fractures

At borehole NPM11D drilled in the NPM pit centre +/-6 m of blasting fractures were encountered at pit surface.

The Transmissivity (T) value of the blasting fractures is 105 m^2/d. The depth of the pit is approximately 160 m and no additional water strikes were encountered after the water filled blasting fractures for approximately up to 340 m in the pyroxenite.

No Storage coefficient (S) was calculated for the blasting fractures but it will be confined to the pit area.

9.5.4. Granite

9.5.4.1. Weathered Granite Zone

The average weathering depth of the granite is 15 m at the NPM compared to 8 m at the NSPP.

No water strikes were encountered in the weathered section of the granite and therefore no T or S values were calculated for this aquifer zone.

9.5.4.2. Fractured Granite Zone

The average depth of the fractured granite formation is 24 m at the NPM compared to 46 m at the NSPP.

Water strikes were prominent in the fractured granite zone with a Transmissivity (T) values ranging from 1.04 to 7.36 m^2/d.

No Storage coefficient was calculated for the fractured granite zone.

9.5.4.3. Deep Fractured to Fresh Granite Aquifer zone

The zone consisting of deep fractures to fresh formation is located below 24 m in the granite. Several groundwater strikes were intersected in this formation.

The Transmissivity (T) values obtained for the deep fractured to fresh granite range from $7.47X10^{-2}$ to 6.16 m^2/d.

No Storage coefficient was calculated for this zone.

9.5.5. Dolerite Dykes and Associated Contact Zones

Dolerite dykes with a characteristic SW-NE direction of strike, laterally extend through the NPM area and have the following influence on the area of investigation:

- The dolerite dykes control the groundwater levels and flow;
- These sub vertical dolerite dykes are impermeable at depth but are weathered near surface;
- Cross flow over dolerite dykes is possible near surface in weathered sections;
- Along the dolerite dyke intrusions highly permeable fractures zones exists in the host rocks, which are responsible for higher flow on contact zones and at shallow depth; and

- These dolerite dykes are impermeable at depth, and are responsible for forming compartments in the host rocks. The compartmentalization is evident from the changes in water levels around the NPM pit.

- The dolerite dykes have an average weathering depth of 12 m at surface and a fracturing depth of 23 m. The fractured dolerite and host rock contact zones are discussed below:

9.5.5.1. Dolerite Dyke and Granite Contact Zones

The hydraulic conductivity values (k) values obtained for the weathered section of the dolerite and granite contact zones range from $7.83X10^{-7}$ to $2.14X10^{-2}$ m/day

High permeable fracture zones were encountered along the fractured dolerite and granite contact zones with Transmissivity (T) values ranging from $4.7X10^{-1}$ to 11.5 m^2/d. The Storage coefficient (S) obtained for this zone is $1.65x10^{-5}$.

The deep fractured to fresh contact zones had Transmissivity (T) values ranging from $4.91X10^{-2}$ to $4.62X10^{-1}$ m^2/d. The Storage coefficient (S) obtained for this zone is $2.33\ x10^{-5}$.

Storativity will be mainly adjacent to the strike direction.

9.5.5.2. Dolerite Dyke and Pyroxenite Contact Zones

Very high permeable fracture zones were encountered along the fractured dolerite and pyroxenite contact zones with Transmissivity (T) values ranging from 123 to 148 m^2/d.

The deep fractured contact zones had Transmissivity (T) values ranging from $7.41X10^{-2}$ to $3.39X10^{-1}$ m^2/d.

The Storage coefficient (S) obtained for this zone is $3.13\ x10^{-5}$, and Storativity will be mainly adjacent to the strike direction.

9.5.6. Fault zone

The north south striking fault zone which runs through the centre of the NPM pit and has displaced some of the dolerite dykes were intersected at NPM1D at a depth of 156 m and with a test yield of 2.73 l/s.

The Transmissivity (T) values obtained for the fault zone is 6.12 m^2/d.

No Storage coefficient (S) was calculated for the fault zone.

CHAPTER 10: Impact Assessment

An impact assessment of phosphate open pit mining was done using the approach of construction, operational and closure/rehabilitation phases.

10.1. Rating of Groundwater Assessment

10.1.1. Impact Assessment Methodology

The impact assessment was done according to the following methodology:

- **Direction of an impact** may be positive, neutral or negative with respect to the particular impact (e.g., a habitat gain for a key species would be classed as positive, whereas a habitat loss would be considered negative).

- **Magnitude** is a measure of the degree of change in a measurement or analysis (e.g., the area of pasture, or the concentration of a metal in water compared to the water quality guideline value for the metal), and is classified as none/negligible, low, moderate or high. The categorization of the impact magnitude may be based on a set of criteria (e.g. health risk levels, ecological concepts and/or professional judgment) pertinent to each of the discipline areas and key questions analysed. The specialist study must attempt to quantify the magnitude and outline the rationale used. Appropriate, widely-recognised standards are used as a measure of the level of impact.

- **Duration** refers to the length of time over which an environmental impact may occur: i.e. transient (less than 1 year), short-term (0 to 7 years), medium term (8 to 15 years), long-term (greater than 15 years with impact ceasing after closure of the project) or permanent.

- **Scale/Geographic extent** refers to the area that could be affected by the impact and is classified as site, local, regional, national, or international.

- **Probability of occurrence** is a description of the probability of the impact actually occurring as, improbable (less than 5% chance), low probability (5% to 40% chance), medium probability (40 % to 60 % chance), highly probable (most likely, 60% to 90% chance) or definite (impact will definitely occur).

- **Impact significance** was rated by using the scoring system shown in the box below. (Refer to Figure 73 below).

Magnitude	Duration	Scale	Probability
10 Very high/ don't know	5 Permanent	5 International	5 Definite/don't know
8 High	4 Long-term *(impact ceases after closure of activity)*	4 National	4 Highly probable
6 Moderate	3 Medium-term (5 to 15 years)	3 Regional	3 Medium probability
4 Low	2 Short-term (0 to 5 years)	2 Local	2 Low probability
2 Minor	1 Transient	1 Site only	1 Improbable
1 None			0 None

Maximum SP is 100 points

SP>75	High environmental significance
SP 30 to 75	Moderate environmental significance
SP<30	Low environmental significance

Figure 73: Scoring System for Assessment of Significance

After ranking these factors for each impact, the significance of the two aspects, occurrence and severity, was assessed using the following formula:

SP (significance points) = (magnitude + duration + scale) x probability

The maximum value is 100 significance points (SP) (Table 36). The potential environmental impacts were then rated as of **High** (SP >61), **Moderate** (SP 31 - 60) or **Low** (SP <30) significance, both with and without mitigation measures on the following basis:

Table 36: Significance Points Table

SP >60	Indicates **high** environmental significance	Where it would influence the decision regardless of any possible mitigation. An impact which could influence the decision about whether or not to proceed with the project.
SP 30 - 60	Indicates **moderate** environmental significance	Where it could have an influence on the decision unless it is mitigated. An impact or benefit which is sufficiently important to require management. Of moderate significance - could influence the decisions about the project if left unmanaged.
SP <30	Indicates **low** environmental significance	Where it will not have an influence on the decision. Impacts with little real effect and which should not have an influence on or require modification of the project design or alternative mitigation.
+	**Positive impact**	An impact that is likely to result in positive consequences / effects.

10.2. Study phases

For the purposes of this impact assessment the Foskor PEP project has been subdivided into three phases, as follows:

- Construction Phase
- PEP pit operational Phase or mining of the PP &V area; and
- Closure/Rehabilitation Phase.

10.3. Construction Impact Assessment

Foskor (Pty) Ltd proposes to operate the PEP project for a period of 54 years.

From a groundwater perspective, Table 37 summarises the potential impacts that are related to the construction phase of the proposed PEP project, and provides a significance rating for each impact before and after mitigation.

Table 37: Environmental Impact Assessment Matrix for Foskor (Pty) Ltd PEP Project- Construction Phase

Potential Groundwater Impact (Construction:)	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	Total	SP	M	D	S	P	Total	SP
Effect of construction phase of PEP project	2	2	1	2	10	L	-	-	-	-	-	-

•

The following sections describe the potential impacts associated with the construction, as summarised in the table above.

10.3.1. Effect of Construction on groundwater quality

The proposed pyroxenite expansion project (PEP) will involve the construction of an ore stock pile and a conveyor belt to transport the pyroxenite to Foskor's existing processing plant. The construction of a new processing plant, process water dam and railway line.

A low impact is associated with the construction phase on the groundwater.

10.4. Operational Phase Impact Assessment

From a groundwater perspective, Table 38 summarises the potential impacts that are related to the operational phase of the mining of the PP &V area and provides a significance rating for each impact before and after mitigation.

Table 38: Environmental Impact Assessment Matrix for Foskor (Pty) Ltd PEP Project- Operational Phase

Potential Groundwater Impact (Operational Phase of PP & V area)	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	Total	SP	M	D	S	P	Total	SP
Depression of water levels around the PEP pit	6	4	2	2	24	L	-	-	-	-	-	-
Loss of water supply to existing users	6	4	2	2	24	L	-	-	-	-	-	-
Impact on surface water quantity	6	4	2	3	36	M	-	-	-	-	-	-
Impact on groundwater quality	4	4	1	3	27	L	-	-	-	-	-	-

The following sections describe the potential impacts associated with the operational phase as summarised in the table above.

10.4.1. Depression of water levels surrounding the PEP pit

The assumption is made that the impact on the groundwater level will reach the Selati River. This indicates that a relatively large cone of depression will form although focused around the dolerite dykes and thus a moderate impact. Mitigation measures are not required as no groundwater users are present in this area and thus a low impact is assumed as indicated in Table 38.

10.4.2. Loss of water to existing users

- The impact on existing users in the area due to loss of water supply is low. This is based on the fact that the surrounding land is own by Foskor. Apart from the abstraction boreholes within the NSPP area used by Foskor and PMC for dewatering and pollution control purposes, there are no other groundwater users. Mitigation measures are not required as no groundwater users are present.

10.4.3. Impact on surface water quantity

- The impact on surface water quantity due to loss of water supply is rated as moderate as the Selati river acts as an effluent river system.
- Volumes can be quantified by means of groundwater flow modelling.

10.4.4. Impact on groundwater quality

- Based on the sulphate concentration of the groundwater, the quality of the groundwater is being affected by the mining activities. The impact on the groundwater quality is seen as low and the dewatering will contain the contamination close the mining area.

10.5. Decommissioning and Closure

From a groundwater perspective, Table 39 summarises the potential impacts that are related to the decommissioning and closure phase, whereby the mining of the PP &V area will cease.

Table 39: Environmental Impact Assessment Matrix for Foskor (Pty) Ltd PEP Project -Decommissioning and Closure Phase

Potential Groundwater Impact (Decommissioning & Closure Phase)	ENVIRONMENTAL SIGNIFICANCE											
	Before mitigation						After mitigation					
	M	D	S	P	Total	SP	M	D	S	P	Total	SP
Depression of water levels around the PEP pit	6	4	2	2	24	L	-	-	-	-	-	-
Loss of water supply to existing users	6	4	2	2	24	L	-	-	-	-	-	-
Impact on surface water quantity	6	5	2	3	39	M	4	2	2	2	16	L
Impact on groundwater quality	4	2	2	2	16	L						

The following sections describe the potential impacts associated with the decommissioning and closure phase.

10.5.1. Depression of water levels surrounding the PEP pit

- The final pit lake water level of will be approximately be 206 mamsl. This is an impact of approximately 60 to 80 m reduction (deeper) in water level.
- The main cause of this is the high evaporation rates and large surface area of the pit lake. Since no groundwater users are present in this area a low rating is calculated.

10.5.2. Loss of water to existing users

- Due to the expected high evaporation rates and the large surface area of the pit lake a significant amount of water will be lost as result of the evaporation. No groundwater users are present in this area and the impact is thus low.

10.5.3. Impact on surface water quantity

- A significant volume of water will be lost due the evaporation from the pit lake after closure. This will induce an expected moderate impact on the Selati River. This impact is seen as moderate as shown in Table 39.
- Practical achievable mitigation measures need to be discussed with Foskor.

10.5.4. Impact on groundwater quality

- The impact on the groundwater quality is low, and the quality is likely to improve after closure.

10.6. Mitigation

At this stage the only mitigation required is:

- Continue with the current bi-annual water level and water quality monitoring and include the newly drilled boreholes. Water level measurements are also recommended within the open exploration boreholes;
- All monitoring data should be stored on a database, as this information will be valuable for future water management strategies;
- The implementation of a well field around the pit will remove groundwater by pumping before entering the pit and being impacted by mining activities;
- If the pit dewatering water is released into the Selati River, the water needs to be monitored for quality ; and
- The pit dewatering water could also be used in the mines process water where monitoring and treatment prior to releasing into the Selati River is not necessary; and
- Either options to release the dewatering water into the Selati River or to be used as part of the process water needs to be further investigated and discussed with Foskor.

CHAPTER 11: Conclusions

11.1. Study Conclusions

From the information gathered during this study the following conclusions are made:

- The area of the NSPP lithology forms part of the Phalaborwa Igneous Complex which was intruded into granite-gneiss of the Basement Complex. The pit comprises of pyroxenite and is intruded by SW-NE trending dolerite dykes;
- Dolerite dykes are near vertical or dip 85 ° north-west and south-east;
- The dolerite dykes split up and compartmentalise the area since they act as preferential flow paths for groundwater;
- 71% of the contact zones drilled dry with only 29% of the upper dolerite dyke contact zones bearing groundwater. All 17 of the lower dolerite contact zones drilled dry;
- The probability of intersecting groundwater in the shallow monitoring boreholes above 50 m is 68.4% and for intersecting groundwater seepage 31.6%;
- From the drilling results the groundwater occurrence are associated with the weathering and fracturing in the host formations, with a 5.8% to 17.6% (assuming no leakage from bentonite seals) of probability for groundwater occurrence below the weathered and fractured zone;
- 82% of the deep monitoring boreholes in the NSPP area intersected no water strikes;
- Three aquifer units can be defined within the rock mass as weathered, fractured and slightly fractured to fresh zones;
- The groundwater contours indicates that groundwater flow is controlled by the dolerite dykes; generally groundwater flow is south-west and south in the direction of the Selati River.

11.2. Groundwater Quality Conclusions

- The groundwater quality is represented by two types of dominate water types, Ca-Mg-SO_4 and Na-Mg-HCO_3 types of water;
- Elevated sulphate concentrations and alkaline conditions is predominant in the groundwater at the area of investigation.

- The majority of the groundwater is a $Ca\text{-}Mg\text{-}SO_4$ type, and is present for both deep and shallow boreholes, which indicates that both aquifers have already been impacted by the elevated sulphate; and

- The $Na\text{-}Mg\text{-}HCO_3$ type of groundwater is more present in the shallow aquifer than in deep aquifer, and is probably associated with the geological formation.

11.3. Conclusions from the groundwater Impact Assessment

11.3.1. Construction Phase

- A low impact is associated with the construction phase on the groundwater.

11.3.2. Operational Phase

- A moderate impact is associated with the operational phase. A possible mitigation measure could be to release the well field dewatering water into the Selati River.

11.3.3. Closure Phase

- A significant volume of water will be lost due the evaporation from the pit lake after closure. This will induce an expected moderate impact on the Selati River.

- Practical achievable mitigation measures need to be discussed with Foskor and is not included in this report.

11.4. NPM Conclusions

- The area of the NPM lithology forms part of the Phalaborwa Igneous Complex which was intruded into granite-gneiss of the Basement Complex. The pit comprises of pyroxenite and is intruded by SW-NE trending dolerite dykes;

- The dolerite dykes split up and compartmentalise the area since they act as preferential flow paths for groundwater;

- Three aquifer units can be defined within the rock mass as weathered, fractured and deep fractured to fresh zones;

- The probability of intersecting groundwater at the NPM in shallow monitoring boreholes above 58 m is 42.9% and for intersecting groundwater seepage 57.1% compared to the probability of 68.4% for intersecting groundwater above 50 m at the NSPP and 31.6% for intersecting groundwater seepage.

- The probability of intersecting groundwater in deep monitoring boreholes at the NPM below 58 m is 81.8% and for intersecting groundwater seepage 18.2%. This percentage is much higher than the 17.6% probability for intersecting groundwater below the weathering and fracturing zone of the NSPP.

The difference in groundwater occurrence between the two areas (NSPP and NPM) is probably related to the following:

- The NPM pit is currently developed to approximately 160 mbgl (compared to approximately 60 mbgl at the NSPP) and a dewatering cone has developed around the NPM pit. This dewatering cone will initially affect the upper weathered and fractured zone around the NPM which give rises to less water strikes in this zone (43%) compared to water strikes in the same region at the NSPP (68%). This statement is supported by the fact that existing shallow monitoring boreholes of 30m deep close to the NPM pit has dried up;

- The NSPP pit area is more extensively intruded by north east to south west striking dolerite dykes, and these dykes are impermeable at depth and tend to compartmentalize the formation. This could be a reason for encountering more water strikes at depth at the NPM (82%) to 18% at the NSPP; and

- Differences in crystallization temperatures, crystallization times and geological compositions will also play a role.

CHAPTER 12: Recommendations

12.1. Study Recommendations

Based on this thesis the following recommendations are made:

- It is recommended to include the newly drilled boreholes into the groundwater monitoring system to assess the variation in sulphate in the groundwater, and be implemented with the existing monitoring system;
- Continuous monitoring and analyses of all groundwater samples collected from the existing and newly drilled boreholes for pH, EC, TDS, all major cations and anions and trace elements using an ICP scan;
- Currently bi-annually groundwater monitoring is conducted by Groundwater Consulting Services (GCS), and as mining activities seem to have impacted on the sulphate concentrations of the groundwater all quality issues of concern reported should be receive further attention;
- Installation of de-watering boreholes will cause a reduction in pit inflows (and increase the pit stability) and it is therefore recommended to establish a de-watering well field. This recommendation is not based on any geotechnical pit stability information and must be confirmed if this information is available.
- As part of the de-watering campaign water levels and abstraction rates must be monitored weekly. This information will be valuable for updating the numerical model to increase the accuracy of predictions and assist with sound water management.

CHAPTER 13: Comparison with Previous Case Studies and Study Limitations

13.1.Comparison with Findings of Previous Case Studies

13.1.1. Aquifer Zones

Three water bearing aquifer zones were defined in this study by means of the deeper drilling at the NSPP and NPM areas to the two zones (weathered and fractured zones) from previous studies, namely:

- Shallow weathered aquifer zone, with weathering ranging to 15 m in the granitic gneiss and to 30 m in the pyroxenite at the NSPP and 32 m at the NPM;
- Deep fractured aquifer zone; the fracturing zone range to 20m in the granitic gneiss and to 50 m in the pyroxenite formation at the NSPP and 58 m at the NPM; and
- Fresh to slightly fractured aquifer zone (previously not defined) below 50 m, this aquifer zone was confirmed with deep drilling in borehole PEP6D of 0.6 l/s in the granitic-gneiss and at the NPM at:
    - NPM1D at150 m (0.4 l/s)156 m (0.6 l/s),
    - NPM2D at 139 m (0.1 l/s), 166 m (0.3 l/s),
    - NPM6D at 61 m (0.1 l/s), 140 m (0.3 l/s); and
    - NPM9D at 69 m (0.5 l/s), 105 m (3.4 l/s).

All these groundwater strikes occurred after shallow water strikes were sealed off and drilling fresh formation for several meters.

Table 40 compares the findings regarding aquifer zone thickness of different studies.

Table 40: Aquifer zone Comparison with Previous Studies.

Aquifer Zone	**Pervious Study Case I**	**Pervious Study Case II**	**NSPP Study Area**	**NPM Study Area**	**Comments**
	Depth (mbgl)	**Depth (mbgl)**	**Depth (mbgl)**	**Depth (mbgl)**	
Shallow Weathered Aquifer	14-35 (Average 25)	30	15 - Granite 30 -Pyroxenite (Average 22.5)	15 - Granite 32 -Pyroxenite	Good comparison
Deep Fractured Aquifer	22-52 (Average 45)	Northern side of main dyke 30-50 (Average 40) Southern side of the main dyke 30-82 (Average 56)	20- Granite 50 - Pyroxenite (Average 35)	24- Granite 58 - Pyroxenite	Good comparison.
Fresh to Slightly Fractured	Not defined	Not defined	50 - 146	58 -166	Confirmed with drilling at NPM

13.1.2. Dolerite Dykes

- All the groundwater studies in the area confirmed that groundwater occurred in the fractured zones of the host rocks (pyroxenite and granitic-gneiss) next to the dolorite dykes; and
- The contact zones bear little groundwater; however there is a 53% probability for intersecting groundwater in boreholes targeting dolerite dykes in both study areas(NSSP and NPM). Where the lower dolerite contact zone was intersected only 10% of boreholes had groundwater for the NPM area whereas all the lower contact zones intersected at the NSPP area drilled dry.

The number of boreholes intersecting dolerite for each study area is summarised in Table 41.

Table 41: Number of Boreholes Intersection Dolerite

	Pervious Study Case I	Pervious Study Case II	Feasibility study	NSPP Study Area	NPM Study Area
Number of BH	17	18	9	36	26
Boreholes Intersecting Dolerite	8	12	7	15	15
Number of BH Intersecting Dolerite with WS	3/8	5/12	1/7	8/15	8/15
Dolerite Water strikes (%)	38%	42%	14%	53%	53%

13.1.3. Groundwater Strikes and Yields

- Case study I had groundwater strikes were from 16 to 48 m with yields ranging from 0.1 to 11 l/s;
- Case study II had groundwater strikes from 7 to 48 m with yield ranging from 0.3 to 10 l/s;
- NSPP area had water strikes from 4 to 129 m with yields ranging from 0.1 to 25 l/s; and
- NPM area had groundwater strikes from 8 to 166 m with yield ranging from 0.2 to >1 l/s.

The water strikes for the different study areas are summarised in Table 42.

Table 42: Groundwater strikes for different Study Areas

	Pervious Study Case I	**Pervious Study Case II**	**Feasibility study**	**NSPP Study Area**	**NPM Study Area**
Number of BH	17	18	9	36	26
Water Strikes Depth(m)	16 to 48	4 to 48	6 to 82	4 to 129	8 to 166
WS Range (l/s)	0.1 to 11	0.3 to 10	0.1 to 24	0.4 to 8.3	0.6 to >10
Number of BH Intersecting WS	9/17	8/18	3/9	16/36	16/26
BH with Water Strike (%)	**53%**	**44%**	**33%**	**44%**	**62%**

13.2. Study Limitations

The limitations of this study are as follows:

- This study is based on selective areas in the PIC namely the groundwater occurrence of drilling results at NSPP and NPM;
- Groundwater probabilities and findings are based on the available data set; and
- Drilling results are confined to 180 m depth.

CHAPTER 14: References

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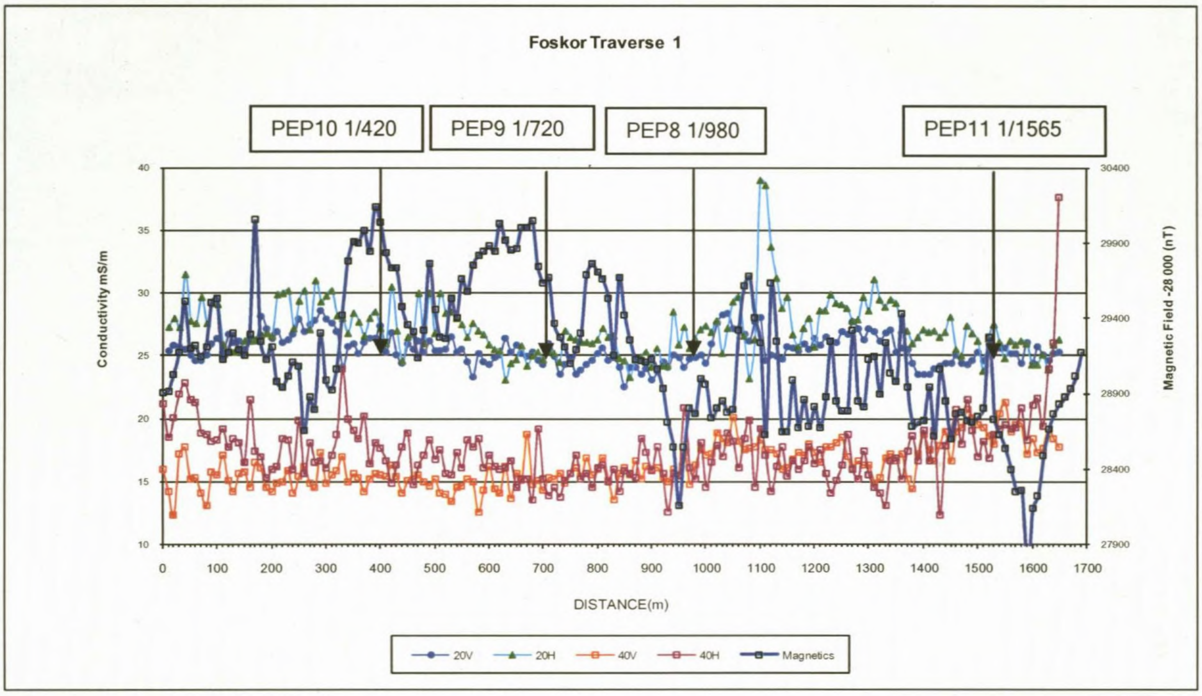
CHAPTER 15: Appendixes

15.1.Appendix A

15.1.1. Geophysical Traverses

EM 34 and Magnometer



ABEM LUND 2D Resistivity Image

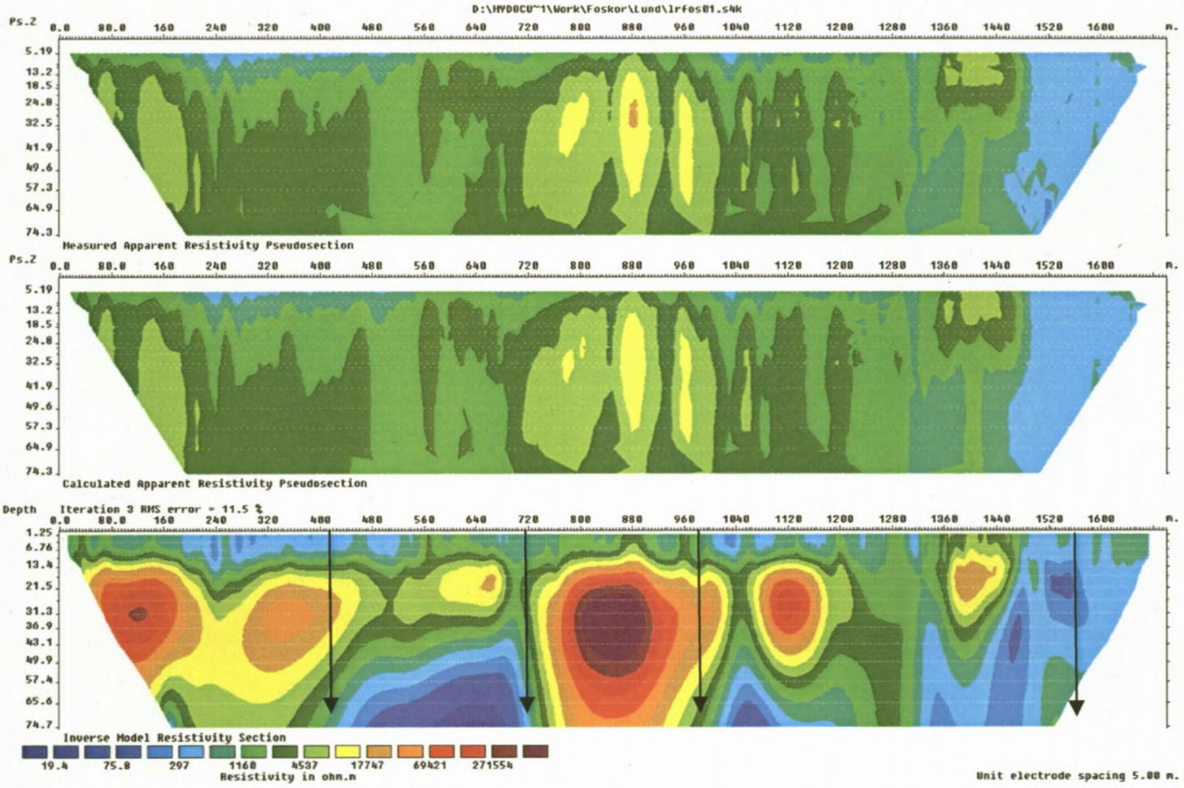
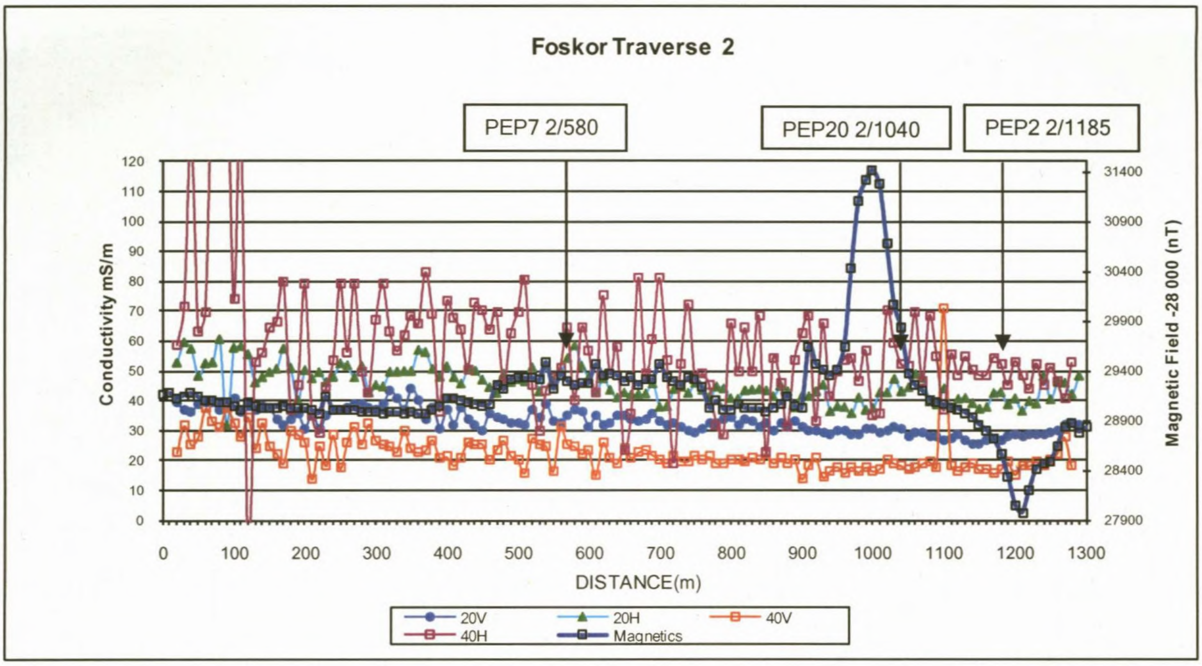


Figure 74: Geophysical Traverse 1

EM 34 and Magnometer



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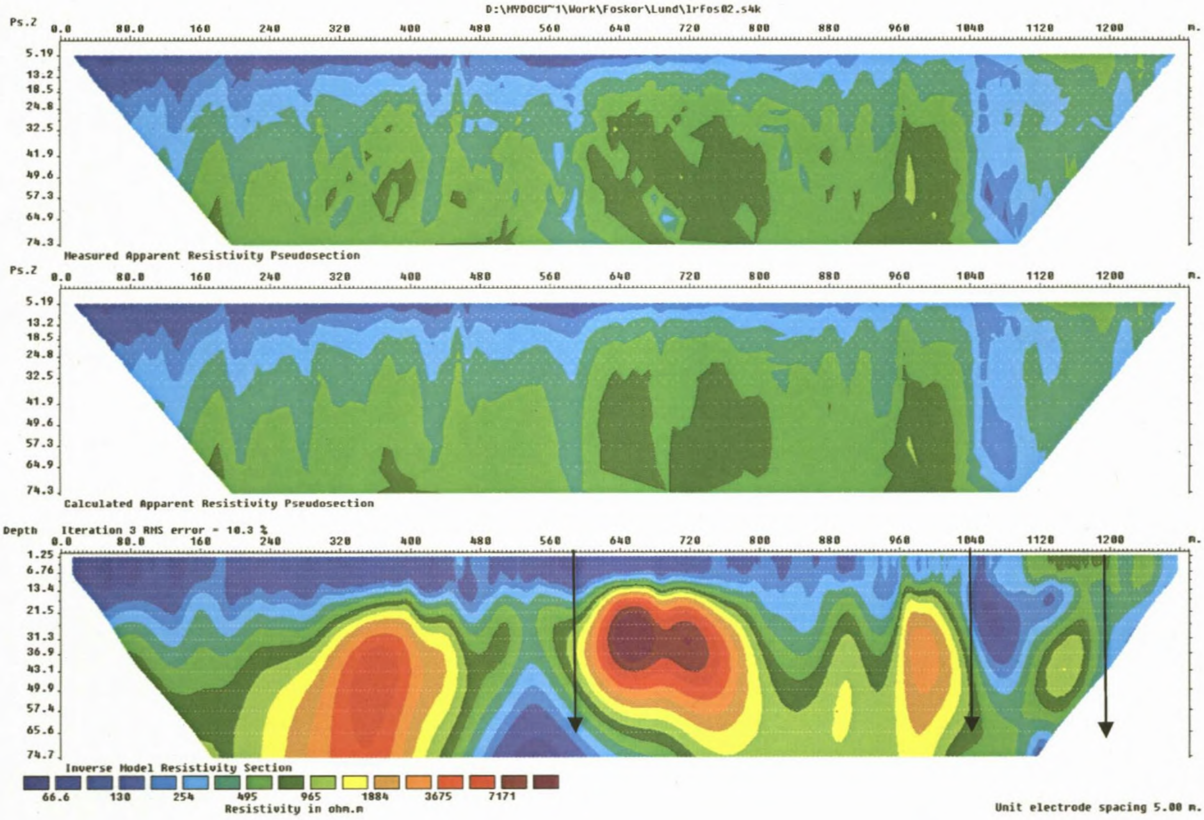
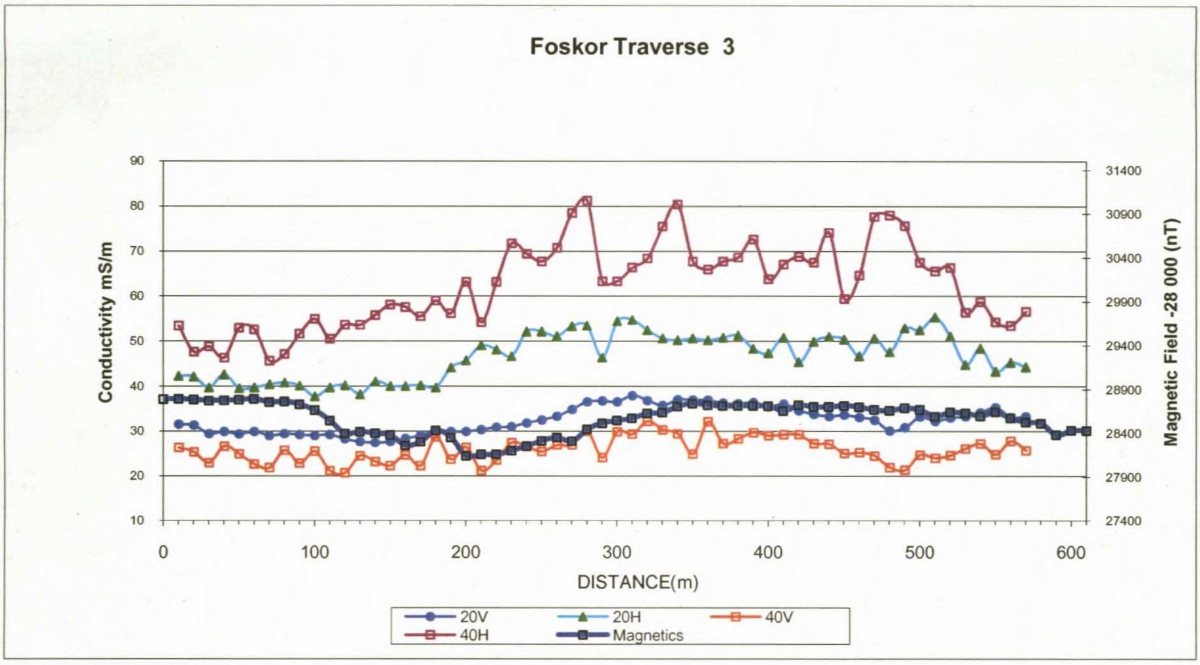


Figure 75: Geophysical Traverse 2

EM 34 and Magnometer



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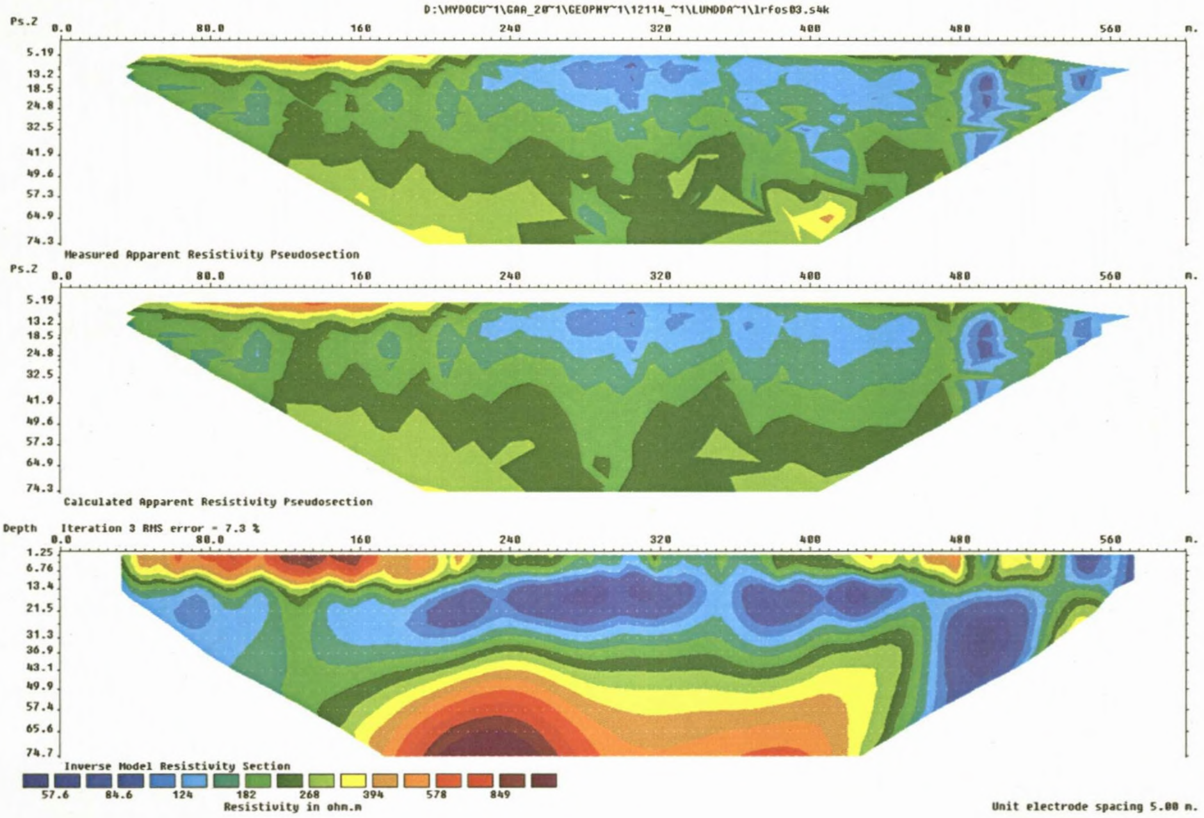
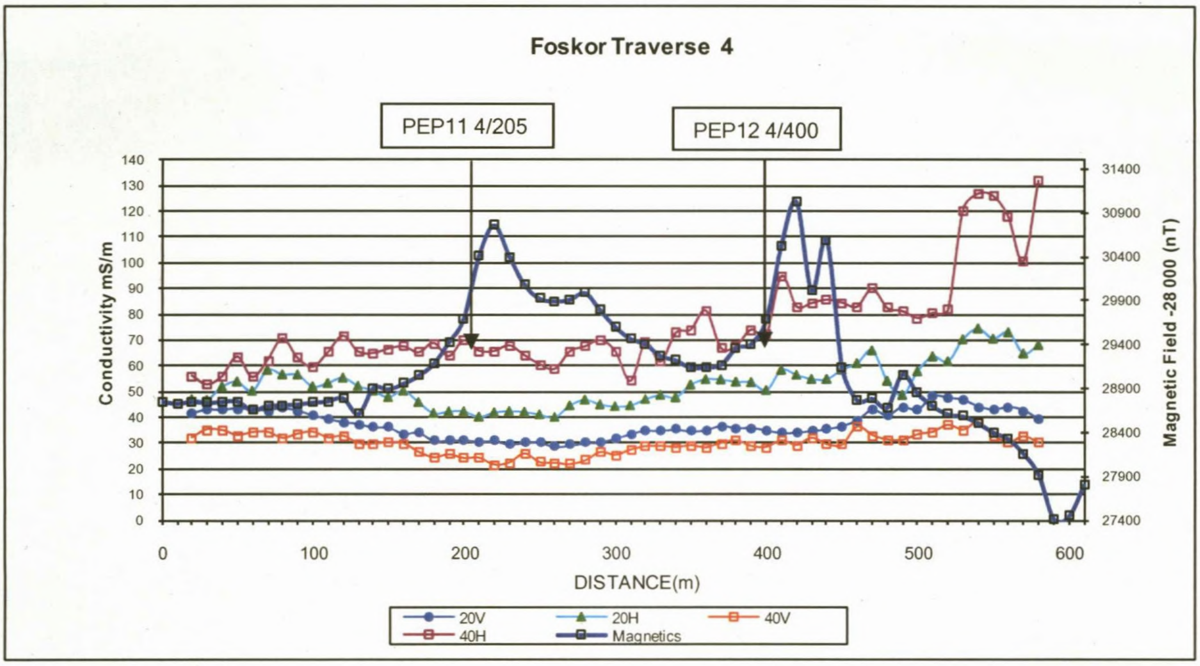


Figure 76: Geophysical Traverse 3

EM 34 and Magnometer



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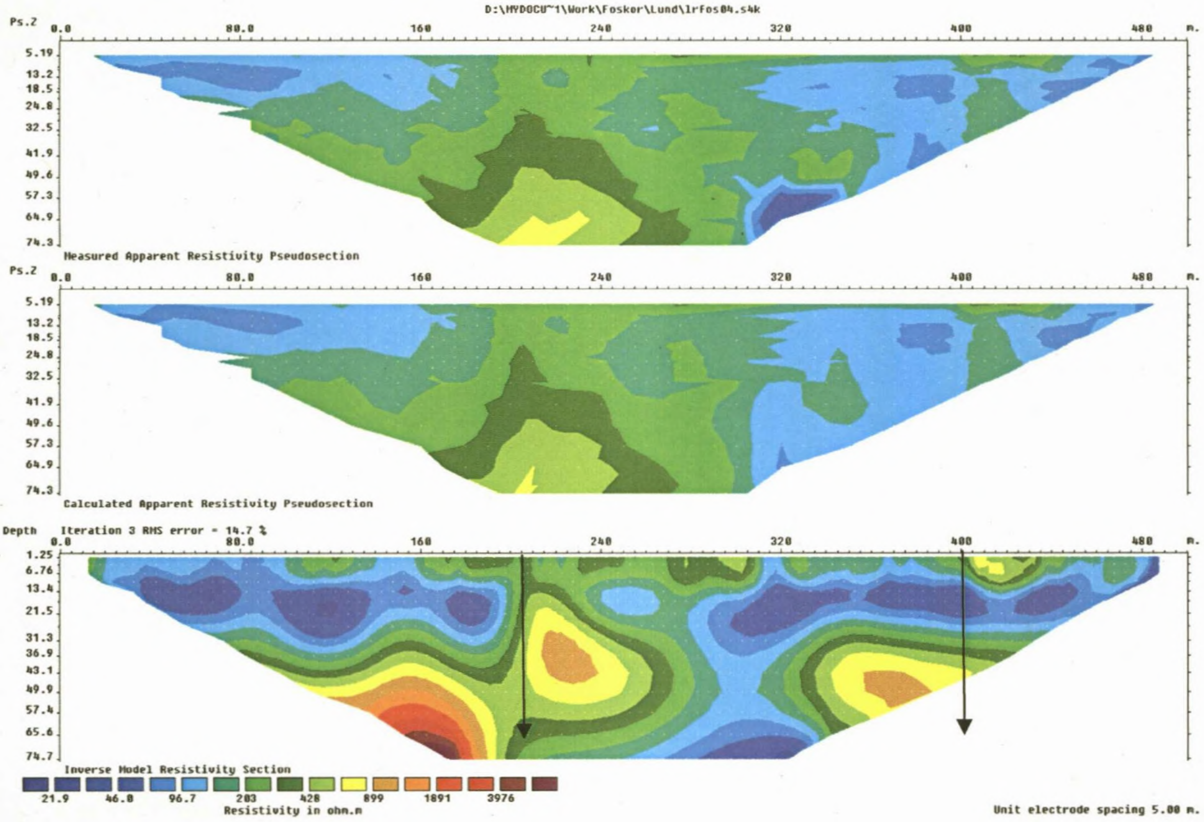
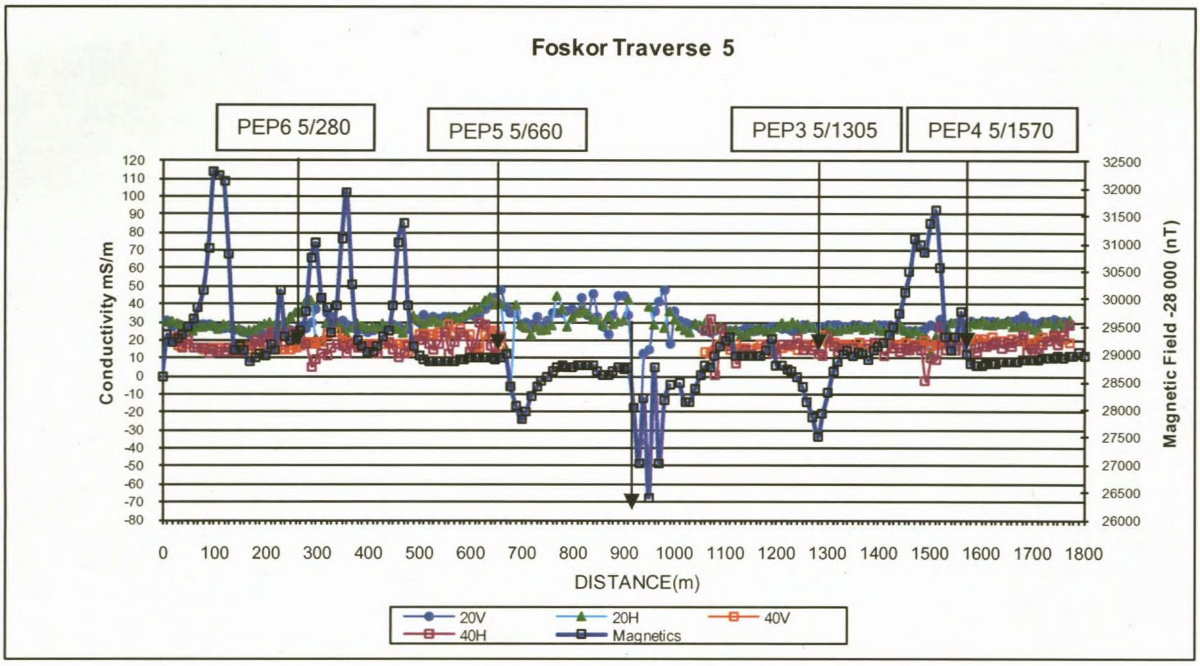


Figure 77: Geophysical Traverse 4

EM 34 and Magnometer



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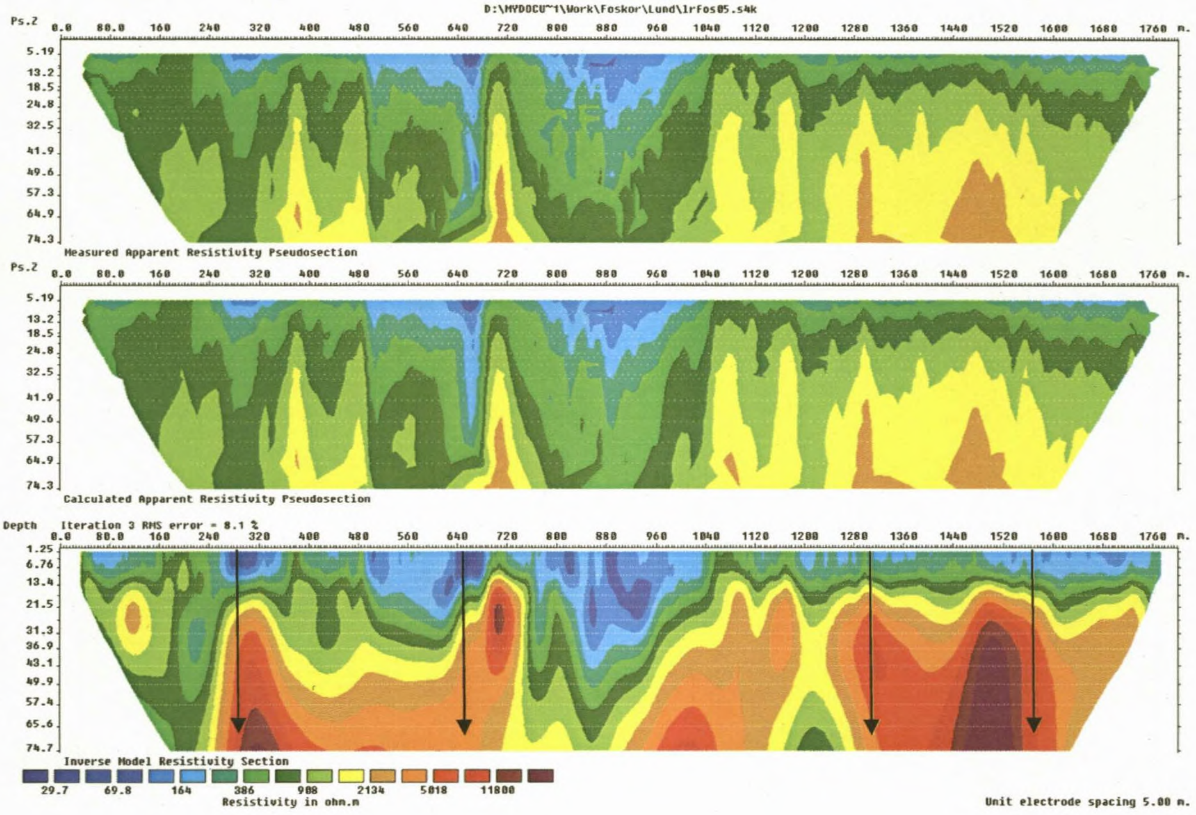
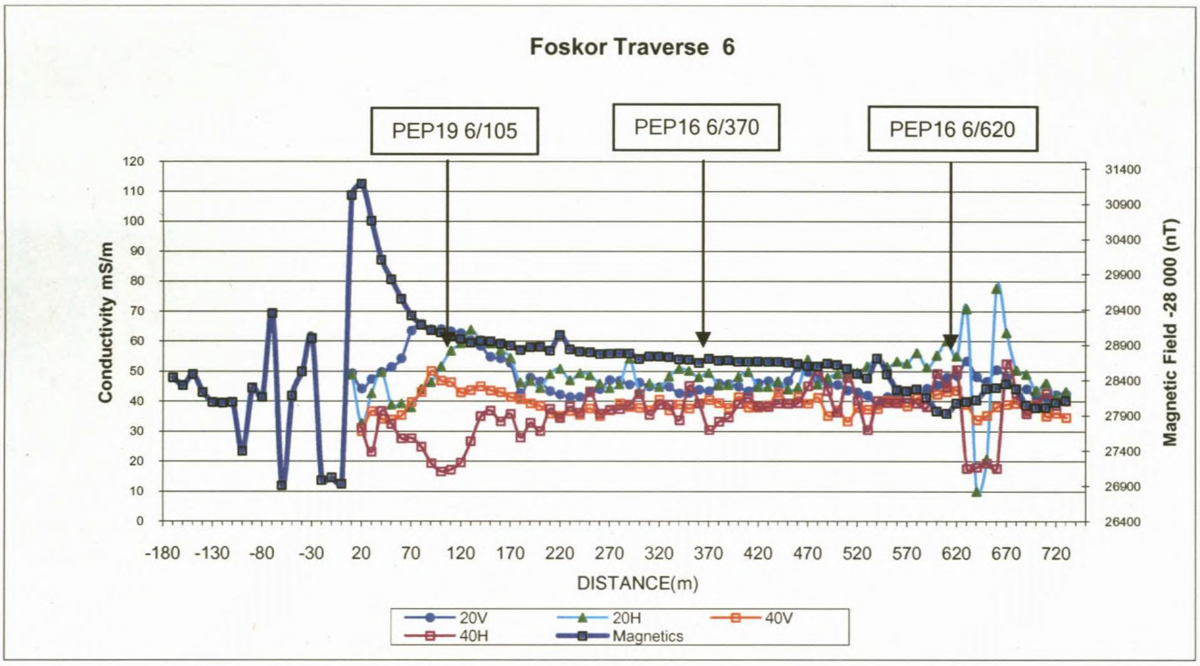


Figure 78: Geophysical Traverse 5

EM 34 and Magnometer



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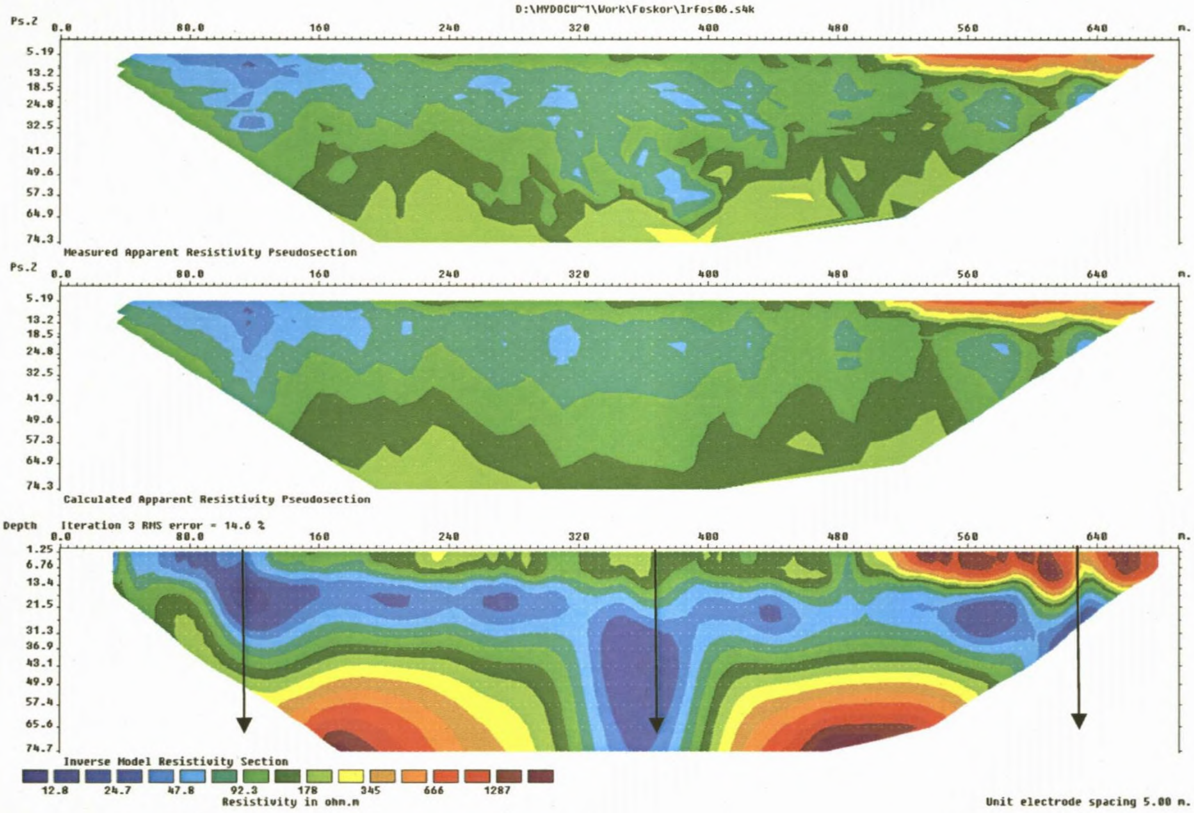


Figure 79: Geophysical Traverse 6

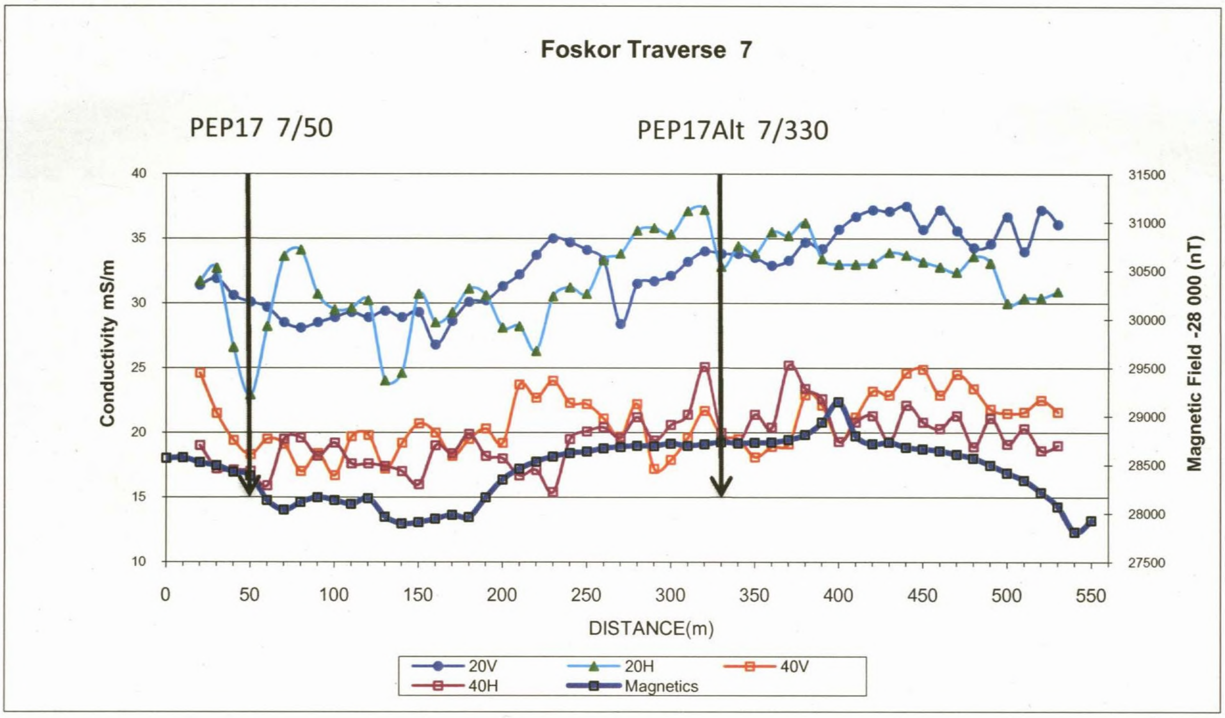


Figure 80: Geophysical Traverse 7

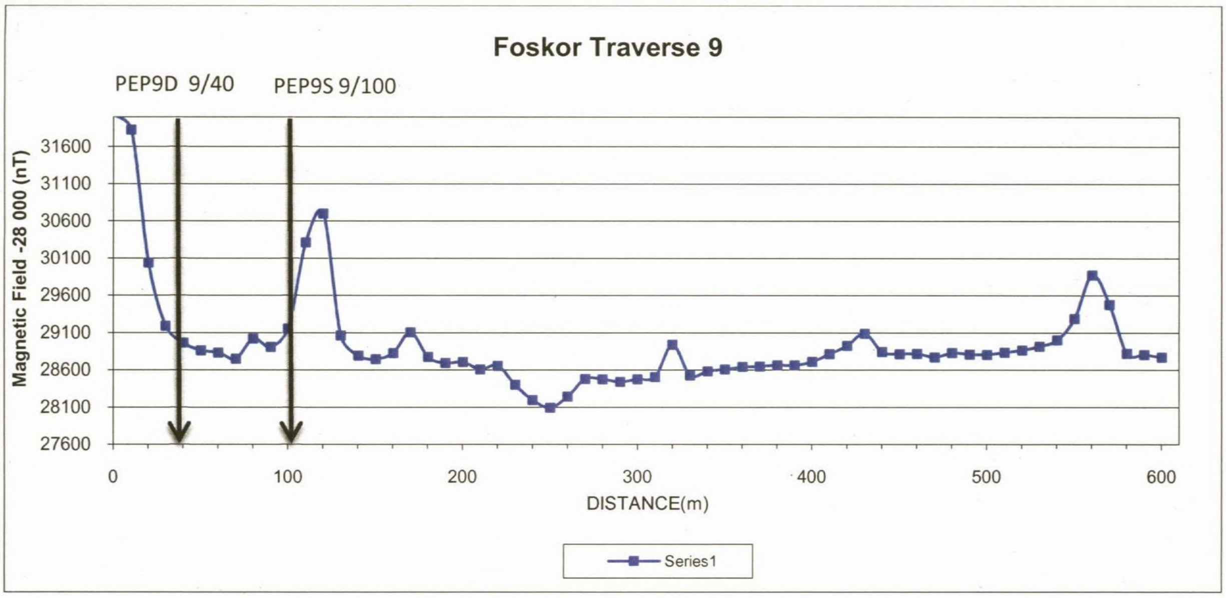
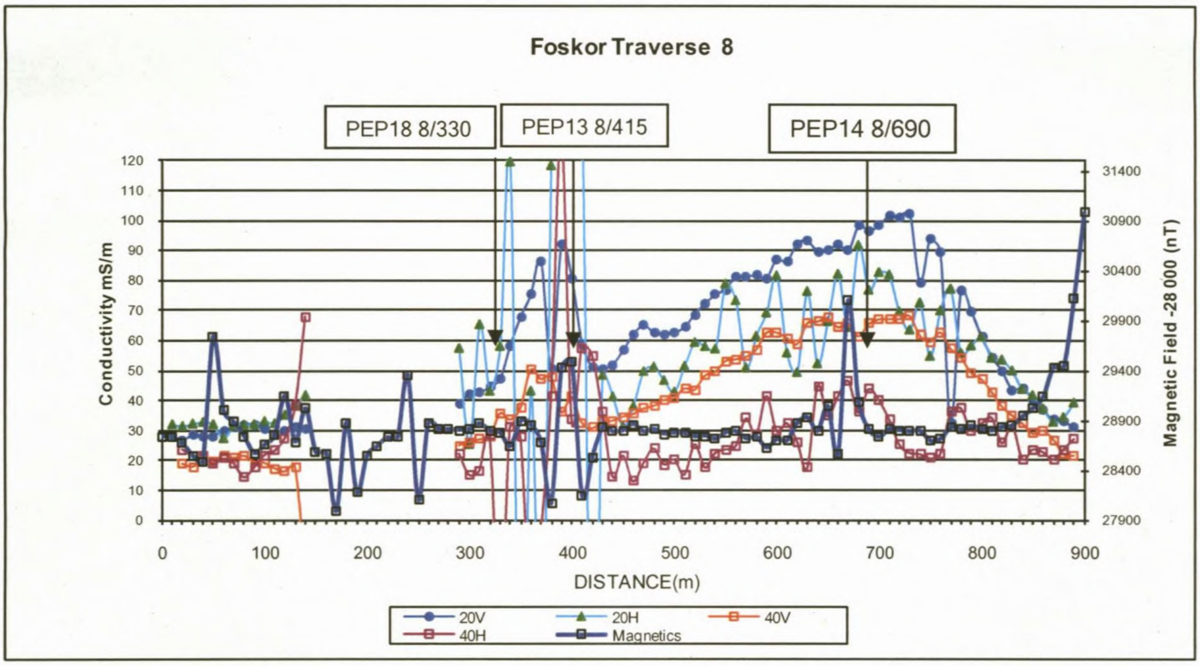


Figure 81: Geophysical Traverse 9

EM 34 and Magnometer



ABEM LUND 2D Resistivity Image

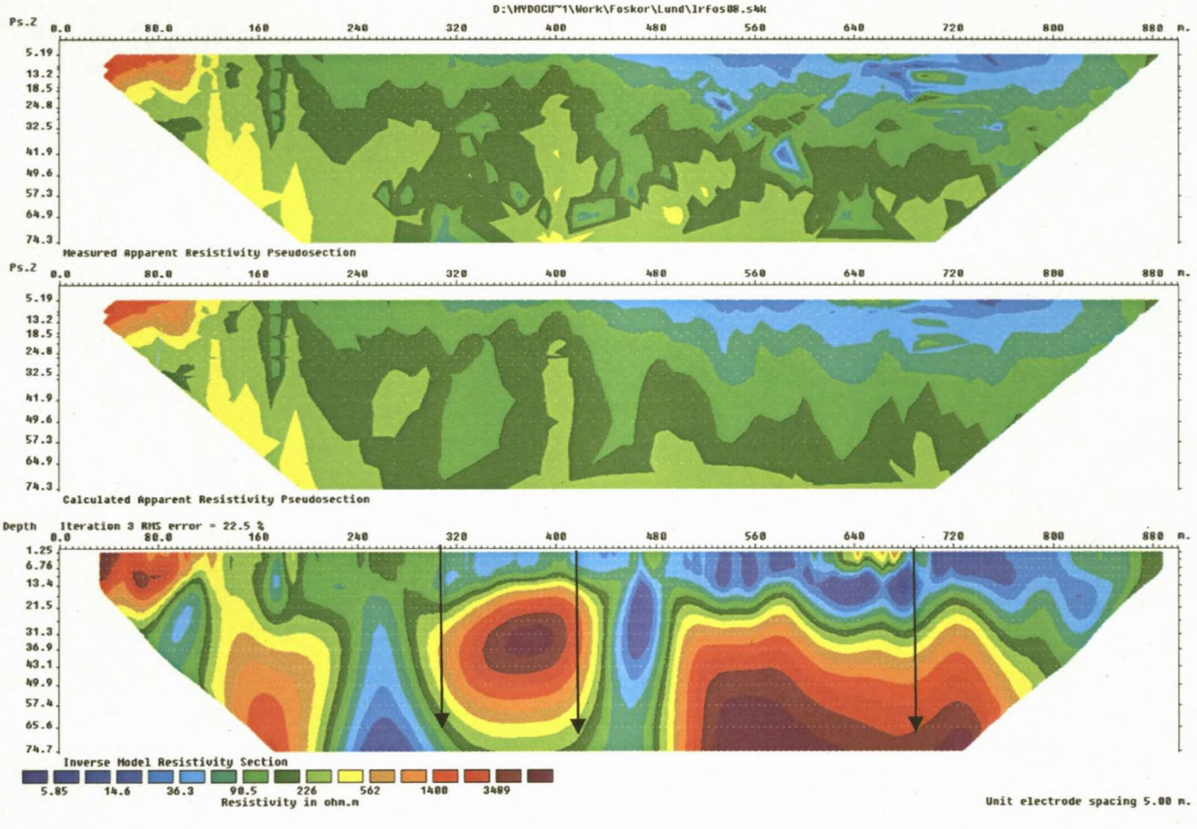


Figure 82: Geophysical Traverse 8

15.2.CD Folders

15.2.1. Analytical Test Certificates NSPP

15.2.2. Detailed Borehole Logs of NPM

15.2.3. Detailed Borehole Logs of NSPP

15.2.4. NSPP Drilling Results Discussion and Photo Record

15.2.5. Pumping Testing Graphs of NPM

15.2.6. Pump Testing Graphs of NSPP

Summary

Three water bearing aquifer zones were defined in this study for the Phalaborwa Igneous Complex, namely a shallow weathered aquifer zone, fractured aquifer zone and the fresh to slightly fractured aquifer zone. The probabilities for groundwater occurrence in the different aquifer zones in the Phalaborwa Igneous Complex are based on the available data set.

The Phalaborwa Igneous Complex has intruded into granite-gneiss of the Basement Complex and is intruded by SW-NE trending dolerite dykes. These dolerite dykes are near vertical or dip 85 ° north-west and south-east and act as preferential flow paths for groundwater and compartmentalisation of the area.

The probability of intersecting groundwater at the NSPP in the shallow aquifer zone above 50 m is 68.4% and for intersecting groundwater seepage 31.6%. The probability of groundwater occurrence below the weathered and fractured zone (50m) in the NSPP area is 5.8% to 17.6%.

The probability of intersecting groundwater in shallow aquifer zone above 58 m at the NPM is 42.9% and for intersecting groundwater seepage 57.1%. The probability of intersecting groundwater below the weathered and fractured one at the NPM below 58 m is 81.8% and for intersecting groundwater seepage 18.2%.

The Phalaborwa Igneous Complex has intruded in to the Bushveld Igneous Complex, and is mined for phosphate and other minerals by Foskor and PMC. Foskor (Pty) Ltd is currently one of the world's leading phosphate and phosphoric acid producers, with approximately 95% of South Africa's production.

The world phosphate reserves are sufficient to supply the world with the required amounts and types of needed phosphate products for some centuries to come. However high grade and economic reserves are being depleted, which could result in mining lower grade phosphate rocks at higher cost.

The 95% of the global phosphate production used in agricultural production much contributed to providing enough food to ever growing world population. To sustain the large amount and high quality of food obtained today worldwide, and in particular in developing countries, are largely due to the use of phosphate fertilizers, phosphorus-based herbicides and insecticides, and plant hormone, let alone the use of phosphorus in animal feeds.

There are many non-agricultural applications of phosphate-based products. These applications are currently using limited quantities of phosphates, but they cover various sectors essential to everyday life.

Modern technologies, some based on incremental improvement of existing technologies and others on entirely new concepts, should be developed to further the use of phosphates in the non-agricultural sector.

Phosphate mining has a negative impact on the quality of groundwater. Dewatering strategies for open pit phosphate mining should be developed where a dewatering well field pump the groundwater away from the pit before it is contaminated in the mining process. This water should be monitored for quality and be released in to the ecosystem, or it could be used in the mining process. Groundwater quality should also be monitored with a groundwater monitoring network in order to contain groundwater pollution.

Opsomming

Drie water draende akwifeer sones is vir die Phalaborwa Stollings Kompleks geidentifiseer gedurende hierdie sudie, naamlik 'n vlak verweerde akwifeer sone, 'n gefraktueerde sone en 'n effens gefraktueerde tot solliede akwifeer sone. Die waarskynlikheid vir die voorkoms van grondwater in die Phalaborwa Stollings Kompleks is gebaseer op die beskikbare data.

Die Phalaborwa Stollings Kompleks het ingedring in die granite-gneis gesteentes van die Bosveld Stollings Kompleks in en is deurdring met doleriet gange met 'n SW-NE strekkings rigting. Hierdie dolerite gange is amper vertikaal of hel teen 85 ° noord-wes en suid-oos en dien as voorkeur vloei roetes vir grondwater, hulle verdeel ook die area in kompartemente.

Die waarskynlikheid om grondwater te kry by die NSPP area in die vlak akwifeer sone bo 50 m is 68.4% en om slegs grondwater invloei in die sone te kry 31.6%. Die waarskynlikheid om grondwater benede die verweerde en gefraktueerde sone (50 m) in hierdie area te kry is tussen 5.8% tot 17.6%.

Die waarskynlikheid om grondwater in die vlak verweerde akwifeer sone by die NPM (bo 58 m) te kry is 42.9% en om slegs grondwater invloei te kry is 57.1%. Die waarskynlikheid om grondwater benede die verweerde en gefraktueerde sone van die NPM area te kry (benede 58m) is 81.8% en om slegs grondwater invloei te kry is 18.2%.

Die Phalaborwa Stollings Kompleks het ingedring in die Bosveld Stollings Kompleks in en word gemyn vir fosfaat en ander minerale deur Foskor en PMC. Foskor (Pty) Ltd is tans een van die wereld se leiers in fosfaat en fosfatiese suur produseerders, en is na beraming verantwoordelik vir 95% van Suid Afrika se fosfaat produksie.

Die wereld se fosfaat reserwes is voldoende om aan die wereld behoeftes en tipes van fosfaat produkte te voorsien vir die volgende paar dekades. Hoë graadse en ekonomiese reserwes raak egter uitgeput, met die gevolg dat lae graadse fosfaat gesteentes gemyn sal moet word teen hoër kostes.

95% van die globale fosfaat produksie wat in landbou verbruik word, dra by dat voldoende voedsel aan die steeds groeiende wereld populasie voorsien word. Fosfaat kunsmis, plantvoedsel, insekdoders, plant hormone asook veevoere maak die groot hoeveelheid en hoe kwaliteit voedsel veral in ontwikkellende lande volhoubaar.

Daar bestaan ook 'n wye reeks van nie landbou toepassings van fosfaat basis produkte. Hierdie fosfaat toepassings gebruik klein hoeveelhede fosfaat, maar hulle dek sektore wat essentieel is vir alledaagse bestaan.

Ontwikkeling van moderne tegnologie waarvan sommige gebaseer is op 'n inkrementele verbetering van bestande tegnologie en ander op totale nuwe konsepte moet ontwikkel word om die gebruik van fosfaat in die nie landbou sektor te bevorder.

Fosfaat mynbou het 'n negatiewe impak op die kwaliteit van grondwater. Ontwaterings strategieë vir oop groef mynbou moet ontwikkel word in so 'n mate, dat grondwater weg vanaf die groef af gepomp word voordat dit besoedel raak deur die myn proses. Die kwaliteit van hierdie water moet gemonitor word voordat dit in die ekosisteem vrygelaat word, of dit moet in die myn proses gebruik word. Grondwater kwaliteite moet ook gemonitor word deur 'n moniterings netwerk om besoedeling vroegtydig waar te neem en te kan beperk.