THE DEVELOPMENT OF A PRE-MINING GROUNDWATER MONITORING NETWORK FOR OPEN PIT MINES IN SOUTH AFRICA

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Declaration

I, Ferdinand Goussard, hereby declare that this dissertation, submitted for the degree Master in the Faculty of Natural and Agricultural Sciences, Institute for Groundwater Studies, University of the Free State, Bloemfontein, South Africa, is my own work and has not previously been submitted by me at another University / Faculty.

I declare that all sources cited or quoted are indicated and acknowledged by means of a list of references.

I further cede copyright of the dissertation in favour of the University of the Free State.

F. Goussard

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List of Acronyms / Abbreviations

Acronym / Abbreviation	Definition
AMD	Acid mine drainage
ARD	Acid rock drainage
BBE	Black Economic Empowerment
CD	Compact disc
CDT	Constant drawdown test
COD	Chemical oxygen demand
Department	Department of Water Affairs
DO	Dissolved oxygen
DRO	Diesel range organics
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
EEA	European Environment Agency
EMPR	Environmental Management Plan Report
FC-method	Pumping test analysis in fractured rock aquifers
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
GRO	Gasoline range organics
IGRAC	International Groundwater Resources Assessment Centre
I&AP	Interested and Affected Parties
K	Hydraulic conductivity
KPMG	Klynveld Peat Marwick Goerdeler Firm for audit, tax and advisory services
MPRDA	Mineral and Petroleum Resources Development Act (Act 28 of 2002)

Acronym / Abbreviation	Definition
MTBE	Methyl Tert-Butyl Ether (gasoline additive)
NEMA	National Environmental Management Act (Act 107 of 1998)
NGDB	National Groundwater Database
NGO	Non-Government Organisation
NWA	National Water Act (Act 36 of 1998)
NW-SE	Northwest - Southeast
PAH	Polynuclear aromatic hydrocarbon
S	Storativity
SANS	South African National Standard
SDT	Step drawdown test
SOG	Oil and grease
SRK	Steffen, Robertson and Kirsten
SS	Suspended Solids
T	Transmissivity
TDS	Total dissolved solids
TKN	Total Kjeldahi nitrogen
TP	Total phosphorus
UN/ECE	United Nations Economic Commission for Europe
VPH	Volatile petroleum hydrocarbons
WGS84	World Geodetic System 1984
WISH	Windows Interpretation System for the Hydrogeologist
WUA	Water User Association

List of Units/Symbols

Units/Symbols	Definition
%	Percentage
$	Dollar
Ca	Calcium
Cl	Chloride
cm	Centimetre
CO_3	Carbonate
Fe	Iron
ha	Hectare
HCO_3	Hydrogen carbonate
K	Potassium
km	Kilometre
L/s	Litre per second
m	Meter
Mg	Magnesium
mg/l	Milligram per litre
mm	Millimetre
mm/a	Millimetre per annum
m^3/a	Cubic metre per annum
m^2/d	Square meter per day
m^3/h	Cubic metre per hour
Ml	Mega litre
Mt	Million ton

Units/Symbols	Definition
Na	Sodium
NaCl	Sodium chloride
NH_4	Ammonium
NO_3	Nitrate
NO_2	Nitrite
PO_4	Orthophosphate
R	Rand
SO_4	Sulphate

Chapter 1
INTRODUCTION

1.1 MINING IN THE SOUTH AFRICAN CONTEXT

After the discovery of minerals mining undoubtedly formed the backbone of the South African economy. Within decades the economy was transformed from one previously based on agriculture and trade into a thriving economy supported by the vast rich mineral reserves underground.

Large scale and profitable mining started after the discovery of a diamond on the banks of the Orange River in 1867 followed by the discovery and exploitation of the kimberlite pipes (near Kimberley) a few years later. The gold rushes at Pilgrim's Rest and Barberton were precursors to the biggest discovery of all, the main reef on the farm Langlaagte in the year 1886 that led to the Witwatersrand gold rush.

For nearly 150 years mining has been the driving force behind the country's economy that led to the establishment of numerous towns, the development of infrastructure, the catalyst for the development of other economic sectors and in doing so being one of the biggest employers in the country for years.

Although diamond and gold production may be down from their peaks the country is still a large producer of these two commodities together with coal and iron ore. Today the country is still the largest producer of chrome, manganese, platinum, vanadium and vermiculite in the world. It is reckoned that South Africa is holding the world's largest reserves of gold, platinum-group metals and manganese ore. South Africa have mineral deposits matched by only a small number of countries and have the potential for the discovery of other world class deposits as certain areas have not been exhaustively explored yet.

Over the years the mining sector contributed a substantial portion to the country's Gross Domestic Product (GDP) but declined since the peak period of the 1970's. According to Fedderke and Pirouz (date unknown) the contribution of the mining sector declined from 21.3% in 1970 to 9.9% of the private sector's GDP in 1998.

In the article "Mining's contribution to South Africa's global competiveness" published by Brand South Africa (2015) it was noted that despite a declining in contribution to the country's GDP and employment the mining sector still remains a pillar of the South African economy. The sector contributes 8.6% (R263 billion) to the GDP and is responsible for 500 000 direct and indirect jobs respectively.

It is forecasted that mining will continue to play an important role in the economy to earn foreign exchange and also as an employer of the country's workforce in the foreseeable future. According to a report by Smit (2013) the mining industry will however have to make some changes to stay relevant, these include:

- *Sustainable mining methods which take into account the social and environmental impact of the industry*
- *Adding value through beneficiation*
- *Achieving BBE targets*
- *Promoting more equitable sharing in our rich resource base*

The contribution that mining had on the South African economy is probably best reflected when the Rand (which refers to the Witwatersrand with its vast wealth of gold deposits) was introduced as the country's currency in 1961 prior of the country becoming a Republic and replacing the British Pound.

With the total mineral reserves estimated to be worth $2.5 trillion one can be assure that the mining sector will still play a pivotal role in the South African economy in the years to come.

1.2 OBJECTIVES OF DISSERTATION

The objective of the dissertation is to provide a comprehensive guide for the establishment of a pre-mining groundwater monitoring programme for open pit mines in South Africa.

It must be bear in mind that every mining activity is unique with specific site conditions that will require that some of the guidelines given in the dissertation have to be adjusted or might not even be practical or applicable for the specific mining activity.

The different phases for the establishment of a monitoring programme is discussed in detail and will give the reader insight and guidance in the planning, conducting of the fieldwork and setting up of the monitoring network to ensure that all the groundwater aspects can be manage effectively.

Besides the guidelines for the establishing of a groundwater monitoring programme the following aspects are also discussed namely the impacts of mining on groundwater, the environmental legislation, the hydrogeology of South Africa and the importance of groundwater monitoring.

1.3 STRUCTURE OF DISSERTATION

The dissertation consists of 11 chapters in which the importance of mining, the impacts of mining on water resources, groundwater monitoring and finally the processes for the development of a pre-mining monitoring programme are outlined. The following aspects are discussed in the chapters:

- **Chapter 1:** Gives an overview of the mining sector's contribution (past and current) to the South African economy.
- **Chapter 2:** Provides an overview of the water act and the relevant environmental and mining legislations regarding groundwater in South Africa.
- **Chapter 3:** The chapter discuss the impacts that mining activities have on water resources and the factors contributing to the phenomenon.
- **Chapter 4:** Discussion on the hydrology of South Africa with reference to the different aquifer types, the importance of groundwater and the usage thereof.
- **Chapter 5:** Literature review focussing on the components and aspects of groundwater monitoring globally.
- **Chapter 6:** The chapter discuss the aspects of groundwater monitoring namely the reasons and importance thereof with the focus on monitoring in a mining environment.
- **Chapter 7:** Gives a background on the exploration history of the case study area (Kolomela Mine) followed with discussions on the construction and infrastructure phases that transformed the project into a mining operation and the developing of the dewatering and monitoring networks on the mining areas.
- **Chapter 8:** Discusses the geology and hydrology of the case study (Kolomela Mine) and the regional area with in depth discussion on the results of the historical water level and water quality monitoring of the area.
- **Chapter 9:** Describes the development of the pre-mining groundwater monitoring network and the execution thereof in the case study area in detail. Results of the data obtained during the hydrocensus are also discussed.
- **Chapter 10:** In this chapter a guideline is provided for the development of a pre-mining groundwater monitoring network for open pits.
- **Chapter 11:** This chapter contains the conclusive remarks for the establishment of a monitoring network and highlights related aspects.

In the chapter an overview is given of the importance and contribution mining had on the South African economy over the past century and the role it will continue to play in the years to come. The objective of the dissertation is to provide a guideline for the establishment of a pre-mining groundwater monitoring programme for open pit mines.

Chapter 2

SOUTH AFRICAN ENVIRONMENTAL LEGISLATION

2.1 INTRODUCTION

During the first three centuries of South African law the three most prominent environmental aspects were:

- The control of drinking water
- Pollution
- The conservation of wildlife which came increasingly important when the first conservation areas were established in the late nineteenth and early twentieth centuries

In the three decades from 1940 to 1969 environmental concern intensified and several important legislation were passed like the Water Act; Act 54 of 1956. During this period the legislation was however not strictly enforced as the legislature only responded to concerns on an “ad hoc” basis.

From 1970 to 1994 a variety of new laws were passed and several Acts were updated but it was only after 1994 that the legislation placed strong emphasis on equitable access for all residents to the country’s resources as outlined by section 24 of the Constitution of 1996.

In the late 1990’s a number of Acts were promulgated, the important ones from a water resource point being the National Environmental Management Act (NEMA); Act 107 of 1998 and the National Water Act (NWA); Act 36 of 1998.

2.2 CONSTITUTION OF SOUTH AFRICA

The “Constitution of the Republic of South Africa, 1996” is the supreme law of the country. It provides the legal foundation for the Republic; sets out the rights and duties of the citizens and defines the structure of the government.

The current constitution (the country’s fifth) was drawn up by the Parliament elected in 1994. The constitution was promulgated on the 10^{th} of December 1996 and came into effect on the 4^{th} of February 1997.

Section 24 sets out a number of environmental rights for humans under the Constitution. Article 24 specifically puts the environmental rights into the context of human health stating that “*Everyone has the right to an environment that is not harmful to their health or well-being*”.

The Article further recognized the rights of future generations in the context of sustainable development by stating "*to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that*

- *prevent pollution and ecological degradation*
- *promote conservation*
- *secure ecologically sustainable development*
- *use of natural resources*

while promoting justifiable economic and social development."

As the custodian of the nation's mineral and water resources the State regulate and protect the resources through a number of Acts, for example the Mineral and Petroleum Resources Development Act, the National Environmental Management Act and the National Water Act. These Acts are discussed below.

2.3 THE MINERAL AND PETROLEUM RESOURCES DEVELOPMENT ACT

The Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA) governs the activities regarding the mineral and petroleum resources of the country. The MPRDA was amended by Act 49 of 2008 and oversees the permits and rights for prospecting, exploration, mining and production related activities.

The MPRDA has a number of objectives; the one compelled to the protection of the environment is the State's obligation to ensure that the environment is protected for the benefit of the present and future generations and to ensure ecologically sustainable development.

The MPRDA also states that the holder of a prospecting/mining right, retention/mining permit or a previous owner/holder of an old order permit of works that has ceased to exist remains responsible for any environmental liability, pollution, ecological degradation, pumping and treatment of water as set out in the environmental authorisation until the Minister has issued a closure certificate in terms of this Act.

The closing certificate may not be issued unless the Chief Inspector and the government departments related to any matter affecting the environment have confirmed in writing that the provisions pertaining to health and safety, the management of polluted water resources, the pumping and treatment of extraneous water have been addressed according to the conditions as set out in the authorisation.

In cases where the prospecting, reconnaissance, exploration, mining or production activities resulted in the degradation of the ecology, pollution or damage to the environment or where the activities are in contravention of the conditions of the environmental authorisation the Minister may direct the holder of the right or permit in terms of this Act to:

(a) *investigate, evaluate, assess and report on the impact of any pollution or ecological degradation or any contravention of the conditions of the environmental authorisation;*
(b) *take such measures as may be specified in such directive in terms of this Act or the National Environmental Management Act, 1988; and*
(c) *complete such measures before a date specified in the directive.*
(d) *If the holder fails to comply with the directive, the Minister may take such measures as may be necessary to protect the health and well-being of any affected person or to remedy ecological degradation and to stop pollution of the environment.*
(e) *Before the Minister implements any measure, he or she must afford the holder an opportunity to make representations to him or her.*
(f) *In order to implement the measures contemplated in paragraph (a), the Minister may by way of an ex parte application apply to a High Court for an order to seize and sell such property of the holder as may be necessary to cover the expenses of implementing such measures.*
(g) *In addition to the application in terms of paragraph (c), the Minister may use funds appropriated for that purpose by Parliament to fully implement such measures.*
(h) *The minister may recover an amount equal to the funds necessary to fully implement the measures from the holder concerned.*

If the holders of a reconnaissance, prospecting, mining right/permit, previous owners or their successors in title is deceased or cannot be traced or in the case of a juristic person has ceased to exist, has been liquidated or cannot be traced the Minister may instruct the Regional Manager to take the necessary measures to prevent pollution and ecological degradation of the environment or to rehabilitate and make an area safe.

2.4 NATIONAL ENVIRONMENTAL MANAGEMENT ACT

The National Environmental Management Act 107 of 1998 (NEMA) commence on 29 January 1999. The Act focussed on the sustainable development and use of natural resources and the managing thereof with the necessary environmental management programmes.

Emphasis is placed on the prevention and avoiding of pollution, degradation and disturbance on ecosystems. It's obliged that reasonable measurements must be taken to prevent such pollution or degradation from occurring. Where these impacts cannot altogether be avoided they must be minimised and remedied.

The use and exploitation of non-renewable and renewable resources must be done in a responsible manner and the consequences of the depletion of non-renewable resources are to be taken into account and for renewable resources the ecosystems of which they are part off must not exceed the level beyond where their integrity is jeopardised.

The Act stipulates that when an application is made for prospecting, exploration, mining or production related activities the applicant must make the prescribed financial provision for the rehabilitation of the anticipated environmental impacts before the environmental authorisations will be issued. The holders of these authorisations must annually assess his or her environmental liability and if necessary adjust his or her financial provision.

The Act also states that a person, who caused, may or has caused pollution or degradation to the environment must rectify the pollution or degradation and take reasonable measures to prevent these from occurring, continuing or recurring to the environment.

The Act also specify that if a person or organisation unlawfully, intentionally or negligently commit any act which causes or are likely to cause significant pollution or degradation to the environment is guilty of an offence and liable on conviction to a fine or imprisonment and in some cases for both a fine and imprisonment. Depending on the offence the fine may vary between R1 to R5 million and 1 to 10 years imprisonment.

2.5 NATIONAL WATER ACT

According to the National Water Act (No. 36 of 1998) water use is defined not only as abstraction but also as impacting on a source by pollution through either direct or indirect mechanisms.

The NWA focus strongly on the protection, use, development, conservation, management and control of water resources and take among others the following factors into account:

- The basic human needs of the present and future generations
- Equitable allocation of water resources
- Promote the efficient and sustainable usage of water
- The protecting of aquatic and ecosystems
- Reduce and prevent pollution and the degradation of water resources
- Meeting of international obligations
- Dam safety
- Managing of floods and droughts

The monitoring, recording and assessing of information on water resources are critical for achieving the objectives of the NWA. The NWA places a duty on the Minister to establish national monitoring systems. The purpose of these systems are to co-ordinate the various aspects of water resource monitoring and the collecting of these data from the different sources including government organisations, water management institutions and water users which include the mining operations. The Minister may also make regulations prescribing the guidelines, procedures, standards and methods for the monitoring to be done.

In the Government Gazette of 4 June 1999 Government Notice 704 was published. The intent of this Notice is specifically to regulate the use of water for mining and related activities with the aim to protect water resources.

Procedures and prescriptions that must be adhered to are listed for a number of matters and situations, for example the reporting of an incident involving a water resource. In the event of such an incident the Department must immediately be notified with the following information:

- *the date and time of the incident;*
- *a description of the incident*
- *the source of the pollution or potential pollution;*
- *the impact or, potential impact on the water resource and the relevant water users;*
- *remedial action taken or to be taken by the person in control of the mine or activity to remedy the effects of the incident; and*
- *within 14 days after the date of an incident the Department must be informed in writing of measures taken to correct and prevent a recurrence of such incident*

The Notice also provide guidelines on the position of infrastructure, the carrying out of prospecting or any other activity and the placement of residue or substance that is likely to cause pollution to any watercourse or estuary by taking the 1:50 and 1:100 year flood-lines into consideration.

Requirements for the design, construction, maintenance and operation of clean and dirty water systems are also specified.

The Notice also authorized the Minister to request any person in control of a mine to arrange for a technical investigation or inspection which may include an independent review to be conducted on any aspect aimed at preventing pollution of a water resource or damage to the environment that is linked to the operation of the mine.

A programme of implementation to prevent or rectify the pollution or damage as recommended by the investigation must be submitted to the Minister. After implementation the monitoring information and results also needs to be submitted for evaluation.

From a legal prospective the protection of the country's water resources gain momentum after the promulgation of the Constitution in 1996. As the nation's custodian of the mineral and water resources the State regulate and protect these resources through a number of Acts, the important ones from a mineral and water resource point being the Mineral and Petroleum Resources Development Act, the National Environmental Management Act and the National Water Act.

Chapter 3

IMPACTS OF MINING ON WATER RESOURCES

Open pit mining usually requires the drawdown of the water table as operations are normally conducted below the groundwater table. This affects the regional groundwater levels and also changes the regional hydrological balance.

The development of the cone of depression in a horizontal and vertical direction is subjected to a number of factors, the most important ones being the geological structural setting of the area and the hydrogeological characteristics (transmissivity and storativity) of the different geological zones.

The time period over which the abstraction is done and the volume abstracted will also play a role in the developing of the cone of depression that can stretch over a number of kilometres.

The use of water at mining operations has the potential to affect the quality of surface water as well as groundwater. Water that is used for mineral processing, metal recovery, controlling of dust and at workshops is usually contaminated. If this water is not treated or prevented to come into contact with the surface and groundwater it can easily led to the pollution of these water resources.

Water pollution from mines is often cited as a major concern from stakeholders due to direct dumping of tailings and effluents on land surfaces and into rivers that beside the surface water can also pollute the groundwater resources. Unlike surface water, groundwater cannot easily be intercepted and current treatment mostly involves the pumping thereof to surface where treatment is done. In instances where the polluted groundwater is not threatening the water resources for humans or the ecology the water might be contained underground. Pollution of water resources can also occur due to:

- unlined or improperly constructed tailing dams
- seeping or leaching from waste rock piles
- improper mine closure conditions or the absence thereof

Possibly one of the worst form of pollution is acid mine drainage (AMD) which refers to the outflow of acidic water from metal or coal mines which usually pollute surface water bodies. Tailing piles and waste rock dumps are also an important source of acid mine drainage due to oxidation of the metal sulphides after being exposed to air and water. Examples of water resources polluted by acid mine drainage are shown in Figures 1 and 2 below.

Source: Wikipedia, 2016 (Environmental impact of mining)

Figure 1: AMD – Portugal **Figure 2: AMD in Rio Tinto River - Spain**

In some environments acid rock drainage (ARD) occurs naturally due to natural rock weathering processes but the areas under concern is where large scale earth disturbances occur from mining and construction activities within rocks containing an abundance of sulphide minerals.

According to an article in Miningfacts (2012) "What are the water quality concerns at mines" the potential for pollution of water resources at a mine site depends on a number of factors, such as:

- **Type of ore mined:** Sulphide ores are more chemically reactive than other ores and have a greater tendency to dissolve and contaminate water.
- **Chemicals used in extraction processes:** If chemicals like cyanide, sulphuric acid and organic chemicals are used to process metal ores the chance of pollution are increased considerable comparing to mines where these chemicals are not used.
- **Life stage of the mine:** When a mine is under construction, operating or closed can affect its potential for the pollution of the water resources, for example when the mine are subjected to a flood during the operational phase the chances for the pollution of the water resources are much higher than after mine closure if the remediation after closure was done in a proper way.
- **Environmental management practices:** Modern water management practices and mine design can greatly reduce the potential for pollution at mine sites. In general old mine sites have a much higher potential for pollution as most of the control techniques that are in today's environmental regulations were not in place when the "old mines" opened or closed.

On the positive side many of the impacts caused to the environment in the past are nowadays avoidable due to advances in technology and changes in management techniques as knowledge of water management and impact reduction has greatly increased over time.

Mining companies are also making efforts to reduce and minimise the footprint of their activities which include restoring ecosystems post-mining.

There are also beneficial uses of mine water as the majority of mine waste is inert and therefore unlikely to contaminate water. A number of cases are also recorded where mine water (refers to any surface or groundwater present at the mine site) is considered to be of high enough quality that it requires no or little treatment before it can be released into the environment. In the above mentioned article in Miningfacts the following examples are listed for the beneficial usage of mine water to the environment, communities and economy:

- Wetlands that were constructed to treat acid mine drainage generated by coal mines are now supporting ecosystems
- Treated mine water being used as an additional drinking water source by communities
- Water supplied to industries, agricultural sector and other mines that don't have sufficient water needed for their processes
- Dissolved metals in some mine waters are sufficiently valuable to be extracted for a profit
- Iron-rich mine waters are in some instances being used in water treatment plants to remove other contaminants
- Mineralised mine waters being used in spa's

It is also worth noting that groundwater exploration associated with mining development often contribute significantly to the scientific knowledge and understanding of specific groundwater systems that would otherwise never been investigated.

Although the mineral industry consumes a relatively small quantity of water (less than five percent) at global level comparing to the agricultural, manufacturing, power generating and municipal sectors it does not alleviate the impact that mining has on the water resources. It's of the utmost importance that the mining sector kept on improving in their efforts and finding solutions to minimize the pollution footprint caused by their operations.

The use and abstraction of water at mining operations has the potential to affect the quality and quantity of the water resources at the mining sites and beyond. On the positive side mining developments often contribute significantly to the scientific knowledge and understanding of the water systems in the areas they operate in and in cases where the mine water requires no or little treatment it can also be used in a beneficial manner to the environment, communities and economy.

Chapter 4
HYDROGEOLOGY OF SOUTH AFRICA

4.1 INTRODUCTION

South Africa is regarded as a relative dry country as the average rainfall of ˜500 mm/a compares unfavourable with the world average of ˜860 mm/a. Twenty one percent of South Africa receives less than 200 mm/a, which per definition classifies it as “desert”.

South Africa is ranked as the 30th driest country in the world (Braune *et al.,* 2014) and has less water per person than countries like Namibia and Botswana that are considered to be much drier. The country has limited water resources and in many parts the point is approached where all of the easily accessible freshwater resources are fully utilised. However groundwater played a pivotal role in the establishment of many settlements in the previous century. The association with water are reflected in a number of town names, for example, De Aar, Springs and all the town names ending with “fontein” meaning fountain.

The low average rainfall in great parts of the country together with the geology hamper the development of regional scale highly productive aquifers as ninety percent of the country is underlain by sedimentary and crystalline basement rocks with relative little primary porosity.

However high quantities of groundwater can be abstracted from the dolomitic and quartzite aquifers systems found in the northern and southern parts of the country as well as from a number of primary aquifers along the coastline.

Despite this somewhat gloomy reality groundwater plays a very important role in the supply of water for domestic, industrial, agricultural and mining users.

4.2 IMPORTANCE AND USAGE OF GROUNDWATER

According to Adams (2011) groundwater’s role in South Africa is often underestimated whereas two thirds of the country’s rural population is depended on groundwater for their domestic needs.

Groundwater is also essential for the supply of water to towns such as Beaufort West, Prince Albert, Graaff-Reinet, Atlantis, Mussina, Kathu, Kuruman and even large cities like Pretoria and Johannesburg are partly dependant on groundwater supplies.

According to the Department of Water Affairs Groundwater Strategy (2010) the volume of available renewable groundwater is estimated at 10 343 million m^3/a and 7 500 million m^3/a under drought conditions while the usage are between 2 000 and 4 000 million m^3/a.

In terms of South Africa's total water consumption the contribution from groundwater resources is determined to be approximately 15 percent. A sectorial breakdown on the use of groundwater (Braune *et al.,* 2014) indicates that 59 percent of all groundwater abstracted is used for irrigation whilst the usage for mining, water supply services, livestock watering and schedule 1 are 13, 12.9, 6 and 5.7 percent respectively. The remaining 3.4 percent are used by the industrial, recreation, aquaculture and power generation sectors.

Although groundwater is a vital source of water for many and has given rise to several short and medium socio economic benefits, this has placed pressure on many aquifers throughout the country due to high abstraction rates. Until 1998 groundwater was considered a privately owned asset but after the promulgation of the new National Water Act in 1998 groundwater was declared a public resource that exposes the water resources to further exploitation.

4.3 AQUIFER TYPES

The word aquifer was derived from the Latin words aqua, meaning "water" and ferre, meaning "to bear", an aquifer thus literally means to bear water. According to the Wikipedia web page an aquifer can be defined as "*an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt) from which groundwater can be extracted using a water well.*"

The aquifers in South Africa are however more complex than the above definition and the Department of Water Affairs and Forestry (2010) defined an aquifer as "*A specific rock formation or a group of rock formations, which are vertically and/or horizontally hydraulically linked, to such an extent that any quantity (abstraction or recharge) and quality (pollution) impact(s) could potentially affect the whole aquifer but with the provision that the no-flow boundaries may, under specific conditions, i.e. high groundwater levels, manifest as if no boundaries exists*."

The different aquifer types found in South Africa are summarised in Table 1 below:

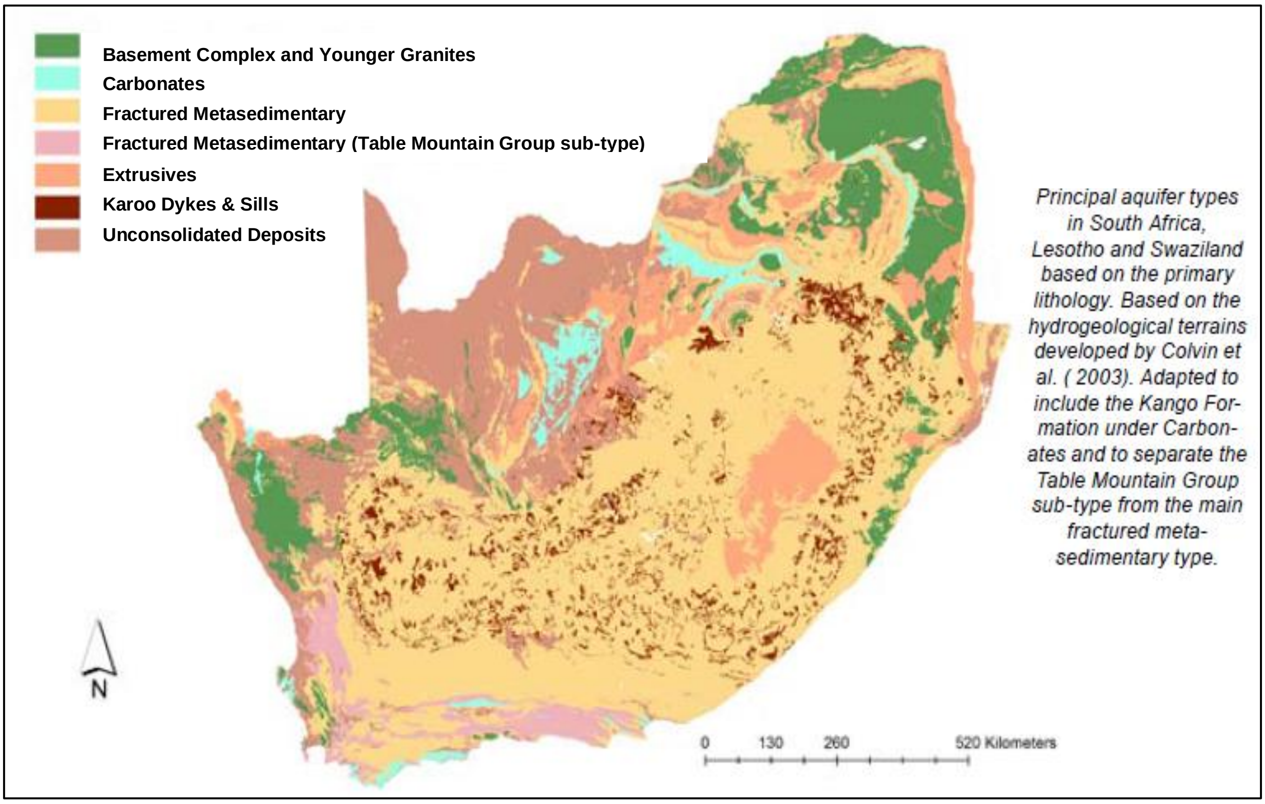
TABLE 1: AQUIFER TYPES FOUND IN SOUTH AFRICA

Aquifer type	Basic information
Dominantly Unconsolidated	
Coastal sand, gravel and other unconsolidated sediments; alluvial sand and gravel in river valleys	These aquifers are usually less than 30m thick and unconsolidated. Yields in alluvial are typically 3 to 8 L/s and 3 to 16 L/s in coastal sands. Recharge rates are high and aquifers are highly vulnerable.
Sedimentary – Intergranular & Fracture flow	
Karoo Supergroup	Aquifer has low permeability in shale and mudstone but better permeability in sandstone layers. Groundwater flow is largely via fractures and other discontinuities. Although borehole yields are usually between 1 and 3 L/s it is an important aquifer with variable groundwater quality.
Table Mountain Group	An important aquifer where the groundwater are often more than 100 m deep. Groundwater is usually of Na – Cl type with low pH, hardness and dissolved solids (Pietersen 2004).
Sedimentary – Fracture flow	
Dolomite	Very important aquifer. Karstic features developed in the dolomite that can form high yielding aquifers. Borehole yields are typically 20 to 50 L/s. Dissolution channels developed along fractures can extend to surface allowing direct recharge. Aquifers are vulnerable to pollution.
Volcanic rocks	Up to the present little is known on the groundwater potential of these rocks.
Intrusive igneous rocks	In these rocks groundwater occurs in fractures and weathered zones which are often associated with structural features such as folding, faults and dykes. The water bearing features are usually best developed in the uppermost metres of these rocks. The water quality is often affected by elevated fluoride levels (Pietersen 2004).
Basement	
Crystalline metamorphic and igneous rocks	In these rocks the groundwater is usually found in the shallow weathered zone up to a maximum of around 50m depth. The borehole yields are typically low as these aquifers have limited storage capacity, where they are overlain by unconsolidated alluvium aquifers the groundwater can hydraulically connected increasing the storage and groundwater potential. The groundwater is dominantly of Na – Cl type.

Most of South Africa's aquifers are found in fractured rock ranging in age from Pre-Cambrian to Jurassic. The aquifers found in recent to Tertiary formations are restricted to the coastal dune belts and unconsolidated deposits associated with rivers and Aeolian sands.

According to Pietersen (2004) most of the research has focussed on the main Karoo Basin aquifer and the dolomitic aquifers. There is thus still much to learn about the hydrogeology of the other aquifers.

The different aquifers types are shown in Figure 3 below.



Source: Le Maitre and Colvin (2008)

Figure 3: Aquifer types found in South Africa

South Africa also shares a number of aquifers with its neighbouring countries. According to Altchenko and Vilholth (2013) these transboundary aquifers include:

- The Pomfret/Vergelegen and Ramotswa dolomite aquifers with Botswana
- The Limpopo River alluvial aquifer with Zimbabwe and Mozambique
- The South West Kalahari/Karoo aquifer with Namibia and Botswana
- The Coastal Sedimentary basin (Gariep) aquifer with Namibia
- The Coastal Sedimentary Basin (Incomati/Maputo/Mbeluzi) aquifer with Mozambique
- The Tuli Karoo Sub-basin aquifer with Zimbabwe and Botswana

4.4 AQUIFER VULNERABILITY

In the mid 1990's the Department of Water Affairs and Forestry initiated the development of a groundwater quality management strategy. This involved the i) classification of aquifers in the definition of importance ranging from poor, medium to good, ii) determination of the aquifers susceptibility for pollution and iii) vulnerability or likelihood for contaminants to reach the groundwater system in an aquifer.

The vulnerability of the aquifers were evaluated by the DRASTIC method, the acronyms represent the following seven hydrogeological parameters:

- **D**epth to groundwater
- **R**echarge
- **A**quifer media
- **S**oil media
- **T**opography
- **I**mpact on vadose zone
- **C**onductivity hydraulic

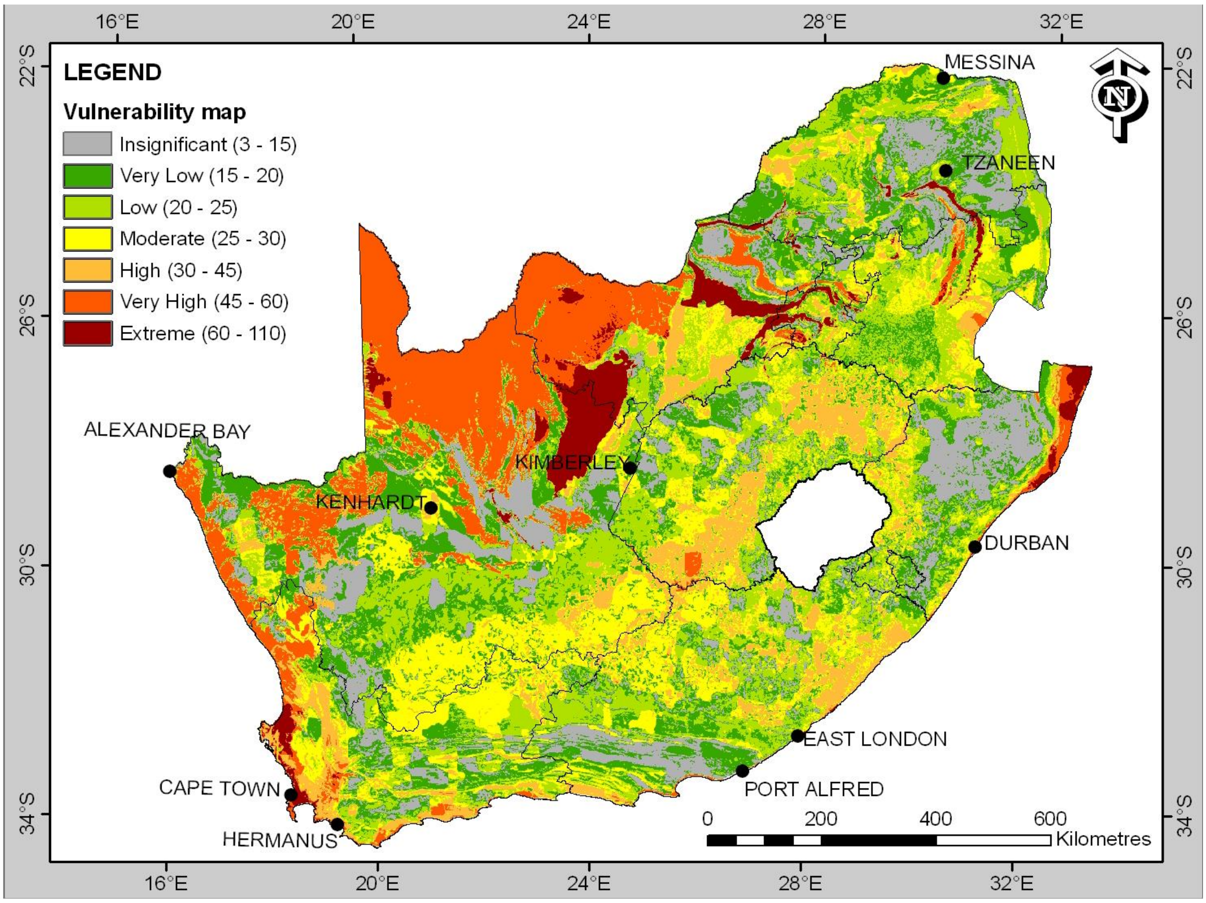
The end result was maps indicating the aquifer classifications, susceptibility and vulnerability, with the main purpose of these maps to facilitate national planning. The maps were also used for example by mining companies and industries to give them guidance on the vulnerability of the aquifers in the areas they operate to assist in the planning and implementing of effective mitigation measures.

The maps also provide valuable support in the planning and development of water supplies to communities that did not have prior access to this resource.

A modified DRASTIC index that incorporates anthropogenic influences on groundwater contamination was proposed by Leal and Castello (2003). An example of an anthropogenic impact is that of agricultural diffuse pollution on contamination.

In terms of land use agricultural chemicals lead to source pollution that place cultivated areas in a higher category for pollution than other land uses. Extensive agriculture land use of the same areas over long periods can result in the altering of the soil colloidal nature and degree of percolation through the soil matrix. Areas exposed to high levels of human activity e.g. built up urban areas also pose a high risk to soil and groundwater pollution (Meinardi *et al*., 1994).

The parameters of the DRASTIC index together with the anthropogenic influences caused by land use were rated, weighted and combined to create a map indicating the vulnerability of the country's groundwater to pollution. The map compiled by Musekiwa and Majola (2013) is illustrated in Figure 4.



Source: Musekiwa and Majola (2013)

Figure 4: Groundwater vulnerability map of South Africa

South Africa is regarded as a relative dry country as twenty one percent of the country receives less than 200 mm/a, which per definition classifies it as "desert. The low rainfall together with the geology hamper the development of productive aquifers as ninety percent of the country is underlain by sedimentary and crystalline basement rocks with relative little primary porosity. High quantities of groundwater can however be abstracted from the dolomitic and quartzite aquifer systems found in the northern and southern parts of the country as well as from a number of primary aquifers along the coastline.

The role of groundwater is often underestimated whereas two thirds of the country's rural population is depended on groundwater for their domestic needs. Groundwater also form an important supply of water for the industrial, agricultural and mining sector.

Chapter 5
LITERATURE REVIEW

According to the International Groundwater Resources Assessment Centre (IGRAC, 2008) the monitoring of groundwater quantity or quality in many countries is minimal or non-existent. At some point the lack of monitoring will result in undiscovered degradation of water resources either due to over abstraction or contamination that can result into the following scenarios:

- Declining in groundwater levels and depletion of groundwater reserves
- Reductions in stream/base flow to sensitive ecosystems such as wetlands
- Reduced assess to groundwater for drinking and irrigation water supply
- Deterioration of groundwater quality
- Increased treatment and pumping cost
- Occurrence of subsidence and foundation damage to infrastructure

Inadequate financial resources and technical capacity are outlined as the major contributors for the lack of monitoring. Even where monitoring programmes are operational they might fail in providing the necessary information to support effective management due to the following:

- The objectives are not properly defined
- The monitoring programme is designed with insufficient knowledge of the groundwater systems
- Inadequate planning for sample collection, handling and storage
- Data are poorly archived and not readily available to inform management

For the design of a groundwater monitoring programme IGRAC proposed the following steps as outlined in Figure 5. The steps comprise the following:

Step 1: Preliminary assessment of the groundwater situation

During this step it is evaluated whether systematic groundwater monitoring is desirable in an area and what the scope and objectives of the monitoring programme should be considering the budget and organisational conditions. It also involves a quick scan of the groundwater situation, the problems and key issues for monitoring in the area.

Step 2: Groundwater system analysis and development of conceptual model

This step involves analysis of the groundwater system and the development of a conceptual model based on the available hydrogeological and hydrological information. The model is used as the framework for the groundwater monitoring network design.

Step 3: Analysis of the institutional setting

This step concerns an inventory of the institutions involved in the groundwater use, management and protection in the area as well as an analysis of their roles, mandates, tasks and manpower. Evaluating these aspects will lead to a better understanding of the scope and limitations of the groundwater monitoring.

Step 4: Inventory of data needs and specification of monitoring objectives

This step includes the listing of the groundwater users and assessing their data needs. The monitoring objectives may include data for assessment, development, use, management and protection of the groundwater resources.

Step 5: Design of groundwater monitoring programme components for identified objectives

The monitoring objectives are analysed and translated into components of the monitoring programme as each objective leads to a monitoring component with its own specific requirement for example the area to be covered, preferential network set-up, parameters needed, frequency of sampling and so forth.

Step 6: Specification of monitoring programme options

The feasibility of a monitoring programme depends among other things on the budget and available capacity within an organisation. It is good practice that a number of monitoring programme options is considered. Options may differ with respect to the area covered, network density, frequency of observation and sampling and so forth. Specification of the different options should be done in consultation with the organisation's representatives responsible for the groundwater monitoring and management.

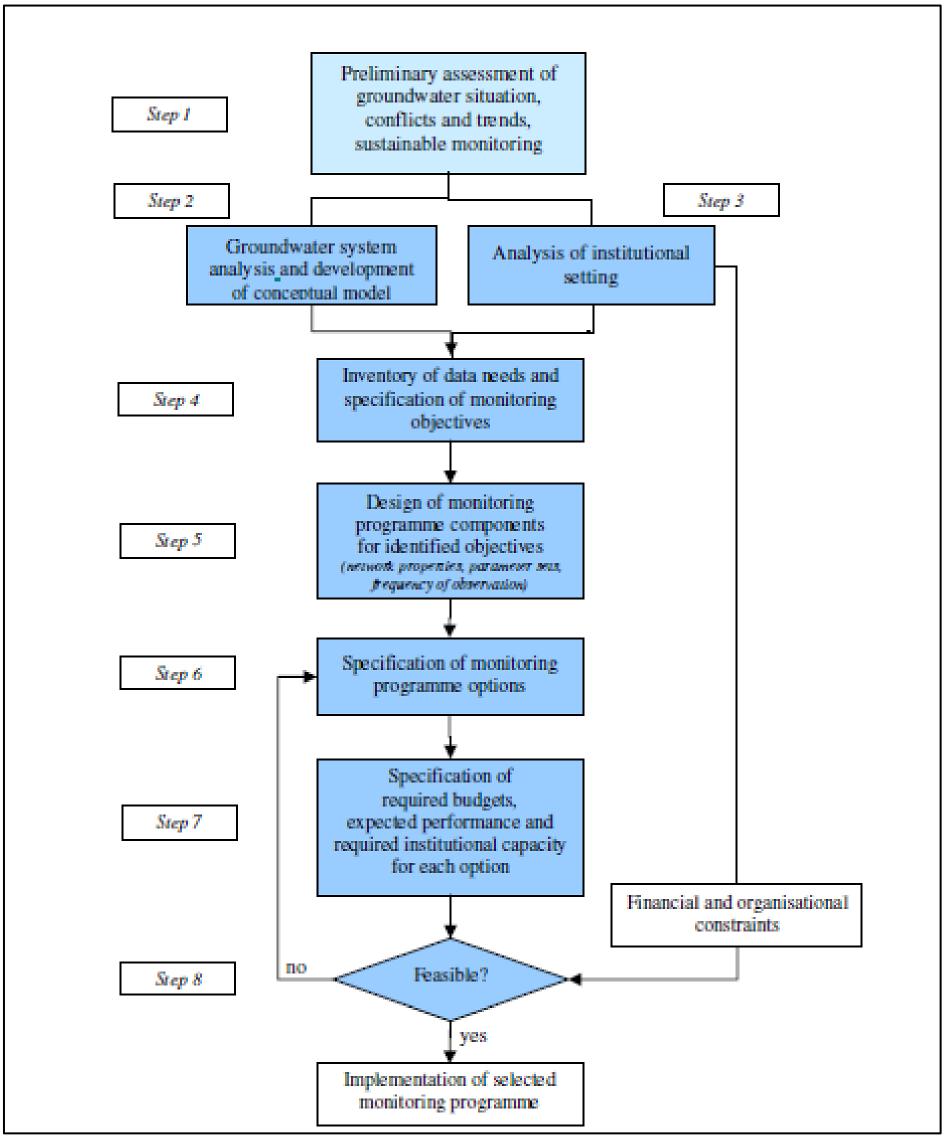
Step 7: Specification of required budget, expected performance and necessary institutional capacity for each option considered

For the selection process further analysis is required for each of the monitoring programme options that include:

- Calculation of the investments and annual costs for the monitoring programmes
- Description of the information level that will be obtained taking the objectives and areas that will be covered, the data accuracy and also the strong points and limitations in consideration
- Organisational capacity needed and of possible limitations

Step 8: Evaluation of feasibility and selection of best monitoring programme option

This step involves the evaluation of the feasibility of the monitoring programme options as determined in step 7 and the selection of the best monitoring option for implementation. If none of the programme options turns out to be feasible it will be necessary that new options be specified (step 6) and analysed as set out in step 7.



Source: International Groundwater Resources Assessment Centre (2008)

Figure 5: Design of groundwater monitoring programme

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The UN/ECE Task Force on Monitoring and Assessment (2000) listed the following basic rules that a monitoring programme must adhere to in order to be successful, these are:

- The objectives must be defined first and the programme adapted according to the objectives and not vice versa. Adequate financial support must be secured for the execution of the programme
- The type and nature of the aquifers must be understood. Maps and information sources that will help in this regard are:
    - Hydrogeological and vulnerability maps of the area
    - Geological information
    - Maps indicating the position of abstraction and monitoring wells
    - Water level, abstraction and water quality data
    - Isotope data concerning the age and origin of the water
- The parameters, frequency of measurements and sampling, and the locations must be chosen with respect to the objectives
- The groundwater monitoring should be coupled with surface water monitoring where applicable
- On a regular base the quality of the data must be checked through internal and external control. The data must be interpreted and assessed by experts with recommendations for management action
- The monitoring programme must be evaluated periodically especially if the general situation or any influence on the groundwater system has changed

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The European Environment Agency (EEA, 2008) stated that there are two important features that distinguish groundwater from surface water which need to be considered when a monitoring programme for groundwater quality and quantity is designed. These are:

- The slow movement of groundwater comparing to surface water with relatively large residence times
- The degree of physicochemical and chemical interdependence between the groundwater and the aquifer material

Accordingly the density of observation points in a groundwater monitoring network will depends on the following:

- The objectives of the monitoring programme
- The size of the area
- The geological and hydrogeological complexity of the area
- Land use in the area
- Access to the area, agreements with land owners to monitoring points
- Existing monitoring systems
- Financial limitation

The EEA states the general demands of a monitoring network as follow:

- All the aquifers should be observed and defined according to the geological information and the known groundwater resources of the area
- The monitoring network should be based on existing boreholes in the area from which hydrogeological data can be extracted. Boreholes drilled for different purposes can be used as this will reduce the cost of drilling new boreholes
- Aquifers that are not being used for abstraction should also be monitored

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In an international newsletter of the consulting firm Steffen, Robertson and Kirsten (SRK, 2012) it is mentioned that the requirement to conduct a mine water assessment in the exploration to feasibility stage usually has a dual purpose. Firstly the focus is on engineering assessments (dewatering, mine stability, water supply, overall water balance) and secondly on environment and social aspects.

To meet these requirements a work program needs to be established that involves the following:

- Development of a conceptual hydrological model
- A seasonal baseline water monitoring and sampling network
- Implementation of a preliminary hydrogeological testing program

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According to Houlihan and Botek (2007) the purpose of a groundwater monitoring program should be defined before monitoring begins that the appropriate procedures, techniques and analyses can be planned in order to meet the specific needs of the project.

The following steps are listed for the preparation of a groundwater monitoring plan.

- Understanding of the hydrogeological and geochemical setting
- Establish data needs and data quality objectives
- Design groundwater monitoring network
- Establish the sampling and analysis methods
- Establish the data evaluation methods
- Develop response criteria and actions
- Evaluation of background conditions

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In an article on groundwater monitoring (Singhal *et al*., n.d.) it is mentioned that the network density and sampling frequency are the most important aspects in the design of a monitoring network. It is also highlighted that monitoring can be executed in three phases:

- **Exploratory investigation** – Construction of a limited number of installations within and around the area of interest based on preliminary data and initial conceptual model. Information is collected on water level and preliminary water quality.
- **Main investigation** – Installation of additional monitoring points to provide better cover across the area. In situ testing to be performed to determine aquifer properties and obtaining additional water level and aquifer quality information.
- **Supplementary investigation** – Further adjustment on monitoring network, where appropriate based on previous findings. In situ testing to further define aquifer characteristics, water level and water quality in specific areas.

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The groundwater monitoring programme that was implemented at the Ridgeway Gold Mine in South Carolina in the United States (Anderson *et al.,* n.d.) is a good example of a monitoring programme that has the structure and components to effectively monitor and manage the groundwater impacts caused by dewatering at an open pit mine.

As part of the permit process a detailed hydrological evaluation was conducted at each of the two proposed open pits to characterize the aquifer conditions that impacts on the streams, springs and groundwater could be predicted.

The groundwater model submitted for the permit application indicated that the “significant” impacts to the groundwater system (drawdowns > 6 meters) would extend to a radius of approximately 1.6 kilometres from the open pits. For a worst case scenario it was concluded that the “significant” impacts would extend to 3.2 kilometres from the pits areas.

Based on the results of the groundwater model that was submitted the mining permit required that the mine retain the services of a third party consultant to conduct a groundwater and surface water monitoring program within a 3.2 kilometre radius from each pit. The monitoring program that was developed consists of three tasks:

- To conduct an inventory within a 3.2 kilometre radius from the pits
- Develop a monthly monitoring plan to track the dewatering at the mine and monitoring the water supplies within the specified radius
- To provide remedial services when privately owned water resources are being impacted by the dewatering

Pump tests were performed at the two pits to characterize the hydrology of the area. In addition numerous packer tests were also performed to evaluate the hydraulic property variation with depth.

Water resource inventory

The purpose of the inventory was to (a) establish the existence, condition and use of each well, spring or stream within the 3.2 kilometre radius from the mining area and (b) to obtain hydrogeological baseline data for the area.

Owners of water resources within the 3.2 kilometre distance from the pit areas were offered the opportunity to have their water resources included in the initial inventory. The owners were contacted by the South Carolina Land Resource Commission and informed of their right to be included in the inventory.

Upon arrival at the owner’s property, the owner or his representative was interviewed regarding the construction, use, and performance history of his water resources. Photos of each resource were taken as well as samples taken for analysis by an analytical laboratory. The following data were obtained during the interview:

- Owners name and address
- Resource type
- Use of the water
- Use of the property
- Alternate source of water, if any

Since water supply for residential use was one of the major concerns, as much information as possible relating to the condition and use of the well were obtained, these include:

- Construction date of well
- Name of the drilling company
- Method of drilling
- Details on construction of well
- Pump details
- Water level

Following the data collection a short pump test was performed to obtain an indication of the production capacity of the wells. The pump test included 15 minutes of pumping followed by 15 minutes of recovery. Water levels and flow rates were recorded at 5 minute intervals.

Water quality samples were normally collected at the beginning of the 15 minute recovery period and placed in containers supplied by the laboratory containing the appropriate preservatives.

As a large amount of information was collected the inventory data was managed using ARC/INFO. The reason for using this programme was the efficiency with which (a) reports could be prepared for the water resource owners, (b) maps are prepared showing information of two or more layers and (c) the performing of trend analyses.

Groundwater monitoring program

The purpose of the monitoring program was to (a) anticipate impacts on the water resources that remedial action can be taken pro-actively and (b) to maintain groundwater data which can assist in determining if water resources have been impacted when complaints from the water resource owners are registered.

As the worst case scenario indicate that the zone of impact may extend out to 3.2 kilometres from the pits a total of 40 monitoring points were selected. The following aspects were taken into account for the selection of the monitoring points:

- Areas of expected impacts
- Areas were private wells were densely populated
- Accessibility to areas
- Suitability of wells for monitoring

Water level monitoring was done monthly. Every six months, or as the impact begins to approach private supply wells, drawdown contours were developed and analyse. The drawdown contours were compared with the initial model predictions and used to further calibrate the model.

Water resource remediation

As part of the permit conditions the third party consultant was besides the monitoring also responsible to investigate complaints and determine if the dewatering activities are impacting groundwater and surface water resources. The consultant also had the discretion to order and direct remedial action.

A toll-free telephone number had been established for residents to report a water supply emergency if it was suspected that the emergency was the result of the dewatering activities at the mine. Before visiting the site the complaint would be discussed with the water resource owner and the information reviewed with that obtained during the inventory survey to determine whether the dewatering activities are a potential cause of the problem.

If necessary an on-site investigation was then conducted to determine whether the status of the water supply is different from that which was recorded during the inventory. If founded that the dewatering was responsible for the impact on the water resource the mine was then directed to provide assistance.

The literature review pointed out that in many countries groundwater monitoring is minimal or non-existent and at some point the lack of monitoring will result in undiscovered degradation of water resources either due to over abstraction or contamination with devastating consequences on the environment and water resources.

The aspects and features to be taken into consideration for the development of a groundwater quality and quantity monitoring programme as listed by various international organisations are discussed in the chapter.

Chapter 6

GROUNDWATER MONITORING IN THE MINING ENVIRONMENT

6.1 INTRODUCTION

Historically the monitoring of groundwater resources didn't received the same attention as that of surface water monitoring. The main reasons were the private legal status of groundwater under the 1956 Water Act and the Department of Water Affairs and Forestry's (DWAF) emphasis on the development of the surface water resources.

The NWA (No. 36 of 1998) changed the situation drastically as much focus was then placed on the DWAF to develop, utilise, protect, conserve, manage and control the groundwater resources of the country. The Constitution of the Republic also promote that governance be devolve to the lowest possible levels. For water it means that the management and monitoring be facilitated by a Water User Association (WUA) or Water Service Authority.

The UN/ECE Technical Task Force defined groundwater monitoring "*as the collection of data, at set locations and depths and at regular intervals in order to provide information which will be used to*":

- *determine the state of the groundwater resource base both in a quantity and quality sense, and*
- *to provide the basis for detecting trends in space and time and*
- *to enable the establishment of the cause-effect relationships*

6.2 GROUNDWATER MONITORING IN THE MINING ENVIRONMENT

Most open pit mining operations will require that mining be done below the regional water table that will lead to the inflow of water into the workings and a reduction in the slope stability. This will force the implementing of a mine dewatering program to ensure dry mining conditions in order that mining can be done without being hampered by groundwater; it will also reduce mining costs and improve safety performance.

In some cases it will be necessary to reduce the water pressure acting on the materials that form the pit slopes by a dedicated pit slope depressurisation program.

The factors to be considered for a mine dewatering monitoring program will vary according to the regional and local hydrogeological setting, the mine plan (size and depth of the pit together with the rate of excavation) and the hydrogeological characteristics of the different geological lithologies.

According to Read *et al*. (2013) it is necessary that mining operations obtain a good groundwater and surface water baseline and an adequate characterisation of naturally elevated chemical parameters indicating any pre-existing disturbance to the hydrogeological system before mining commenced. A good baseline characterisation is also important to place potential future changes to the hydrogeological system into proper context as mining progresses.

It is concluded that mining operators find it increasingly necessary to demonstrate to the public, regulators and NGO's that some changes to the hydrogeological systems resulted from natural variance or other external developments rather than from the mining activities.

In terms of the scale of investigation Doubek *et al*. (2013) mention that the hydrogeological field program must allow for the characterisation of the groundwater system and hydraulic parameters within the mine area and surrounding district. The data collection, analysis and modelling are usually done on a regional, mine and slope scale.

For a project in a conceptual phase it is important to gain as good an understanding as possible of the regional groundwater system as this will be fundamental in determining the dewatering program and the potential magnitude and extent of hydrological impacts in the area that would be necessary for the permitting processes. It's advisable that the following need to be investigated prior to mining:

- the elevation of the water table and the hydraulic gradient across the site
- the potential of compartmentalisation within the different geology units
- the nature of the recharge boundaries or groundwater flow barriers
- the hydrogeological characterisation of the different geology lithology's
- the groundwater transmitting characteristics between the geological units
- the characterisation of the major structures e.g. faults, dykes and sills
- the water chemistry
- sustainable yield of existing boreholes in the area

When an ore body is discovered it is assessed through a number of studies conducted in phases. Doubek *et al*. (2013) underline the importance that the hydrogeological investigations must mirror the project objectives during all stages in quantifying the ore body.

It is mentioned that in the following situations a detail program of hydrogeological testing would be required at an early stage:

- dewatering is identified to be critical for a successful mining operation and project economics
- where the water balance raises sensitive issues, for example. low water availability in arid regions or where excess water might lead to treatment or discharge
- where groundwater pressure is seen as a significant factor in the slope designs
- where the dewatering may potentially create environmental impacts due to drawdown of the water table or change the groundwater chemistry

During the different study phases to delineate an ore body hundreds of boreholes are drilled across the mine concession area. The majority of the boreholes will be concentrated within the footprint area of the pit but boreholes are also drilled to delineate areas for the waste rock dumps, plant area and for other infrastructure. Although the primary objective of these boreholes is to assess the mineral resource, they provide an important opportunity to "piggy back" for the collection of hydrogeological data as well.

Unfortunately during the early stages of a project the opportunity can easily be missed unless specific preparation is made for it. "Piggy back" data can however also be collected from geotechnical and environmental drilling programs.

6.2.1 Baseline studies

Baseline studies are usually done for the following reasons; i) to comply with the environmental regulatory requirements, ii) to obtain the necessary data/information needed to develop the water management and monitoring programmes for the mining operation and iii) to obtain the pre-mining hydrogeological situation of the regional area that claims from neighbouring land owners can be evaluated in order to determine whether the impacts is caused by the mining operation or not. Doubek *et a*l. (2013) listed the objectives of the baseline studies for the environmental and mining operations as follow:

6.2.1.1 Environmental baseline

The main goal of the baseline study is to define pre-mining conditions in the proposed project area. The ambient groundwater chemistry up and down gradient of the project area must also be determined as this will indicate whether natural elevated chemical parameters exist.

Several categories of analysis for groundwater chemistry can be performed, for example:

- **Field chemistry parameters**. Measurement with portable equipment provides a quick indication of the water quality. Parameters normally include pH, total dissolved solids (TDS), electrical conductivity (EC) and dissolved oxygen (DO).The field testing provides a rapid and low cost measurement of multiple samples for the basic characterisation of the groundwater system.
- **Dissolved major ions.** Calcium, magnesium, sodium and potassium (cations) and chloride, bicarbonate, sulphate and nitrate/nitrite (anions) are measured via laboratory analysis. The composition of each ion is used to group and categorise the type of water. This also indicates the chemical interactions that occur as groundwater moves through soils and rocks.
- **Dissolved metals.** This is also measured via laboratory analysis. Dissolved metals are often elevated in the groundwater near the vicinity of an ore deposit due to the interaction of the groundwater with the deposit. For any mining project it is essential to define the natural background of these dissolved metals to be used as a baseline reference.

For hydrogeological studies it is advised that three sampling sets be defined. The first include the field parameters that can be sampled from many sources on a routine basis, the second comprise the analysing of parameters considered to be important for the particular site being investigated. Lastly a full parameter analyses to determine the characterisation of the groundwater system/s.

Sampling for the full analyses will consequently be done on a less frequent interval than the first two sets. In special situations to determine the age-dating of the water isotope sampling and analysis may be considered.

Of great importance is that the baseline studies are also focused to quantify the natural variability of the hydrological system/s by paying attention to surface and spring flows and groundwater levels. This data is of inestimable value in evaluating whether the mining activities will have an impact on the regional water resources outside the footprint of the mine’s operations in the years to follow.

The number of baseline monitoring stations required will depend on:

- the location of the site and the topography of the area
- the type of climate
- the presence of chemical parameters in the natural hydrological system/s and the variability thereof
- the mine plan relative to groundwater levels and surface water bodies
- the number of local and downstream receptors

- the interest of NGO’s and other public groups
- local regulatory requirements
- internal company standards

The standard baseline monitoring program is normally a minimum of twelve months but may be longer depending on the site characteristics and seasonal variations.

6.2.1.2 Baseline for mining operation

The objectives for obtaining a pre-mining surface and groundwater baseline can be described as follow:

- To supplement the interpretation of the hydrogeological system in terms of the conceptual model, for example zones that are potentially connected or compartmentalised can be defined and locations of groundwater recharge can be identified
- To assist in the planning of the construction materials for the dewatering infrastructure as corrosive groundwater may require stainless steel borehole construction and pumping equipment as this will affect the project costs
- To determine an appropriate strategy for accommodating mine dewatering flows as in some instances the chemistry makes it unsuitable to be used as make-up water in the mineral plant processes
- To determine whether the water need to be treated to be utilise in either the mine set-up or when discharged into the environment
- To predict whether there is a potential for groundwater chemistry impact resulting from the dewatering activities
- To ensure compliance with the environmental monitoring regulations as the ambient groundwater chemistry and natural ranges in variability be used as the basis for the water quality before mining started
- To provide information to aid in the planning of the pits and mine closure after cessation of the mining activities
- To assist in the evaluation of claims from neighbouring land owners stating that their groundwater resources had been deteriorated

For most open pit mining operations it will require that mining be done below the regional water table that will force the implementation of a dewatering program to ensure dry and safe mining conditions. It will be necessary that mining operations obtain a good baseline of the groundwater, surface water and chemical characterisation of the hydrogeological systems before mining commenced.

Factors to be considered for a mine dewatering monitoring program will vary according to the regional and local hydrogeological setting, the mine plan (size and depth of the pit together with the rate of excavation) and the hydrogeological characteristics of the different geological lithology's. The main goal of the baseline study is to define pre-mining conditions as it will place future changes to the hydrogeological system into proper context as mining progresses.

Chapter 7
CASE STUDY – KOLOMELA MINE

7.1 INTRODUCTION

Kolomela Mine is a Greenfield mine of Kumba Iron Ore Limited (member of the Anglo American plc group) who came into operation in 2010. Kolomela is Kumba's second mine in the Northern Cape Province in the Siyanda District Municipality. Kolomela Mine is situated approximately 10 kilometres southwest of Postmasburg, 85 kilometres south of Sishen Mine and 200 kilometres northwest of Kimberley, see Figure 6.

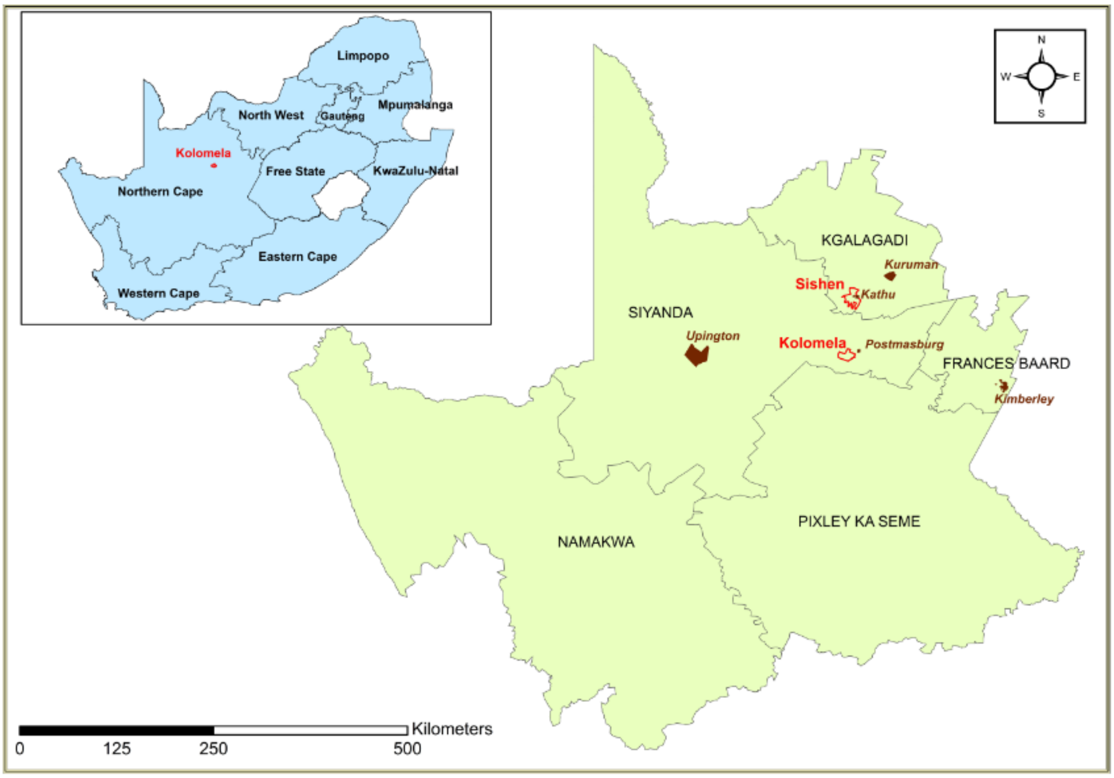


Figure 6: Locality of Kolomela Mine

7.2 VEGETATION AND TOPOGRAPHY

Kolomela Mine is located in the southern part of the Kalahari thorn veld. The land surface is thinly grassed with low thorn scrubs in abundance. Indigenous tree species are sparsely distributed and include Camelthorn, Wild Olive and Shepherd trees. The region is semi-arid with an average annual rainfall of 300 mm.

The topography in the mining area is relative flat with the surface elevation in the northern area at approximately 1300 m above sea level and the southern properties averaging 1250 m. The Groenwaterspruit is a non-perennial stream on the eastern side of the mining area. Numerous depressions and pans are found in the flat lying areas which collect and hold rainwater for short periods during the rainy season that normally stretch from December to March.

7.3 EXPLORATION AND GEOLOGY

In 1953 exploration started on a number of farms in the Postmasburg area and in 1956 the first iron ore outcrops (Figure 7) were discovered on the farm Welgevonden that led to the exploration project commonly being referred to as the Welgevonden project for the next five decades.

Source: Louw *et al.* (n.d.)

Figure 7: Iron ore outcrop on the farm Welgevonden

With iron ore outcrops only found on the western part of the exploration area geophysical surveys followed by an extensive drilling program led to the discovery of buried ore bodies on the farms Leeuwfontein, Klipbankfontein and Ploegfontein situated across the central and eastern parts of the exploration area.

The presence of other high grade deposits scattered over a number of farms were also encountered. The deposits at Leeuwfontein and Klipbankfontein were estimated to contribute 70 percent of Kolomela's life of mine.

Around eighty percent of the Kolomela deposits are covered by sand, dolocrete and calcrete while the ore resource is preserved in geological structures covered by younger rock formations.

Due to thrusting an area of irregular limestone has developed in which erosion has produced sinkholes, fissures and caverns in which the iron ore had been preserved from erosion. Five different types of iron had been classified each with its own unique physical and chemical characteristics namely:

- Laminated ore that is the main ore type consisting 53 percent of the deposit.
- High quality clastic textured ore that form 29 percent of the deposit.
- Collapse breccia ore (10 percent of the deposit) that is a composition of rock fragments cemented together by a fine grained matrix.
- Conglomeratic ore (8 percent) found in rocks with pebbles and gravel embedded in cement.
- Medium grade ore that falls outside the traditional iron (Fe) content greater than sixty percent consisting of Fe rich banded iron formation, conglomerates and collapse breccia. The medium grade ore occur as thin layers and lenses.

It's been estimated that the Kolomela deposits amounts to 373 Mt. The high quality resources and the configuration of the ore bodies allow for a 9 Mt per annum run-of-mine. The ore is crushed, screened and stockpiled into lump and fine ore. This process is known as a direct shipping ore operation. If beneficiation technology is to be introduced it is foreseen that the run-of-mine can grow to an estimated 15 Mt per annum.

The life of mine has been calculated to be in the order of 30 years but the ramp-up schedule of the run-of-mine and economic factors that influence the pit designs will ultimately define the life of mine over the years to come.

7.4 NAME CHANGES

In 2002 the project team changed the name from Welgevonden to Sishen South as the project was situated south of the Sishen Mine. This however caused confusion especially with the environmental and licence applications submitted to the various Government departments for approval as it was often thought that Sishen South was an extension of Sishen Mine.

After the final approval of the mining rights in 2008 the surrounding communities and schools were invited to create a name for the new mine to be established. The criteria to which the name had to oblige to were set to be the following:

- to be in the local African language (Setswana) spoken in the area
- easily pronounceable
- and indicative of the business

None of the submissions were however suitable and the inputs from various specialist were also been asked for. Eventually the name Kolomela (meaning “to dig deeper” or “to persevere”) that was suggested by Professor JSS Shole of the African Languages Department at UNISA was chosen.

7.5 CONSTRUCTION AND INFRASTRUCTURE

In July 2008 the investment approval was given by the Kumba and Anglo Boards for the establishment of the mine. At that point in time last minute changes to the designs were made before construction started in all earnest that would forever change the face of the area from being an exploration project into a mine milieu, see Figures 8 and 9 showing an aerial view of the area before and during construction respectively.

Source: Louw *et al*. (n.d.)

Figure 8: Aerial view of area before mining

Source: Louw *et al*. (n.d.)

Figure 9: Aerial view of area after construction started

The construction for Kolomela Mine not only include the building of the plant sections, dewatering network, workshops and offices at the mine site but also the housing in Postmasburg town with the necessary upgrading and expansion of the plumbing and sewage components.

The construction phase ended in 2012 whereupon the infrastructure was handed over to be incorporated into the mine's operational structures.

7.6 DEWATERING INFRASTRUCTURE

The drilling of exploration boreholes (Figure 10) to determine the dewatering targets started in January 2008 and was completed in May that year. The dewatering boreholes were drilled immediately after the exploration phase and were completed in February 2009. In total 23 exploration and 12 production boreholes were drilled.

Source: Louw *et al*. (n.d.)

Figure 10: Drilling of boreholes

Due to the abundance of groundwater in the Kolomela Mine area special care was taken in designing the dewatering infrastructure as the dewatering needed to be executed on a large scale to keep the pits dry to ensure that mining can be executed in a safe manner. The dewatering infrastructure comprises of kilometres of pipeline connecting the dewatering boreholes (Figure 11) from the three pits, from where the water is being pumped to a 6 Ml reservoir.

Water from the reservoir is being used at the mine for potable, process and fire water. The excess dewatering water is delivered to the Vaal Gamagara network that distributes the water to communities, industries and other mines in the area stretching from north of Postmasburg towards Hotazel.

Figure 11: Dewatering borehole connected to dewatering network

Two pump stations were also built, one at the 6 Ml reservoir and the other at the Beeshoek reservoir. From the 6 Ml reservoir a 14.7 km pipeline was laid to the Beeshoek reservoir and from there a 4.7 km pipeline to deliver the water into the Vaal Gamagara pipeline.

With the starting of the construction and civil works in the middle of 2008 water was sourced from one of the exploration boreholes drilled earlier that year. The dewatering activities, to ensure a dry pit for mining, started in July 2010 with the commissioning of five boreholes with an average dewatering rate of 204 m^3/h.

After completion of the dewatering pipeline network and pump stations the dewatering volume was ramped up to the dewatering target of 1500 m^3/h as determined by the numerical model.

7.7 START OF MINING

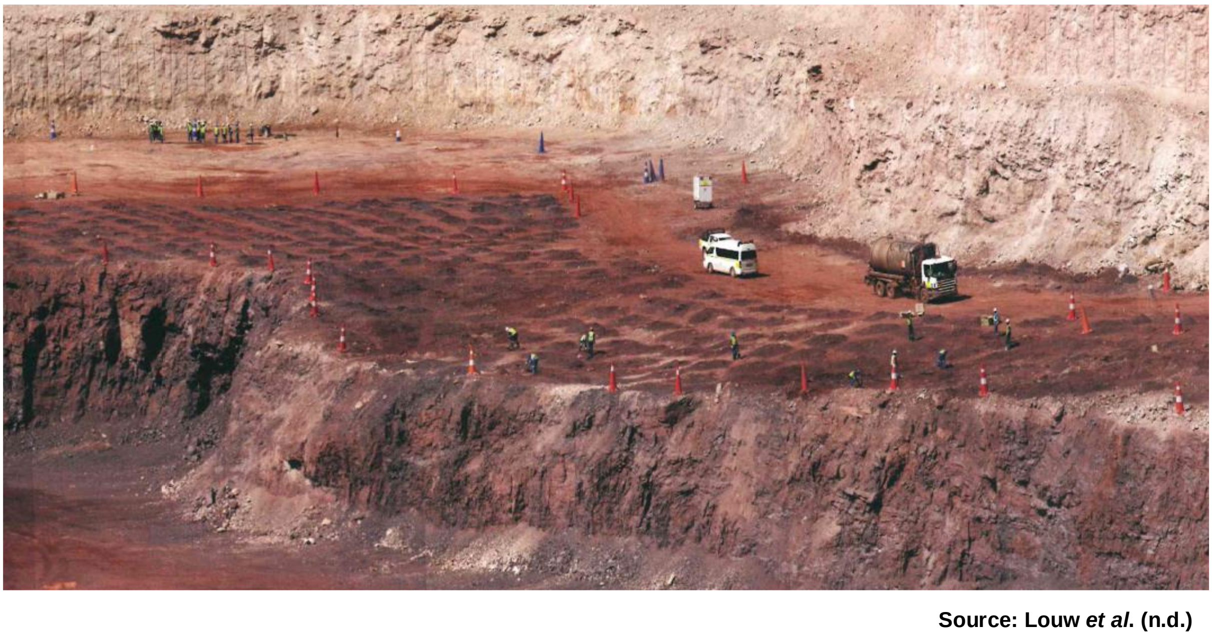
After the mining rights were awarded in September 2008 the mining areas were prepared and the first blast to start the excavating of the Leeuwfontein pit was done in September 2009 (Figure 12).

Source: Louw *et al*. (n.d.)

Figure 12: First blast for the excavating of Leeuwfontein pit

In October 2010 the first ore (Figure 13) was unearthed from the pit to be processed at the plant and in November 2011 the first tonnes of lump ore were dispatched by rail to the port of Saldanha.

The first shipment of 100 000 tonnes of lump ore to China took place in December that year. In June 2012 production exceeded the design capacity of 750 000 tons of ore per month for the plant.



Source: Louw *et al*. (n.d.)

Figure 13: Iron ore unearthed in Leeuwfontein pit

7.8 MONITORING OF WATER RESOURCES

When Kolomela Mine's water licence was awarded on the 6th of June 2008 the monitoring programme (as discussed under point 8.2.2) that consisted of quarterly water level and water quality monitoring for only a number of positions was adjusted and expanded over time. The monitoring program was changed not only to fulfil to the conditions of the water licence, but also the environmental monitoring standards of the company.

The monitoring programme was adjusted over time and currently consists of the components as described below. Although a set programme is drawn up for the testing parameters and monitoring intervals, the programme is revised yearly, but also adjusted should the need arise for ad hoc sampling and analysing.

7.8.1 Dewatering boreholes

- Weekly monitoring of water levels and abstraction volumes
- Quarterly monitoring of the inorganic chemical quality of the groundwater
- Bi-annually analysing for the total oil and grease (SOG) and volatile petroleum hydrocarbons (VPH), the package for the VPH includes analyses for:
    - GROs – Benzene, Toluene, Ethyl benzene, m+p Xylene, o-Xylen and MTBE
    - DROs (C10, C12, C14 & C16)
    - PAH – Acenaphthene, Acenaphthylene, Fluorene, Phenanthrene, Anthracene and Naphthalene
- Annual analysing for heavy metals

7.8.2 Potable water

All drinking water points on the mine are sampled monthly and subjected to inorganic and bacteriological analysis. The bacteriological analysis comprises the testing of total coliforms & E.coli.

7.8.3 Oil separators

Waste water from the Mining workshops is send to oil separators where the effluent is monthly analysed for SOG.

7.8.4 Sewage treatment plants

A sewage plant was constructed on site for the treatment of the water effluent from the construction workers accommodation area when construction started in 2008. After the construction phase a part of the mine's drainage system was connected to this treatment plant but an additional treatment plant was later constructed to fulfil in the mine's needs.

Bacteriological and waste water analyses are done on a monthly interval on the water before and after treatment at the sewage plants. The analyses comprise of the following:

- pH
- Conductivity
- Orthophosphate (PO_4) as P
- Ammonium (NH_4) as N
- Nitrate (NO_3) as N
- Nitrite (NO_2) as N
- Total Kjeldahi nitrogen (TKN)
- Total Phosphorus (TP)
- Chemical Oxygen Demand (COD) & (COD) filtered
- Suspended Solids (SS)
- Oil & Grease (SOG)
- Total Coliforms & E.coli
- Faecal Coliforms

7.8.5 Surface water

Inorganic analyses are done monthly on samples taken at the process and slimes discard dams situated at the Plant area. Sampling points are also set at the Groenwaterspruit, a drainage channel east of the mining area for inorganic analysing whenever flow does occur in the spruit.

7.8.6 Monitoring boreholes

After completion of the Mining workshops and Plant infrastructure a number of boreholes were drilled for environmental monitoring of these areas. The boreholes are quarterly monitored for inorganic, SOG and VPH.

Monitoring boreholes were also drilled around the pit areas and are quarterly analysed for inorganic constituents. Both aquifers are monitored as shallow and deep monitoring boreholes were drilled. Water levels are also measured when sampling is done.

7.8.7 Artificial recharge

The latest addition to the monitoring program was the artificial recharge project. With the ramp-up of the dewatering it was foreseen that the Vaal Gamagara pipeline will not be able to accommodate all the surplus water at times. To prevent the spillage of water into the environment it was decided that the option for artificial recharge be investigated to ensure that the surplus water can be use in a beneficial way.

The Groenwaterspruit that acts as a surface water drainage channel east of the mine was identified as an area for artificial recharge and was investigated. After evaluation of the test results boreholes were drilled and equipped (Figures 14 and 15a&b) for injection into the alluvial aquifer system. Boreholes for water level and water quality monitoring were also drilled.

Monthly inorganic monitoring is done on the water that is injected into the boreholes as well as on the monitoring boreholes situated around the injection boreholes. During sampling the water levels at the injection boreholes are also manually monitored (Figure 15a&b) to compare with the data of the water level loggers that were installed.

Figure 14: Injection borehole protected by concrete cylinder for artificial recharging of the Groenwaterspruit alluvial aquifer

Figure 15a: Inside concrete cylinder **Figure 15b: Taking water level reading**

Inside the cylinder there is the injection pipe (with blue air valve) and the outlet pipe (far left in Figure 15a) extending to the top of the concrete cylinder into the U pipe as can be seen in Figure 14. Figure 15b indicate the position of the water level logger and where the water level can be taken by a water level meter.

An overview of Kolomela a Greenfield mine, situated 10 kilometres southwest of Postmasburg that came into operation in 2010 is given with reference to the processes transforming the exploration project into a mining operation.

During the exploration phase the extend and magnitude of the groundwater resources in the area was realised which necessitate that the drilling of the dewatering boreholes, the designing and construction of the dewatering pipeline infrastructure be completed before the mining activities commenced. The onsite monitoring programme that was in operation since the exploration phase of the project was expanded and adjusted to ensure that the groundwater levels and quality are thoroughly monitored at all the sites of the mining operation.

Chapter 8

GEOLOGY AND HYDROGEOLOGY AT PROJECT SITE (KOLOMELA MINE) AND REGIONAL AREA

8.1 GEOLOGY

Kolomela Mine is situated at the southern edge of the Maremane Dome that is situated on the south western boundary of the Kaapvaal craton, see Figure 16.

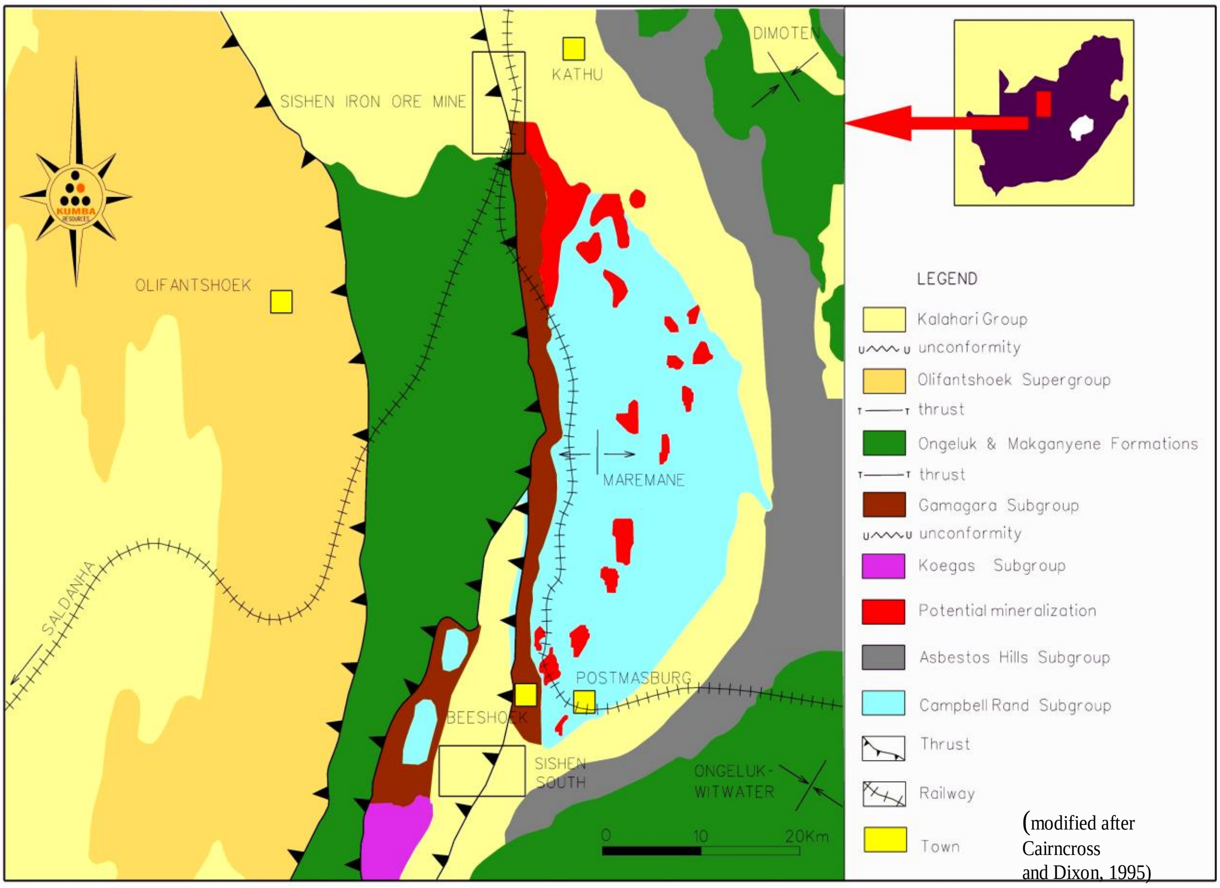
The geology of the regional area has been subjected to intensive structural deformation in the form of thrusting, folding and faulting that led to a series of prominent NW-SE striking fracture zones. Karstification is notable in the area and north south plunging anticlines, synclines and grabens have also been formed on account of the intense thrusting on the stratigraphy.

High grade mineralisation occurs over the Maremane Dome area. Examples are Sishen and Khumani Mines at the northern and Beeshoek and Kolomela Mines at the southern edges of the Maremane Dome respectively (Figure 16). Manganese deposits were also developed with Bishop, Lohatla and Glossam manganese mines operational in the area.

The regional geology is dominated by the dolomites of the Campbell Rand Subgroup, the banded ironstone formation of the Asbestos Hills Subgroup and the lavas of the Ongeluk Formation.

The dolomite forms the oldest lithostratigraphic unit in the area which are overlain by chert breccia which in turn is conformably overlain by the banded iron formation. In some places the upper portion of the banded iron formation have been supergene enriched to iron ore with a Fe content greater than sixty percent.

In places a gabbroic sill intruded the Asbestos Hills Subgroup and usually separates the ore bodies from the underlying host banded iron formation. A thick sequence of sediments comprising of shales, quartzites and conglomerates of the Gamagara Subgroup unconformable overlies the banded iron formation. The Makganyene diamictite overlay the Gamagara sediments which are followed by the andesitic lava of the Ongeluk Formation and the tillite of the Dwyka Formation.



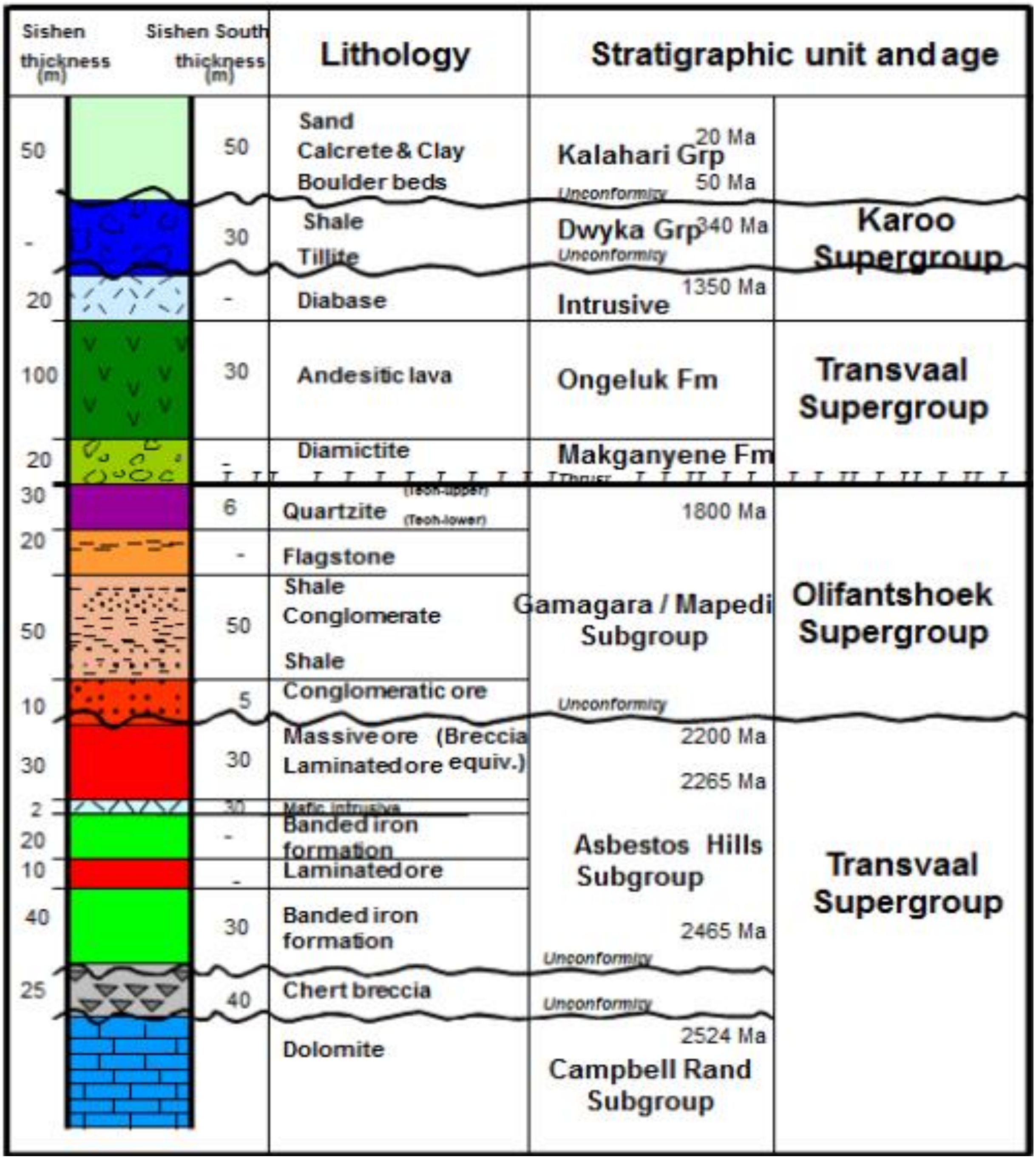
Source: Steenekamp (2005)

Figure 16: Maremane Dome

A layer (10 to 60 m thick) consisting of calcrete, clay and pebbles of the Kalahari Group are unconformably deposited over the older lithologies. The Kalahari Group covers about 90% of Kolomela Mine's total surface area. The exception is the banded iron formation and dolomite of the Asbestos Hills and Campbell Rand Subgroups respectively that outcrops on the western side of the mining property.

The banded iron stone and dolomites also outcrop to the north-northeast of the mining area and form a topographical high that plays an important role in the recharge of the regional area.

See Figure 17 below for the lithostratigraphic summary of the Maremane Dome area.



Source: Geology Department – Sishen Iron Ore Mine

Figure 17: Lithostratigraphic summary of the Maremane Dome area

Numerous intrusive dykes occur in the area but seldom outcrop as the dykes are overlain by the Kalahari Formation and only visible on surface where the soil or sediment cover are very thin and eroded away. The dykes are mainly magnetic but low to non-magnetic dykes are also found.

In general the dykes dip near vertical (80-90 degrees) and can have extensive strike lengths of several kilometres. It is also found that dykes with a low to impervious hydraulic conductivity compartmentalize the dolomitic aquifer. The dyke bedrock contact can act as preferential groundwater flow paths. Near surface its believe that the dykes acts as aquitards restricting lateral water flow and at depth acts as aquicludes preventing water flow across it.

8.2 HYDROGEOLOGY

8.2.1 Background

Before 1997 the only hydrological data collected at the Sishen South project were blow-out yields from the geological exploration boreholes. Since 1997 till 2005 groundwater investigations have been done at an ongoing base with relative low intensity.

The magnitude of the blow-out yields recorded at some of the boreholes accent the necessity for further investigations of the aquifer characteristics. During the late 1990's a couple of pumping tests were done to verify the measured blow-out yields and to quantify the transmissivity and storativity parameters of the aquifer.

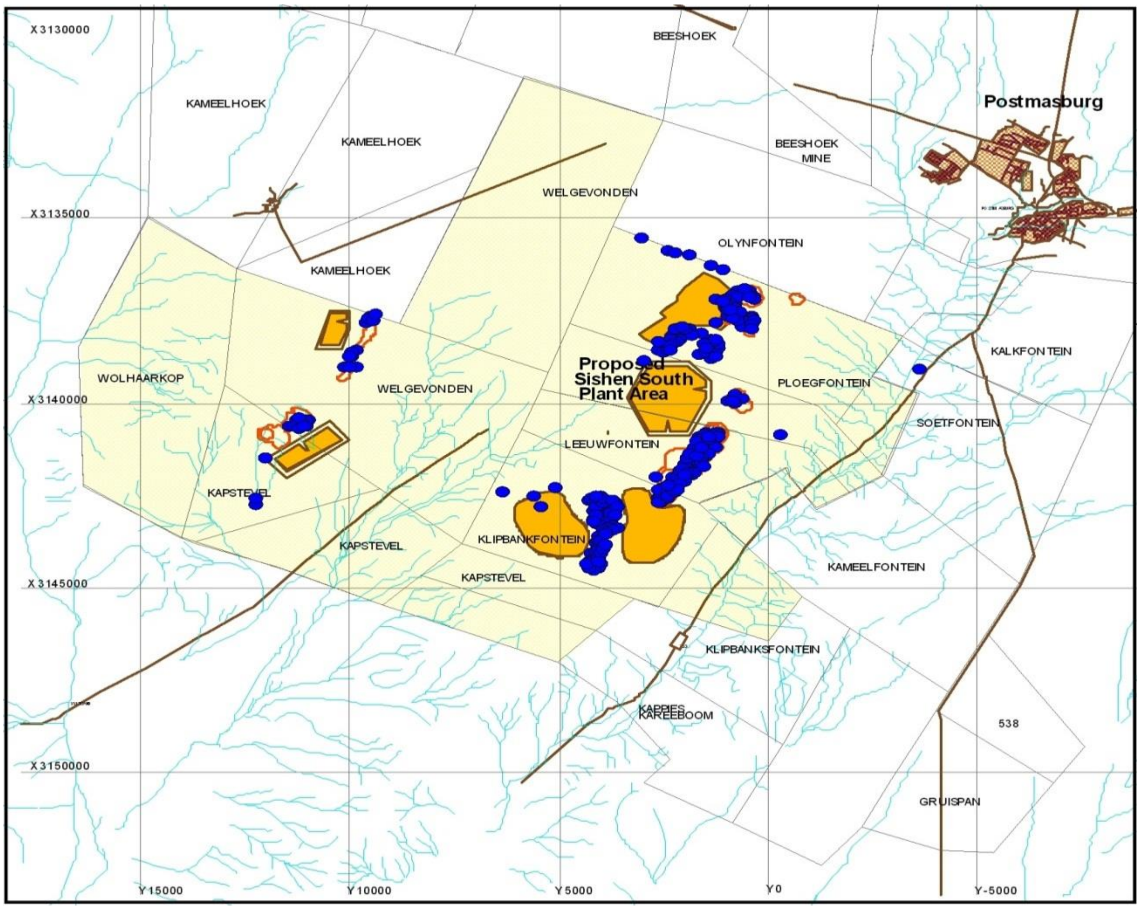
After interpretation of the pumping test data a numerical model was constructed for the project. As can be expected after this first round of defining the aquifer characteristics and modelling exercise information gaps were identified.

To address the information gaps, additional boreholes were drilled with the specific purpose for aquifer testing in order to obtain an in-depth understanding of the aquifer regime especially in terms of the role the structural geometry play in the groundwater flow within the aquifers. Both the physical and chemical properties of the groundwater regime were studied during the investigations that followed during the period 1998 to 2001.

8.2.2 Water level and water quality information

It is not clear when the official recording of water level data and sampling of water for quality analyses on the project site started. It is possible that monitoring started prior 1999 but it is only since then that data was captured in a database.

The data was mainly from boreholes drilled on the farms Ploegfontein, Leeuwfontein and Klipbankfontein. At that stage only a few boreholes were drilled on the farms Welgevonden and Kapstevel. Figure 18 show the position of the boreholes for which water level information exists.



Source: Steenekamp (2005)

Figure 18: Position of boreholes where water level information exists

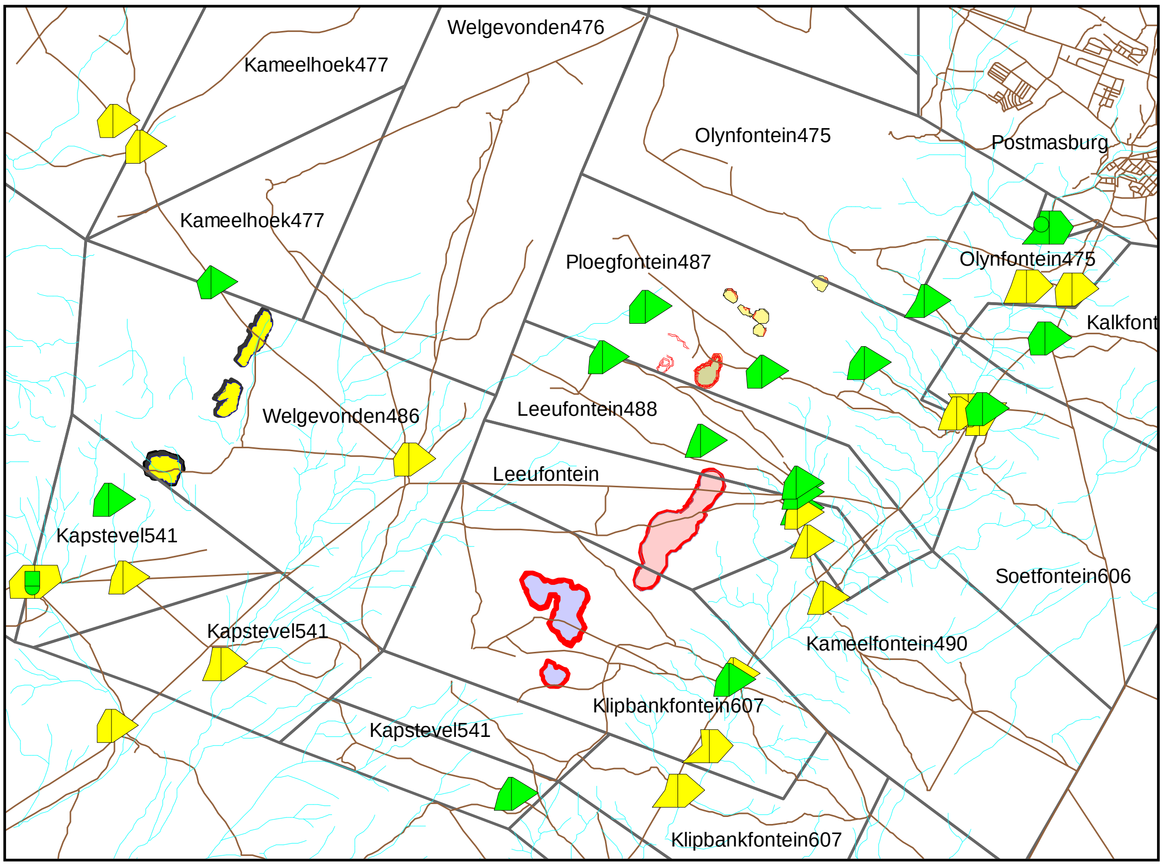
In 2002 a hydrocensus was conducted on the project site and the farms adjacent, except the farms south of the project area. In total 78 boreholes, 6 springs/fountains and 7 wells were recorded of which 35 water samples were taken and analysed. Figure 19 indicates the sampling positions.

Unfortunately the data of the points on the private properties visited during the hydrocensus was not captured in the database together with the data of the boreholes of the project site that were recorded since 1999. The chemical analyses and data results of the boreholes on the adjacent farms were only accessible from a report where they were displayed in tables and figures.

As co-ordinates of these points are not available comparison between the data (for example the water levels and chemical parameters) of the 2002 hydrocensus and data obtained at a later stage could not be made between specific boreholes. However in spite of this, valuable information was obtained from the project area and farms adjacent to the project site that provided insight into the hydrological setting of the project and regional areas.

The yields of the boreholes visited during the hydrocensus varied between 1 and 40 m^3/h. It was noted that most of the boreholes belong to the upper unconfined calcrete aquifer of the Kalahari Formation while a small number of boreholes were representative of the deeper fractured aquifer.

Although the groundwater was mainly used for domestic supply and stock watering, irrigation of maize and lucerne on a number of farms in the Groenwaterspruit and Lucasdam Vlei areas (32 ha in total) to the east and west of the project area was also in practice.



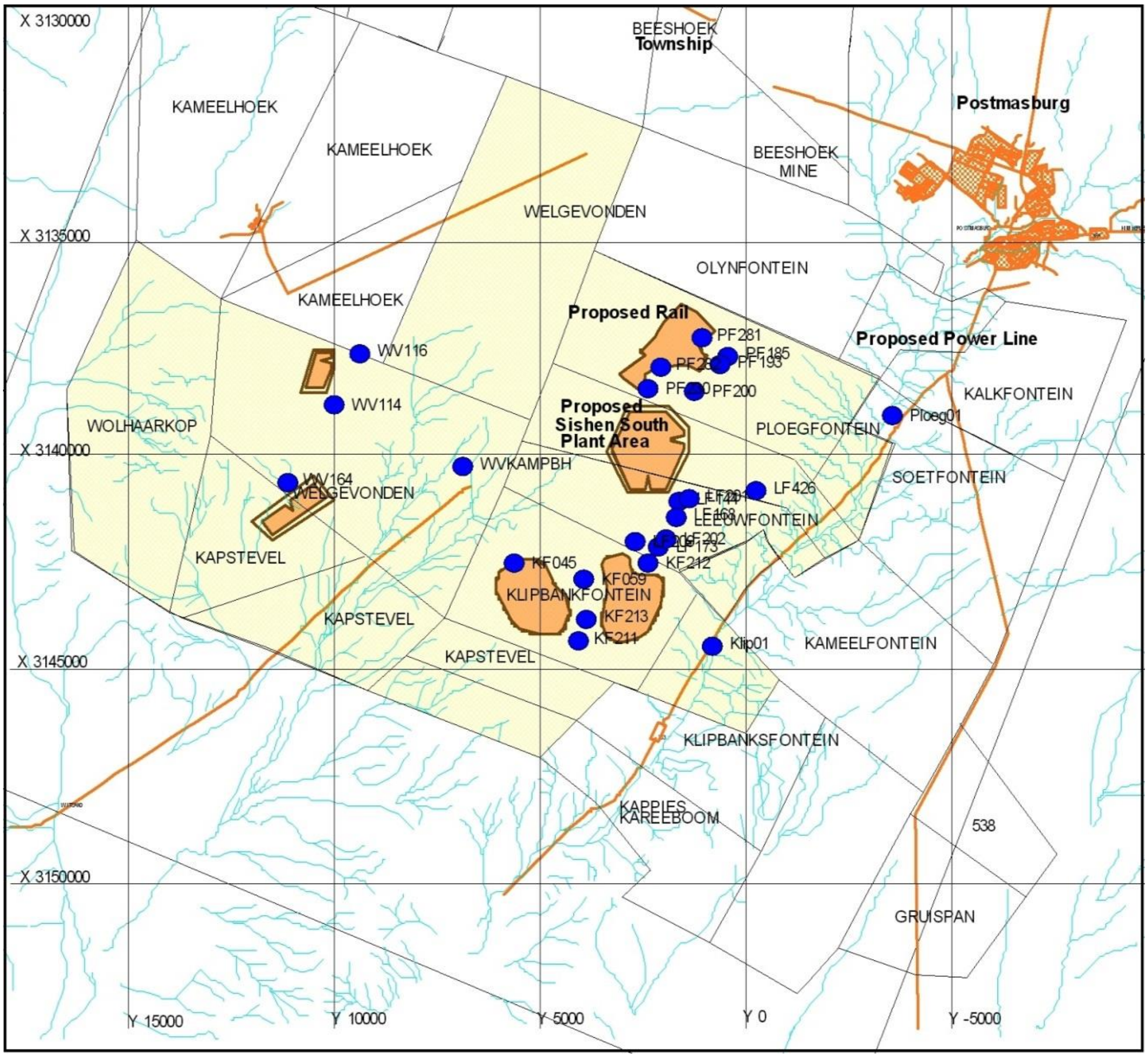
Source: Steenekamp (2005)

Figure 19: Position of sampling positions during the hydrocensus

At the time of the hydrocensus the municipality of Postmasburg utilised groundwater from a number of boreholes in the Groenwaterspruit upstream of the project area which accounted for a significant amount of the town’s water supply. This practice is still in operation today.

After the hydrocensus a structured monitoring programme was introduced with the implementing of a quarterly monitoring programme that included the measurement of groundwater levels and water quality analyses consisting of all the major constituents.

The monitoring programme consisting in the order of twenty boreholes was however restricted to the project area and the monitoring points were also not evenly distributed over the Kumba properties but mostly concentrated around the proposed pit positions (see Figure 20).



Source: Steenekamp (2005)

Figure 20: Position of groundwater level and quality monitoring points for project area

When Kolomela Mine was awarded its water licence the monitoring programme, as developed for the project area, continued but the programme was adjusted and expanded over time in order to cover the entire mining activities and addressing the requirements as stipulated by the water licence.

8.2.3 Numerical modelling

Beeshoek Mine situated just north of the Kumba properties (Figure 20) started with mining activities dating back as far as the 1930’s. Groundwater was abstracted for mining and plant usage as well as to ensure dry and safe mining conditions over the years.

From the early 2000's the abstraction rate increased and a continuous water level monitoring system was implemented by Beeshoek Mine in 2003. The groundwater levels together with the abstraction volumes that were recorded since 2001 were made available to the project.

The data from Beeshoek Mine together with the data of the project's monitoring programme were used as input to develop the first numerical groundwater model in 2005. The data from the project's monitoring programme indicated a significant change in the water levels for the farms Ploegfontein, Leeuwfontein and Klipbankfontein over the period 2002 until 2005 (see Table 2).

TABLE 2: AVERAGE WATER LEVEL CHANGES IN PROJECT AREA

Area	Water level 2002	Water level end 2003	Water level 09/2005	Drawdown 2002 - 2005
Ploegfontein North	22	30	60	**38**
Ploegfontein Central	18	22	46	**28**
Leeuwfontein North	15	20	39	**24**
Leeuwfontein Central	11	16	30	**19**
Klipbankfontein North	6	12	24	**18**
Klipbankfontein Central	4	10	18	**14**
Welgevonden Central	30	30	30	**0**
Kapstevel Central	20	20	20	**0**

Source: Steenekamp (2005)

Simulations done by the numerical model in 2005 (Figure 21) indicated that the dewatering of Beeshoek Mine resulted in a depression cone that predominately extends from the abstraction points in a northeast southwest direction, as this is the main strike direction of the faults and geological lineaments in the area.

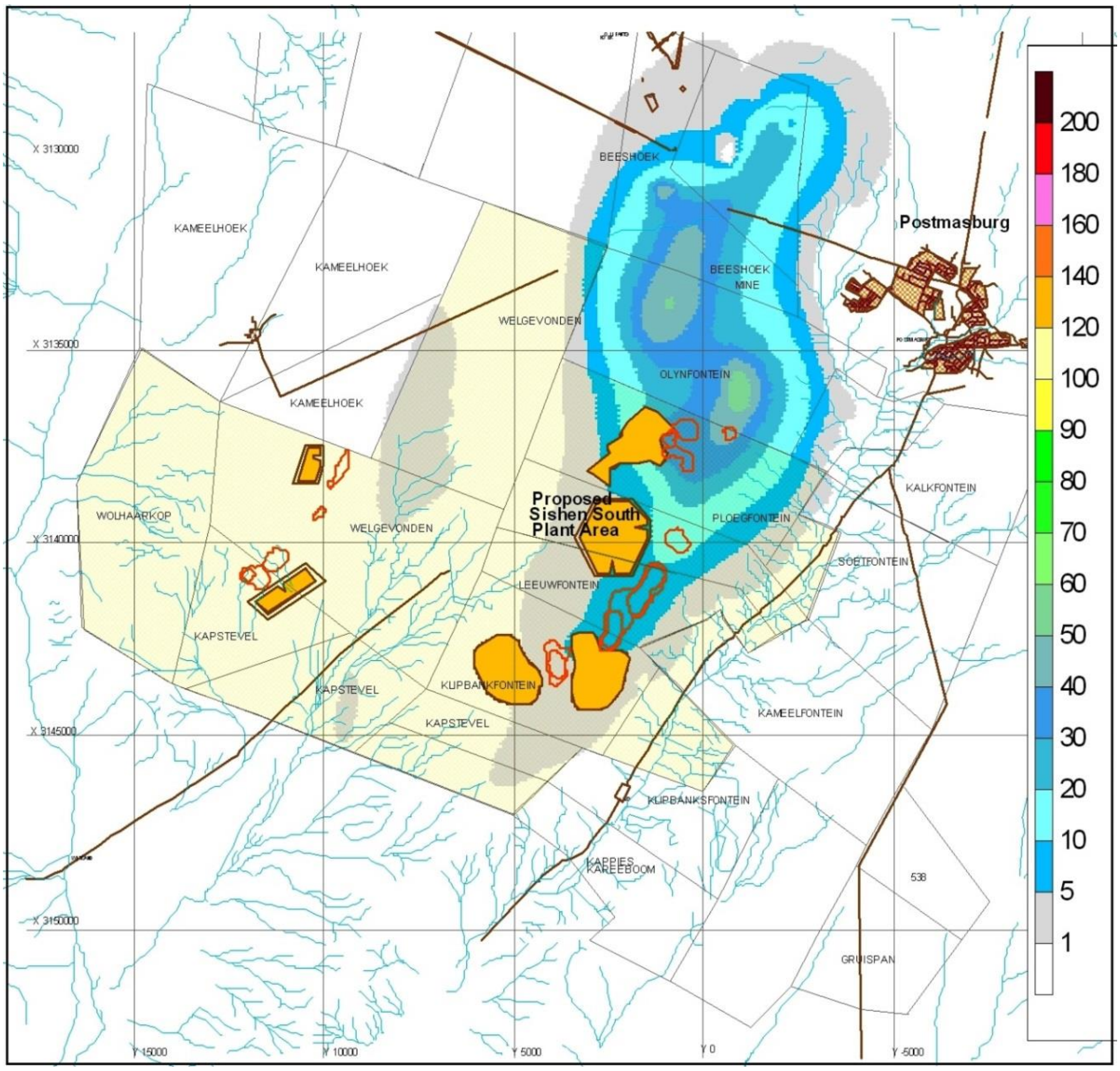
At that time the southern tip of the dewatering extended to the northern part of the farm Klipbankfontein on the Kumba properties. The model was updated and re-calibrated as new data became available.

A commendable effort was made to estimate the transmissivity and storage values of the aquifer. A total of nineteen boreholes were pump tested with calibration, multi-rate step and constant rate tests. The constant rates tests were performed for at least 72 hours and water level behaviour was measured in a number of observation boreholes up to 400 m from the pumped boreholes.

A comprehensive distribution of transmissivity and storativity values were obtained over the model area as the tested boreholes were distributed over all the project's farms namely Ploegfontein, Leeuwfontein, Klipbankfontein, Welgevonden, Kapstevel and Wolhaarkop.

Aquifer transmissivity (T) is a measurement of the amount of water that can be transmitted horizontally trough a unit width of the full saturated thickness of the aquifer under a hydraulic gradient of 1. Transmissivity is expressed in m^2/day and is the product of the aquifer thickness and the hydraulic conductivity (K) of the aquifer.

Storativity (S) or the storage coefficient is the volume of water that a permeable unit can absorb or release from storage per unit surface area per unit change in head and is a dimensionless quantity.



Source: Steenekamp (2005)

Figure 21: Simulated drawdown contours due to Beeshoek Mine dewatering till 2005

The pump test data were evaluated and the T and S values were calculated at early and late stages during the pumping periods. For the boreholes where the pumping test yield was too low to dewater the fractures during the 72 hour period, the T and S values for only the early stages were calculated.

The early T and S values represent the fracture dominated flow while the late T and S values the matrix dominated flow. The early T values range from 8.7 to as high as 1600 m^2/d while the late T values were considerably lower and range from 2.4 to 120 m^2/d. The early S values were usually lower than the late S values. The early S values were calculated to be between 10^{-2} to 10^{-25} comparing to the late S values of 10^{-1} to 10^{-10}.

The transmissivity and storativity values confirmed the characteristics of groundwater flow through a fractured medium where fractures, although highly transmissive, occupy small volumes and their storativity is very small. The aquifer matrix, especially dolomite (as in this case), has a very low transmissivity but more storage volume for water in the aquifer.

From the pumping tests it was derived that the transmissivity of the chert breccia and banded iron stone formations were very high, indicating that high groundwater flow rates will occur through these formations that would result in a depression cone covering an extensive area.

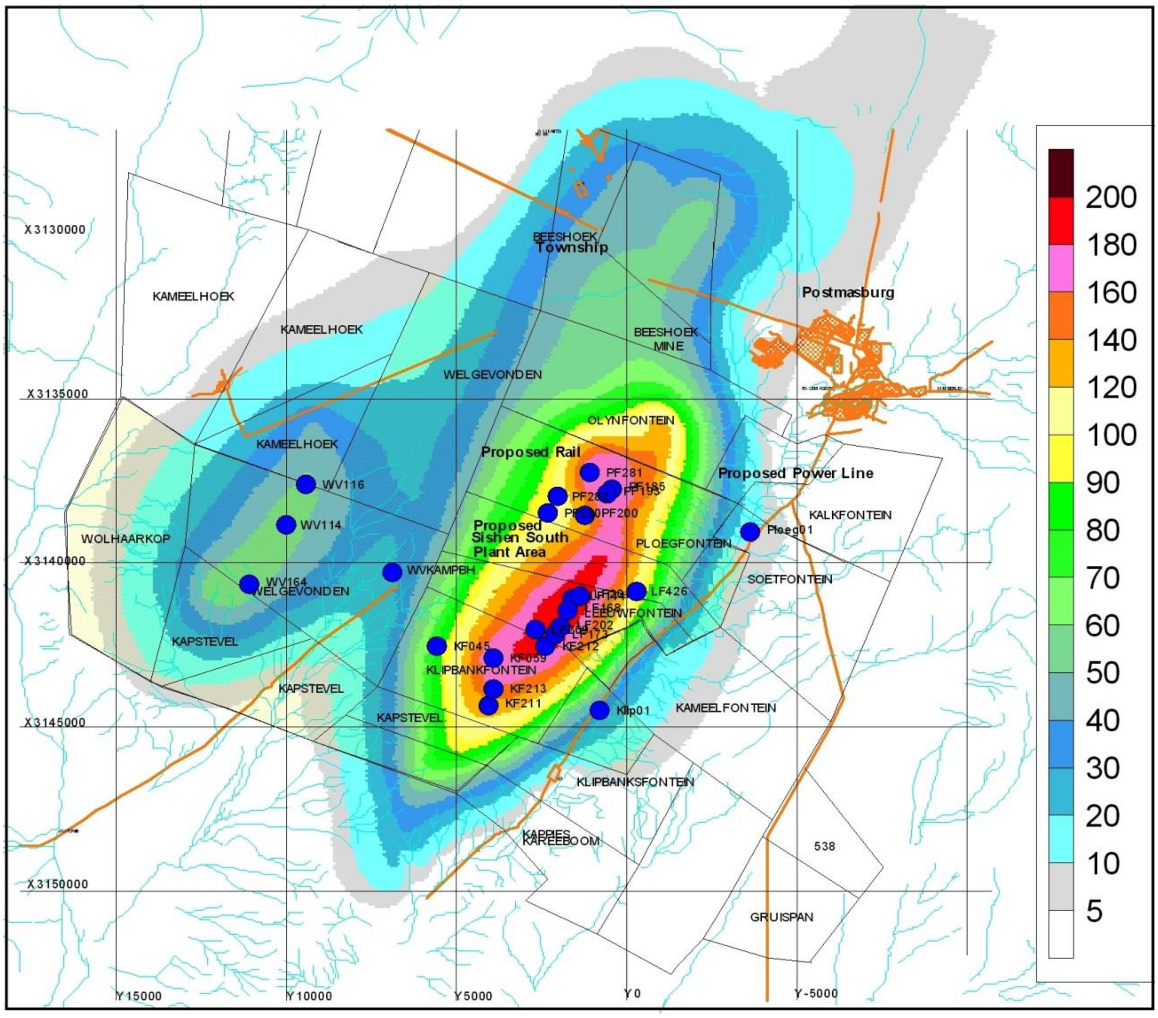
Due to the high transmissivity is was anticipated that a large area should successfully be dewatered with a relative small number of dewatering boreholes although high pumping rates will need to be maintained on a constant basis.

Besides the transmissivity and storativity values the recharge value is an important component for any numerical model. A recharge value of 4 percent of the mean annual precipitation was used in the model calibration as it was found that the recharge can vary between 1 to 7 percent over the regional area due to the complex geology setting.

Where surface depressions occur on the project site it was seen as areas with a higher recharge as surface water runoff accumulates in these areas after high rainfall events. It was also observed that the evaporation losses of the water in these depressions are minimal as the water infiltrate in a short period of time.

The numerical model simulations indicated that besides the abstraction done by Beeshoek Mine a significant volume of water will need to be dewatered at the project site to ensure that the pit areas be kept dry in order for the mining activities to be done in a safe manner.

Simulations were also done to get an idea of the area expected to be impacted upon with the combined dewatering activities of Beeshoek Mine and the Sishen South project (see Figure 22).



Source: Steenekamp (2005)

Figure 22: Impacted zone with combined dewatering at Beeshoek Mine and Sishen South

8.2.4 Characteristics of the aquifers in area

The hydrogeological regime in the area can be divided into two main aquifer systems namely an unconfined primary aquifer and a fractured secondary aquifer.

8.2.4.1 Unconfined primary aquifer

The aquifer that occurs in the calcrete can be classified as unconfined to semi-confined and covers most of the surface in the project area. The aquifer is shallow and in most cases occurs up to a depth of 30 m.

The aquifer is usually developed on the contact between the calcrete and the underlying clay layers or within pebble horizons found in the calcrete. The latter are mainly found in the Groenwaterspruit and Lucasdam Vlei areas that are to the east and west of the project area respectively.

These two areas are low lying drainage areas that will receive high recharge from the large surface areas during periods of intense rainfall events. The gravel/pebble horizon is responsible for the high transmissivity zones found in the calcrete. Boreholes drilled in this horizon will have a higher yield than boreholes drilled in the calcrete outside the drainage channels.

The yield of boreholes in this aquifer is relative low and seldom exceeds to 2 L/s but can be as high as 10 L/s in the drainage channels. The aquifer is developed throughout the area and has been the sole reliable source of water supply to farms in the area for more than a century. The water level in the aquifer is mostly shallow and varies between 5 and 20 m below ground level.

In general the calcrete is very hard and can be described as being competent. At the surface the calcrete appears to be relative impermeable but pumping tests have proven that infiltration through small cracks and openings can contribute to a significant recharge under favourable conditions. In the area it was also observed that the calcrete can retain significant amounts of water and remains moist long after rainfall events have passed.

Initially it was assumed that after significant rainfall events recharge through leakage to the deeper aquifer will take a significant time of weeks or even months before changes in the water levels of the deeper aquifer would register. This assumption was based on the presence of clay, diamictite, shale and lava that are characterised as relative impermeable and occur between the upper calcrete aquifer and the deeper fractured aquifer in the banded iron stone, chert breccia and dolomite formations.

Observations from pumping tests however disapproved this assumption to be the standard throughout the area. During some of the pumping tests on the Kumba properties it was found that the discharge from the pumped borehole influenced the water level observations at the close-by monitoring boreholes as well as the pumped borehole as rises in the water levels was recorded after 30 hours of pumping.

A couple of springs/fountains are also found in the area. The existence of these springs in the unconfined aquifer is mainly controlled by topographical factors. The springs occur in areas where the water table is shallow and after periods of significant recharge. Where a steep surface gradient is present the chances are favourable that the water table intersects the land surface resulting in spring discharge.

8.2.4.2 Semi-confined secondary aquifer

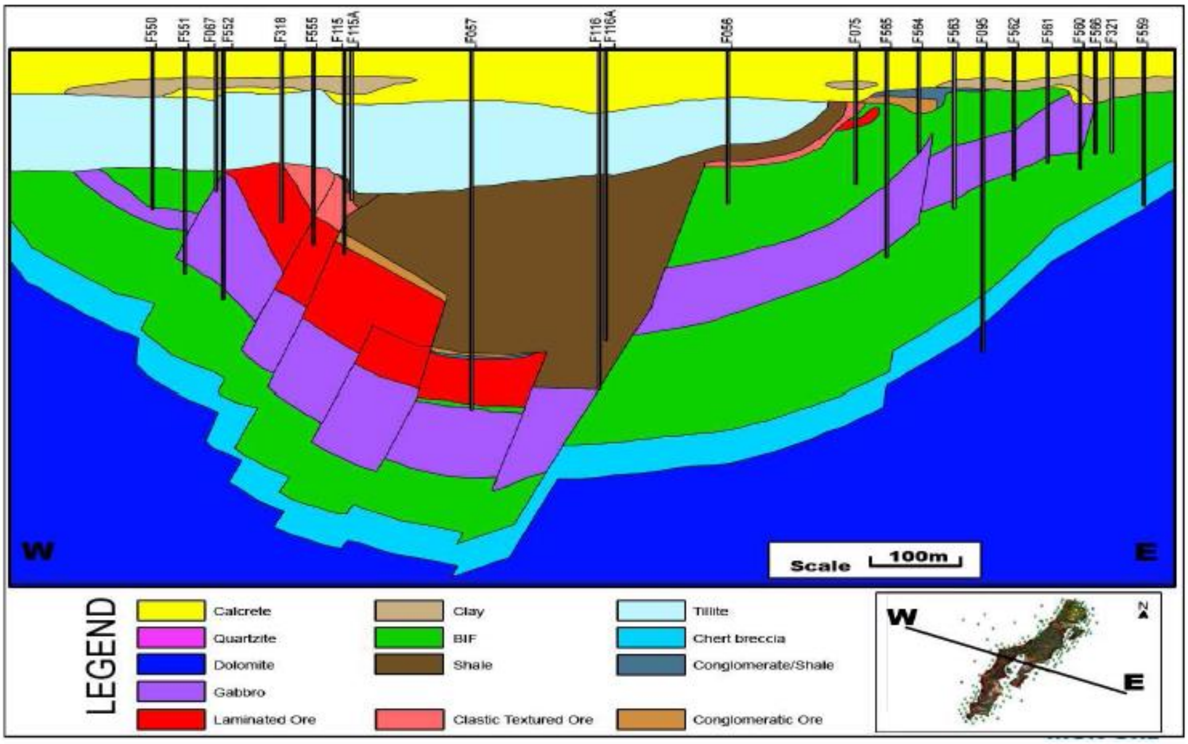
The secondary aquifer is associated with faults, fractures, fissures, joints and other discontinuities within the stratigraphic units of the Transvaal Supergroup (Figure 17).

The geology profile (Figure 23) at one of the pit areas at Kolomela Mine illustrates the presence of a fault and the discontinuities within the bedrock.

The aquifer can be classified as semi confined and the yields of the boreholes vary considerable as they are directly associated with the presence of the geological structures. Pumping test and monitoring results indicated that the structures act as preferred pathways for groundwater flow.

The groundwater flow in an aquifer is controlled by the difference in water level or piezometric head and under normal conditions will usually follow the trend of the surface topography. The natural flow direction of groundwater in the area is from north to south which is also the predominantly orientation of the geological structures. Large scale abstraction like in the case of dewatering can eventually result in the altering of flow patterns in certain areas.

In the area the aquifer occurs at depths exceeding 30 m to more than 300 m below surface. Yields of the boreholes can be as high as 83 L/s (300 m^3/h) in the banded iron stone, chert breccia and dolomite formations. These high yielding boreholes are concentrated near the iron ore deposits where in some places structural processes like faulting, folding and thrusting have caused development of highly transmissive fissures and fracture zones.



Source: Geology Department – Kolomela Iron Ore Mine

Figure 23: Geological profile at pit area

Contrary to the general belief it was found that boreholes in the dolomite do not always have high yields but do have a good storage capacity.

During the hydrocensus of 2002 a number of artesian boreholes (approximately 30) were recorded on the Kumba farms Leeuwfontein and Klipbankfontein. The positions of these boreholes were random and could not be linked to any specific structural lineaments known at that stage. Higher piezo metric levels were however observed with the deeper exploration boreholes indicating that the deeper fractures intersected were subjected to more confined conditions.

The flows from these artesian boreholes were in general around 1 L/s but flows as high as 16 L/s were recorded at some boreholes. The flow gradually decreased over time when the regional water levels started to decline significantly due to the increased abstraction from Beeshoek Mine around mid-2003. The dewatering of Beeshoek Mine caused noticeable impacts on the groundwater levels especially in a north south direction as the geological structures are predominantly orientated in this direction.

8.2.5 Relationship between groundwater and surface water

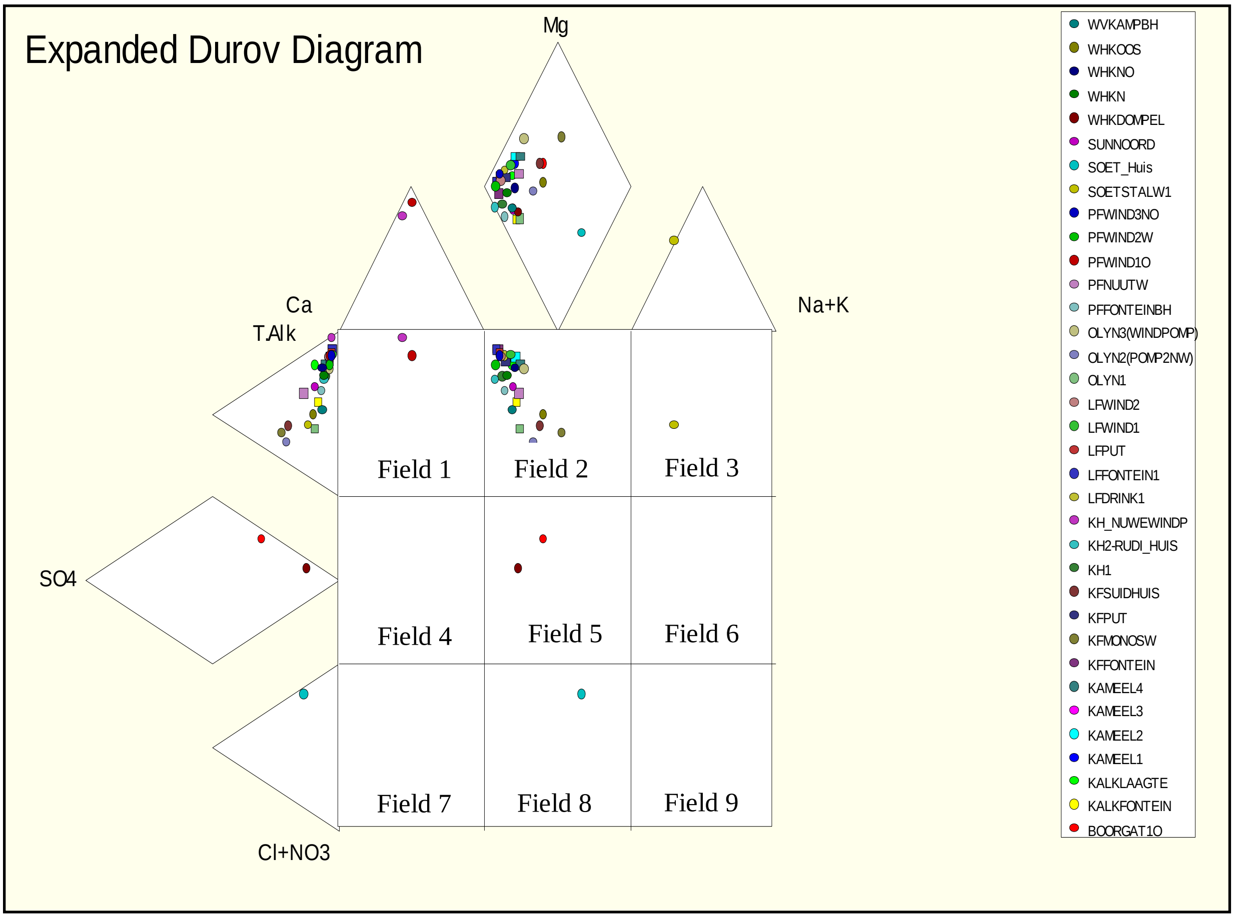
In the regional area the interaction between the surface and groundwater was found to be according to the generalised hydrological cycle and can be described as follow:

- During rainfall events direct sheet runoff will occur on surface.
- Rainwater will gather in surface depressions and then proceeds downwards to the water table.
- The amount of infiltration taking place into the subsurface will depend on the permeability of the geological zone and degree of saturation of the subsurface.
- Evaporation and evapotranspiration will take place directly from surface and through vegetation from the subsurface respectively.
- After recharge of the upper calcrete aquifer the deeper fractured rock aquifer will also be recharged through leakage from the upper aquifer.

8.2.6 Groundwater quality of aquifers

During the hydrocensus performed in 2002 a total of thirty five water samples were taken constituting of boreholes, wells and springs in the project and regional area, Figure 19.

An expanded Durov diagram (Figure 24) was used to plot and interpreted the data as it provides a holistic signature of the water quality.



Source: Steenekamp (2005)

Figure 24: Expanded Durov Diagram

With the exception of six samples the analyses all plotted in field 2 of the Diagram. Only two samples plotted each in fields 1 and 5 and one sample plotted in fields 3 and 8 respectively.

The water quality characteristics of the different fields can be summarised as follow:

Field 1: Fresh, very clean groundwater that has been recently recharged with calcium (Ca), hydrogen carbonate (HCO_3) and carbonate (CO_3) dominated ions.

Field 2: Fresh, clean groundwater that is relative young that has started to undergo calcium (Ca) and magnesium (Mg) ion exchange, usually found in dolomitic areas.

Field 3: This field also represents fresh, clean and relatively young groundwater that has undergone sodium (Na) ion exchange sometimes in sodium (Na) enriched granites or felsic rocks or due to contamination effects from a sodium (Na) rich source.

Field 5: Groundwater in this field is usually a mix of different types, either clean water from Fields 1 and 2 that has undergone sulphate (SO_4) and sodium chloride (NaCl) mixing or old stagnant sodium chloride (NaCl) dominated water that has mixed with clean water.

Field 8: As in the case of field 5 the groundwater is a mix of different types. It can either be clean water from Fields 1 and 2 that have undergone sulphate (SO_4) but especially chloride (Cl) mixing or it can be old stagnant sodium chloride (NaCl) dominated water that has mixed with magnesium (Mg) rich water.

The chemical analyses indicated that the groundwater in the project and regional areas can be described as fresh, recently recharged groundwater of good quality except for the high calcium (Ca) and magnesium (Mg) concentrations resulting into relative to extremely hard water. This phenomenon of high hardness and alkalinity levels are commonly found in calcrete and dolomitic areas.

Outside the project area nitrate (NO_3) concentrations higher than permissible for drinking water was also found in a couple of boreholes. The sources of this pollution were ascribed to fertilisers and animal manure.

With the analysis of the groundwater quality data the following factors were highlighted that have an influence on the quality of the groundwater in the area:

i) Annual recharge
ii) Type of recharge
iii) Flow dynamics within the aquifer
iv) Sources of pollution

i) The annual recharge in the area was determined to be in the order of ~ 4% of the mean annual precipitation of 300 mm. As there was no air and surface pollution in the project area the replenishment to the groundwater was of a good and fresh quality.

ii) The type of bedrock in the area consists mainly of calcrete, lava, quartzite, shale, banded iron stone and dolomite. The calcrete and dolomite have the most pronounced impact on the hydro chemistry due to the ion exchange and dissolution taking place within these formations resulting in high calcium (Ca) and magnesium (Mg) concentrations over the regional area.

The other rock formations are much more inherent and dissolution does not take place in the same extent as in the case of the dolomite.

iii) The flow dynamics within the aquifer does play a role in groundwater quality as it have a major influence on the age of the water. The magnitude of the borehole yields in the project area confirmed that zones of very high transmissivity occur in the aquifers and that the flow system is thus active resulting in relatively fresh groundwater in the proposed mining area.

iv) Besides the drilling of boreholes no other activities exist in the project area that could potentially be responsible for the sources of the high nitrate concentrations found at certain boreholes outside the project area. Therefore it was concluded that the sources of the nitrate pollution were most probably due to fertilisers and animal manure.

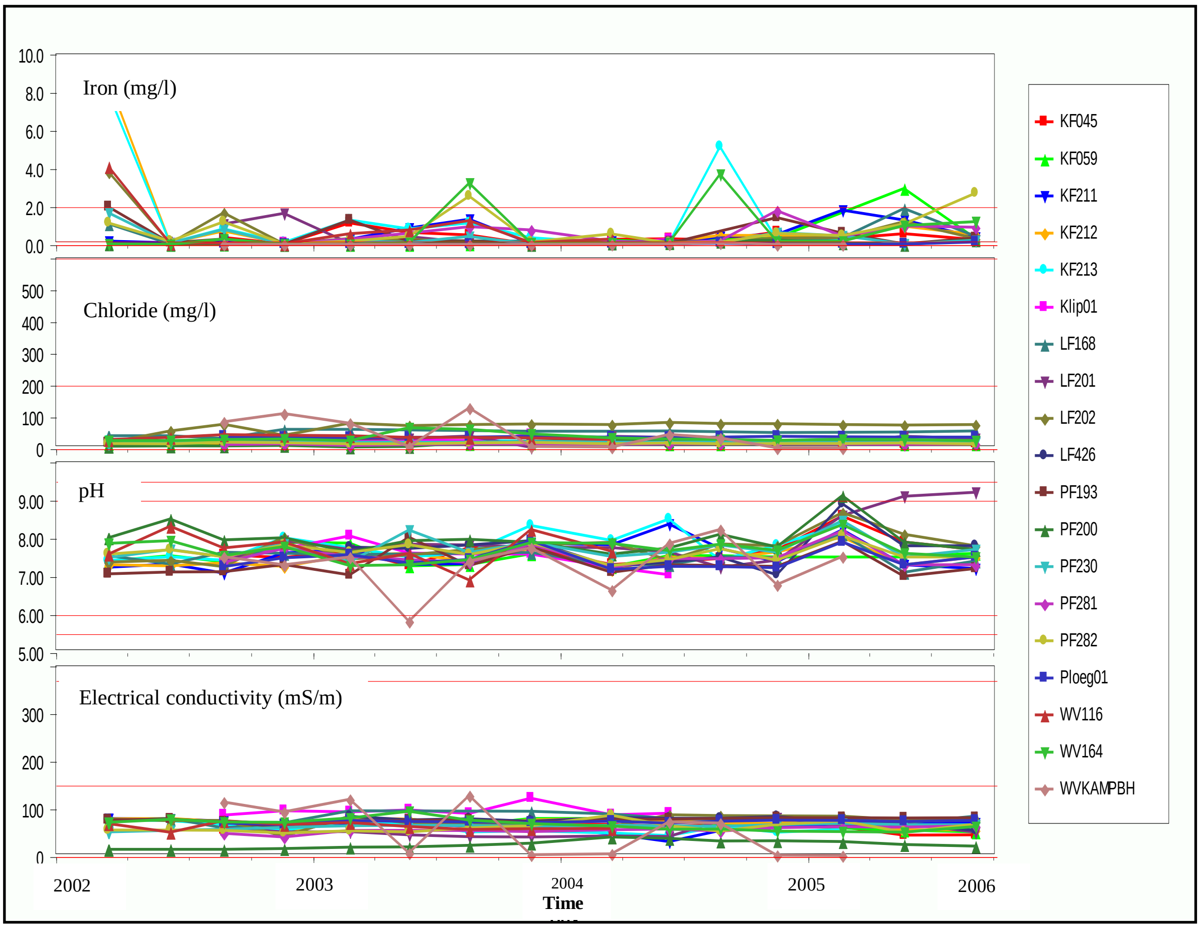
With the evaluation of potential sources and types of contamination, should the project evolved into a mining operation in the future, it was concluded that limited inorganic contamination would occur in a haematite iron ore mining environment due to the inertness of the host rocks.

The greatest risk for inorganic contamination was outlined to be from nitrate as contamination might manifest over time inside the pit areas due to the use of nitrate based explosives in large quantities.

A potential threat to organic / hydro carbon contamination exist with the use of fuels, lubricants and cleaning solvents by the mining equipment and in workshops should effective management and the necessary precaution measurements not be implemented and executed in an effective and responsible manner.

After the hydrocensus a monitoring programme over the project area was implemented whereby nineteen boreholes (Figure 20) were sampled and analysed quarterly for all major inorganic constituents.

For these boreholes the time series plot of the indicator chemical parameters, iron (Fe), chloride (Cl), pH and electrical conductivity (EC), displayed fairly consistent over the period stretching from 2002 until 2006 with only a couple of anomalies in the iron values. The time series plot is shown in Figure 25.



Source: Steenekamp (2005)

Figure 25: Time series plot of indicator parameters

At Kolomela Mine and in the regional area the geology has been subjected to intensive structural deformation in the form of thrusting, folding and faulting that led to a series of prominent NW-SE striking fracture zones. Karstification is also notable in the area and north south plunging anticlines, synclines and grabens have also been formed on account of the intense thrusting on the stratigraphy. High grade mineralisation occurs at a number of places where these structural deformations has taken place.

The hydrogeological regime in the area can be divided into two main aquifer systems namely an unconfined primary aquifer and a fractured secondary aquifer. The former occurs in the calcrete and can be classified as unconfined to semi-confined and covers most of the surface in the project area. The aquifer is shallow and in most cases occurs up to a depth of 30 m with yields seldom exceeding 2 L/s but can be as high as 10 L/s in areas. The aquifer is developed throughout the area and in most cases has been the sole reliable source of water supply to farms in the area for more than a century.

The secondary aquifer is associated with faults, fractures, fissures, joints and other discontinuities. The aquifer can be classified as semi confined and the yields of the boreholes vary considerable as they are directly associated with the presence of the geological structures. The aquifer occurs at depths exceeding 30 m to more than 300 m below surface with yields that can be as high as 83 L/s (300 m^3/h).

The chemical analyses indicated that the groundwater at Kolomela Mine and the regional areas can be described as fresh, recently recharged of good quality except for the high calcium (Ca) and magnesium (Mg) concentrations resulting into relative to extremely hard water. This phenomenon of high hardness and alkalinity levels are commonly found in calcrete and dolomitic areas.

Chapter 9

PRE-MINING GROUNDWATER MONITORING NETWORK AT THE PROJECT SITE (KOLOMELA MINE) AND REGIONAL AREA

9.1 INTRODUCTION

The development of groundwater monitoring programmes are usually done for two reasons, the one to obtain the necessary data/information needed to develop the water management and monitoring programmes for the mining operation to effective protect and manage the groundwater resources in the area they operate within and the other to comply with the environmental and water licence regulatory requirements.

When the decision was taken that the Sishen South project would be developed as a mining operation the hydrogeological data and monitoring programmes functional at that stage (as described above under point 8.2.2) were evaluated in terms of being adequate to serve as a baseline to compare pre-mining groundwater level and quality data to the future trends when mining would commence.

Taking the importance of groundwater in the Southern African context and especially in the Northern Cape in consideration it was evident that the hydrogeological data obtained by the 2002 hydrocensus and monitoring programmes up to that point were not sufficient in setting up a thorough baseline from where future impacts could be identified and managed properly. This was mainly due to the fact that the monitoring up to that point in time with the exception of only a couple of monitoring points was concentrated within the project area.

It was decided that a detailed hydrocensus had to be performed on the private properties adjacent the project area. The objective of this hydrocensus was not only to obtain water level data but all information regarding the boreholes and water infrastructure on the private properties. Following the hydrocensus would be the implementing of a monitoring network for both the regional and the project area.

9.2 HYDROCENSUS

The main objective of the hydrocensus was to obtain the necessary information that informed decisions could be taken on a proactive basis to manage and protect the groundwater resources in the area. The objective can be summarised as follow:

If you don’t measure and monitor you cannot manage.

The hydrocensus started in June 2008 and was completed in October that year. During this period 22 farms around the project area were visited and information of 176 boreholes, 14 wells and 2 fountains totalling 192 points were recorded, Figure 26.

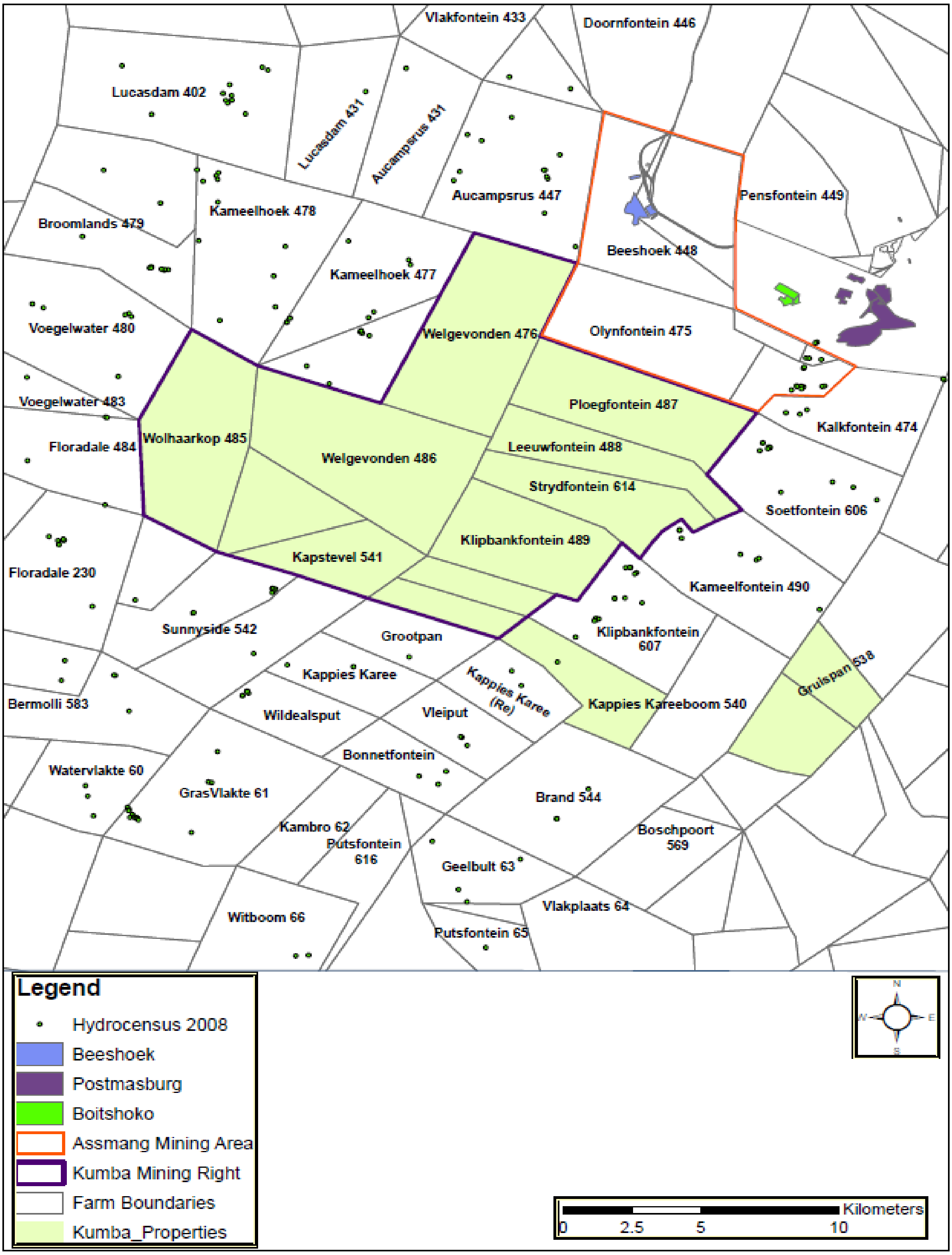


Figure 26: Farms covered during hydrocensus

The hydrocensus covered an area stretching over a distance of 35 kilometres in a north south and 30 kilometres in an east west direction respectively. The hydrocensus took a couple of months to be completed as this had to be scheduled in the “off times” during the drilling and pumping tests of the dewatering boreholes that was at that stage in full progress.

As previously mentioned the objective of the hydrocensus was not only to gather water levels but all information relating to the boreholes and water infrastructure on the farms.

Below a discussion on the information obtained during the hydrocensus and the actions resulted there from.

9.2.1 Desktop study

Before the hydrocensus commenced a desktop study was undertaken where all the geological and hydrogeological data and information of the regional and project site was evaluated and interpreted. Groundwater data was also obtained from the National Groundwater Database (NGDB) of the Department of Water Affairs and the mining company that operated next to the project site.

The data was used to create a conceptual model of the hydrological conditions of the regional area that provided a good idea what to expect during the hydrocensus. The conceptual model also gave guidance in demarcating the area that needed to be surveyed during the hydrocensus.

9.2.2 Land owners

Before the hydrocensus was launched the names and telephone numbers of most of the land owners were available as the exploration project was active for years in the area. Where a name and contact number was not available it was obtained from the neighbouring land owners. In this way all the land owners could be contacted and appointments be made for the hydrocensus on the various farms.

During the visits to the farms the contact details of the farms foreman, where applicable, were also obtained as some of the land owners don’t permanent resident on the farms and thus not always available that access can be arranged.

The contact details that were obtained include mobile and landline telephone numbers as well as email addresses. The latter being the preferable medium for the transferring of data between the two parties.

The contact details of the mining hydrogeologist were also given to the land owners to enable them to make contact should there be any questions or inquiries regarding the information gathered during the hydrocensus.

9.2.3 Borehole numbering

The numbering of boreholes is an aspect that needed some thought and planning. The following were taken into account before numbers were assigned to the boreholes:

- As noted under point 8.2.2 a hydrocensus was conducted on private properties adjacent the project site in 2002. Unfortunately none of the data (water levels) and the numbers assigned to these boreholes during the hydrocensus were registered in the project site's data base and were therefore not available for the "new" hydrocensus.
- No data of the boreholes on the farms could be traced from the mining company operating in the area besides those boreholes drilled by them since 2003. Of the boreholes drilled by them only a couple were located on the farms earmarked for the area that was to be covered by the hydrocensus. Due to the limited number of boreholes it was decided not to use the numbering format of those boreholes but rather to develop a new format.
- The NGDB was searched to determine whether there are boreholes on the farms that are part of the Department of Water Affairs regional monitoring network. A couple of boreholes were found and the Water Affairs number was noted next to the number allotted during the hydrocensus for reference. The Water Affairs borehole numbers (GO102NC to GO114NC as found in the hydrocensus area) does not reflect to specific farms thus the reason to "re-name" these boreholes according to the numbering protocol for those specific farms with the Water Affairs number noted as a sub number.
- The land owners were also consulted on the system they use. Usually the land owners use descriptive naming for the boreholes like "borehole behind house" and "borehole in game camp" and so forth. In cases where a numbering system was used by the land owner those numbers were recorded next to the numbers assigned to the boreholes during the hydrocensus.

On most of the farms descriptive naming were given to the boreholes by the land owners and thus new numbers had to be assigned during the hydrocensus. In some instances the first two or the first and middle characters of the farm name together with a numerical number was used, for example for the farms Aucampsrus and Soetfontein the naming used were AU01 and SF01.

The numbers were marked on the borehole casings (Figure 27) but unfortunately this was not always possible. In such instances the numbers were disclosed on either the windmill structure (Figure 28), the pipeline of the installed pump at the borehole, pump house, dam or any infrastructure associated with the specific borehole.

Unfortunately infrastructure like windmills and pipelines are sometimes moved to other boreholes, thus it is best to place the borehole number on a permanent structure at the borehole where possible.

The numbering was done with a paint pen in such a way that it's clearly visible and easily readable. The land owners were consulted beforehand on how the numbering will be done for example on what infrastructure, the size of the numbering and with what as it can lead to dissatisfaction if a borehole number is spray painted in large format on the side of a zinc dam.

A list with the boreholes as numbered during the hydrocensus on the various farms were provided to the land owners to ensure that both parties are on the same page regarding the borehole numbers for future monitoring and reference.

Figure 27: Borehole number on casing

Figure 28: Borehole number on windmill structure

9.2.4 General borehole information

All the boreholes on the farms were visited whether the boreholes were operational, dry, blocked or never been used. The status of all the boreholes was recorded. This is an important aspect as the status of some of the boreholes change over time from operational to not being in use and vice versa. The change in status usually reflects in the behaviour of the water levels of the boreholes and in such cases the water level behaviour can be explained with more certainty if the statuses were recorded during the hydrocensus.

Effort was made to obtain as much information as possible on the boreholes during the hydrocensus. Where possible the following information was collected:

- **Year when the borehole was drilled.** This information was not commonly available but some of the land owners were able to provide the dates when the boreholes were drilled. In some instances the drilling dates were engraved in the cement block situated around the borehole. The drilling date is of importance, especially in cases where the yield and water level of the borehole at the time of drilling was noted as this provided a good reference of what happened over time.

- **Depth of borehole.** In most cases the boreholes of which the drilled dates were known the land owners could provide the drilled depths as well. Attempts were made not only to measure the depths of these boreholes but of all the boreholes.

  From the data it could be seen whether the boreholes with the known original depths has collapsed over the years as this phenomenon in many situations can contribute to the declining in yield of the boreholes over time as the drilling of farm boreholes are usually stopped within a couple of meters after a water strike and when collapsing occur the water strike area can be neutralised in a great way.

  For the depth measurement a weight was taped to the probe of the water level meter and lowered down the hole. The batteries were also taken out to prevent the instrument from making noises all the time while the probe was lowered down into the water column of the boreholes. The reading from the water level measurement tape was taken at the point where the tape indicates signs of getting slack.

  This method is not hundred percent accurate but gave a good indication of the borehole depth. For the hydrocensus survey this was sufficient but should greater accuracy be needed or when it is not possible to gain access to the borehole with the above method as the borehole is equipped and it is critical to get the borehole depth then it will be necessary to lower pipes down to the bottom of the borehole in order to measure the borehole depth. This will require the use of a tripod or mechanical equipment, the latter is normally use for the installation of equipment for the pump testing of a borehole.

- **Depth of the water strikes.** This information is usually not available but some land owners do keep documentation of the boreholes while being drilled. The water strike information of those boreholes were recorded.

- **Borehole equipment.** If a borehole was equipped notes were made on the type of installation whether it's a windmill, mono or submersible pump. The size (kilo watt) of the mono and submersible pumps were also recorded. Notes were also made whether an up or down grading of borehole equipment had been made over the years and if so the reasons therefore. The depth at which the equipment is installed was also noted.

- **Borehole use.** The use of the boreholes, for example is the boreholes use for human consumption, stock watering, irrigation or a combination thereof was documented.

- **Boreholes yields.** In most cases the land owner was able to give an idea of the yield of the boreholes on the farm either derived from the yields delivered by the installed equipment or from the observations made by the drilling contractor during the drilling of the boreholes. Although this is not an accurate reflection of the borehole yields it does provide acceptable figures for the purpose of the hydrocensus survey.

  Usually in areas where irrigation is done land owners have some sort of documentation on the yields of the borehole as the boreholes are usually being tested before being equipped. This was however not the situation in the hydrocensus area and the yield of the boreholes could only be related to the capacity of the pumps they were equipped with.

  The yield of some of the Department of Water Affair's monitoring boreholes could be obtained from the Department's NGDB.

All the information was recorded on a field report form; an example of the form is shown in Appendix A.

9.2.5 Geological information

As is normally the case, with geological information, the land owners did not have profiles of any of the boreholes but in some instances they could provide an idea of the geology encountered during the drilling. In such cases a note was made that the observations were obtained from the land owner and as such will most probably not be hundred percent correct.

Unfortunately the geological profiles of the monitoring boreholes drilled by the other mining company in the area could not be obtained. There was also no geological information for the monitoring boreholes listed on the Department's NGDB.

9.2.6 Borehole co-ordinates

The co-ordinates of all the boreholes in production together with the ones that were dry, blocked or not in use were taken. Although the Z co-ordinate or elevation of hand held global positioning systems (GPS's) are usually inaccurate for a couple of meters the Z co-ordinate was measured as it can still provide a fairly good glimpse of the water situation of an area when presented as water levels above mean sea level.

The co-ordinates were taken in WGS84 format as this is the most widely used system. It's recommended that before any fieldwork is done a decision must be taken regarding what co-ordinate system is to be used not only for the hydrocensus at that time but also for future surveys as it can get a bit confusing if co-ordinates are taken in different formats and conversions had to be performed every time.

9.2.7 Water levels

In total 140 water levels could be taken at the 192 points visited during the hydrocensus. The points were water levels could not be taken were at boreholes that were either equipped or dry while at a couple of boreholes access for the measuring of the water levels was obstructed by tree roots.

Water levels at some of the boreholes that were equipped could be taken by moving the base plates with a crow bar to create just enough space for the water level meter probe to be lowered down the borehole.

At some of the boreholes, where the base plates could not be moved and where practical possible, holes for the water level meter probe were drilled throw the base plates to gain access for the measuring of the water levels. Figure 29a show the drilled hole in a borehole's base plate and Figure 29b the measuring of the water level through the drilled hole.

Figure 29a: Hole drilled in base plate

Figure 29b: Measuring of water level

For the drilling of the base plate holes a generator and a high Watt (industrial) drill were used with tungsten drill bits of different sizes. At first an 8 mm hole was drilled that was then enlarged to a 12 mm and 18 mm hole respectively as the water level meter's probes are normally 16 mm in diameter.

As a standard the water level meter readings were taken at the top of the borehole casings and the length of the casings above ground level were also measured in order that the correct water level readings could be calculated.

At the wells the position where the readings were taken was noted to ensure that in future the measurements would be taken at the same position. If this procedure is not followed the water levels can easily each time be taken at a different position as the circumference of the wells is a couple of meters. This can lead to inaccurate readings as differences of over 30 cm in height around the circumference at some of the wells were encountered.

Notes were also made when the water levels of the equipped boreholes were taken to indicate whether the borehole was pumping at that time or not. In this way variances in water levels taken at different times can be explained. At the boreholes where the pumps weren't active the time the pumps were switched off before the readings were taken was also noted.

For boreholes equipped with windmills it was noted whether the wind was blowing when the reading was taken and also an indication on the strength of the wind at the time, for example being moderate, strong or very strong. The wind factor can have a huge influence on the water levels especially in the case of the low yielding boreholes.

During the desktop study the water level data for a couple of monitoring boreholes could be obtained from the NGDB of the Department.

Historic water levels from only a few boreholes could be obtained from the land owners as the monitoring of water levels at that stage were not seen as a priority in the management of their farming activities. A list of the boreholes and their water levels as documented on each farm was submitted to the respective land owners and they were asked to participate in future monitoring.

Most of the water levels (52 percent of the 140 measurements taken) varied between 10 and 30 meters below ground level. The water levels less than 10 and over 30 meters accounted for 34 and 14 percent respectively out of the total number of measurements taken. The shallowest and deepest water levels were 3.62 and 77.50 meters respectively. The water level of the fountains and an artesian borehole were measured at surface.

When the data was interpreted it was found that the hydrocensus area was covered sufficiently in terms of the number of water levels that were measured as well as the spatial distribution of the boreholes over the area.

Due to the finding no boreholes were drilled in the regional area at that stage. After complaints were received from land owners about the lowering of water levels and the drying up of some of their boreholes, monitoring boreholes were drilled in those specific areas as recommended during the investigations of the complaints. Additional monitoring boreholes were also drilled on the mine property at a later stage to supplement the monitoring network as mentioned under point 7.8.6.

Unfortunately as none of the 2002 hydrocensus data (as mentioned under point 8.2.2) was captured into the database, a comparison between the water levels of the two surveys could not be made.

9.2.8 Rainfall data

Rainfall plays a major role in the recharge mechanism of the groundwater and provides insight in interpreting the water level behaviour especially over time. The web page of the Weather Bureau was searched and data for only a limited number of rainfall stations in the near vicinity of the hydrocensus area were found.

The land owners were asked for rainfall data but except for one farm the data was mostly periodic and not stretching far back in time. The land owners were asked to continue recording rainfall together with the water level monitoring.

9.2.9 Water chemistry

Emphasis was placed on the chemistry monitoring during the hydrocensus to ensure that a sound base line would be established that would be sufficient to be used for future reference as the mine activities developed in the area.

Of the 192 points visited (Figure 26) a total of 110 samples were taken, 11 at wells and the rest (99) at boreholes. In situations where a number of boreholes were spaced closely to each other (within a couple of meters) only the operational boreholes were sampled and analysed.

The water samples at open boreholes and wells were obtained by bailing (Figures 30a&b) while samples at the equipped boreholes were collected either at taps at the boreholes or at dams where the water was pumped to, Figures 31 and 32.

Figure 30a&b: Bailing of water sample at open borehole

Figure 31: Sampling at equipped borehole

Figure 32: Sampling at dam

All the samples were analysed for major inorganic constituents and the results were evaluated against the Department of Water Affair's water quality guideline for domestic and irrigation use and livestock watering.

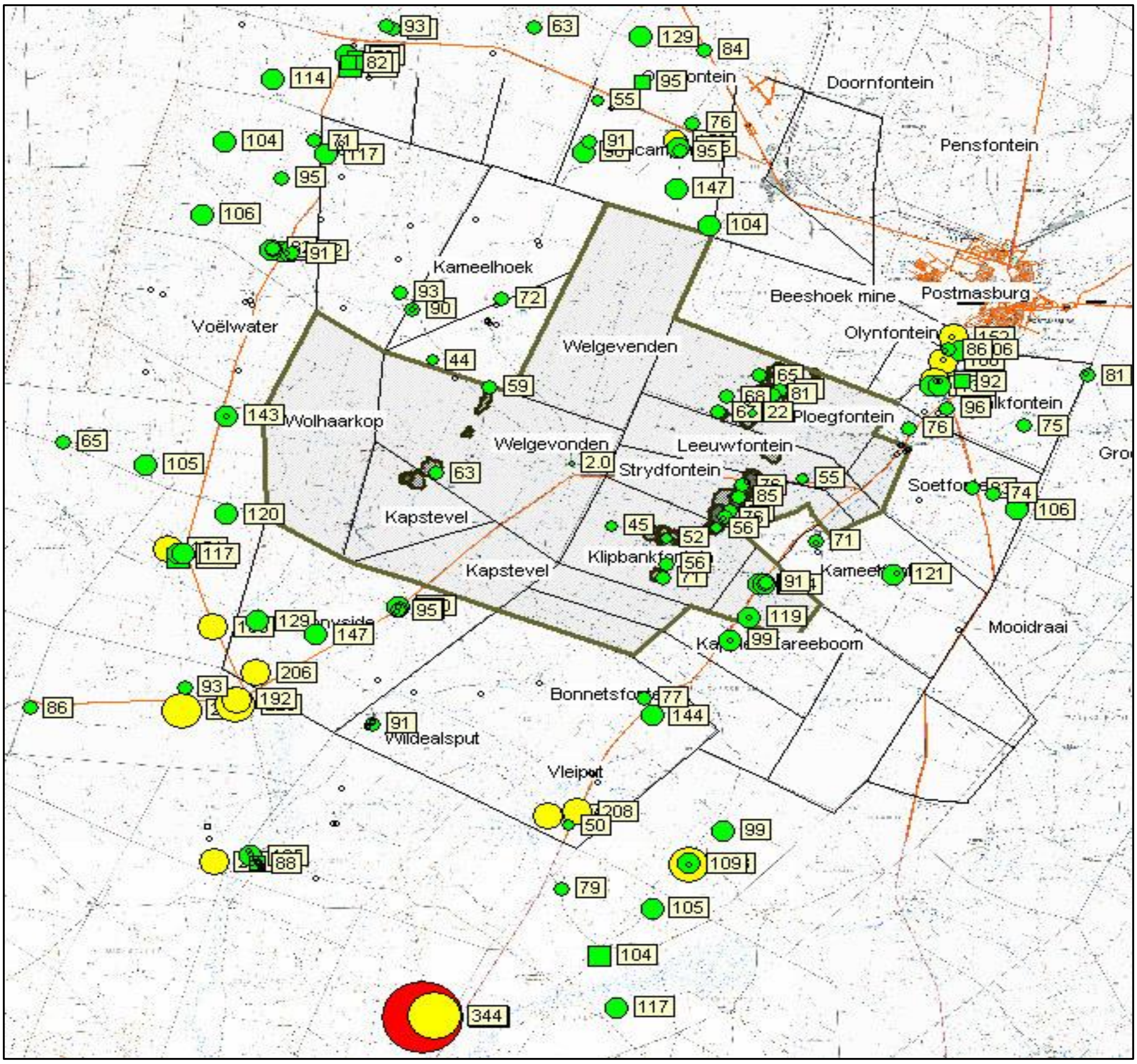
On the maps below the concentration values of the specific constituents are indicated for every borehole sampled during the hydrocensus. The colouring of the monitoring points are indicative of compliance to the SANS 241 drinking water guideline where green refer to compliance (good water quality), yellow to non-compliance (marginal water quality) and red also non-compliant but the water is of poor quality.

The analyses of the following chemical parameters indicated anomalies during the hydrocensus. For comparison the results of the monitoring points on the project site were also included.

9.2.9.1 Salinity

Electrical Conductivity (EC) is the measurement of ease which water conducts electricity. It can also be expressed as the sum of the dissolved salts (Ca, Mg, K, Na, Cl and SO_4) in water. High concentrations that exceeded the water guideline standard were recorded on a number of farms east and specifically south of the project site, Figure 33.

From Figure 33 it can be seen that the salinity tends to increase towards the southern parts of the hydrocensus area as very saline water conditions were recorded on some of the farms in that area.



Source: Clean Stream Scientific Services (2008)

Figure 33: Spatial variation of EC concentration across the hydrocensus area

The higher salinity in the southern part of the hydrocensus area can mainly be ascribed to the influence of the recharge to the groundwater system and the aquifer flow dynamics in that region.

Recharge: Although the average rainfall is in the order of 300 mm per annum over the regional area the effective recharge percentage is higher in the dolomitic areas covering mostly the northern hydrocensus area.

In overall the groundwater in this area is of good quality with salinities lower than that found in the southern area where a lower recharge percentage is experienced as the hydrocensus localities in this area are located on the less permeable shale, quartzite and lava formations comparing to the more permeable dolomites towards the north.

The chemical analyses of the 2002 hydrocensus also confirm this theory. The hydrocensus was not carried out on the farms south of the project area (as stated under point 8.2.2) but on farms east, west and north of the project area as can be seen in Figure 19. In total 83 percent of the 35 samples plotted in field 2 of the Expanded Durov Diagram (Figure 24) indicating that it was fresh clean groundwater that is relative young and has started to undergo calcium (Ca) and magnesium (Mg) ion exchange that is usually found in dolomitic areas where good groundwater recharge is experienced.

The electrical conductivity (EC) and chloride (Cl) analyses (Figure 25) of the monitoring points on the project site (Figure 20) that were done from 2002 until 2006 are all within the water standard guidelines and correlate with the electrical conductivity (EC) analyses results of the 2008 hydrocensus. This further strengthens the theory that the percentage of recharge is higher in the northern area comparing to the southern area.

Aquifer flow dynamics: The aquifer flow dynamics sometimes cause the development of marginal to poor quality groundwater. This will usually happen when the fractures are poorly connected or not interconnected at all with each other. This can result in stagnant conditions that will lead to the groundwater become saline over time.

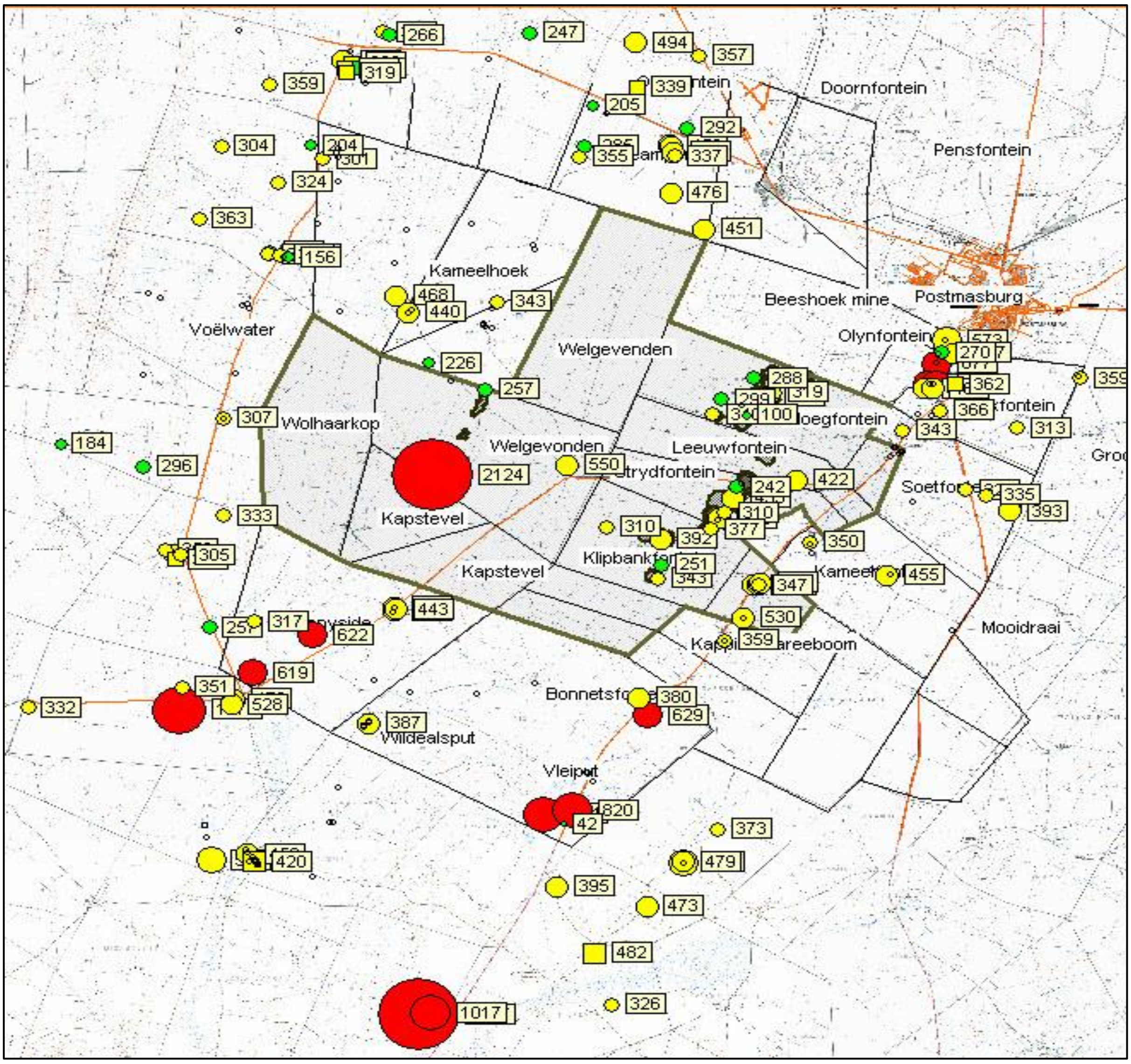
The consuming of water with a high salinity on a continuous basis might lead to the following health effects:

- Disturbance in the salt balance of infants
- Adverse effects on individuals with heart diseases and high blood pressure
- Individuals with rental and kidney diseases might also be exposed to adverse effects

9.2.9.2 Total Hardness

As can be seen on Figure 34 most of the monitoring points were non-compliant to the drinking water standard. This was however not surprising as high hardness concentrations are commonly found in the Northern Cape region due to the presence of soluble calcium (Ca) and magnesium (Mg) in the groundwater.

Water with extreme hardness in excess of >600 mg/l were recorded on numerous farms at the southern part of the hydrocensus area with a borehole also located on a farm within the project site. Use of this water should be avoided by individuals experiencing problems with kidney and gallbladder stones and by infants under the age of 1 year. Excessive hardness of water also leads to the scaling of pipes and hot water appliances



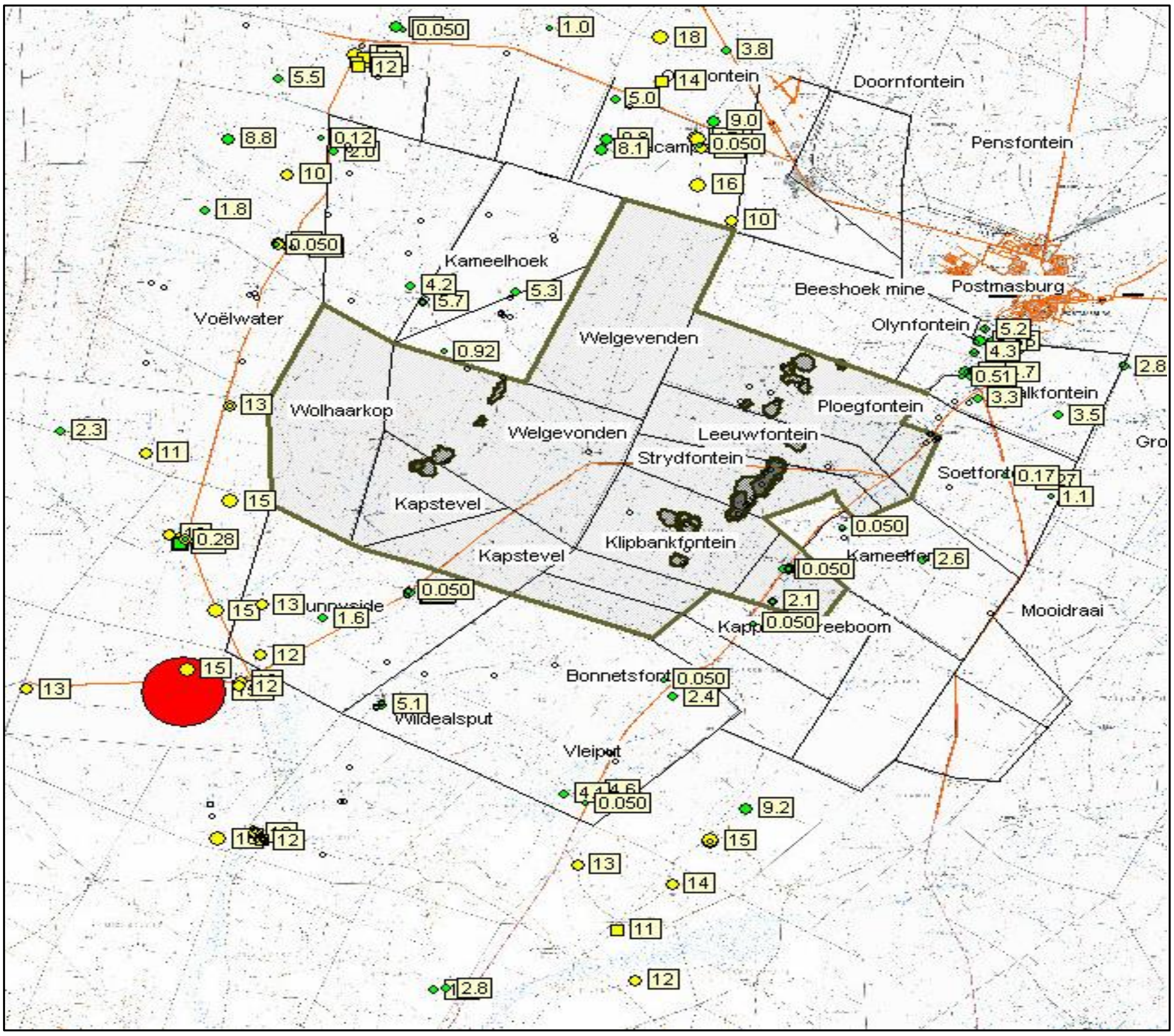
Source: Clean Stream Scientific Services (2008)

Figure 34: Spatial variation of total hardness across the hydrocensus area

9.2.9.3 Nitrate

In fresh unpolluted water the nitrate (NO_3) concentration is often below 2 mg/l. Nitrate (NO_3) concentrations are produced by the decay of plant, animal and human waste and is often found where intensive land use activities take place. In the latter situation concentrations exceeding 20 mg/l is not unusual.

As can be seen in Figure 35 more than half of the monitoring points were compliant to the drinking water standard. Dangerous nitrate (NO_3) concentration was recorded at a borehole on the south western side of the hydrocensus area. The nitrate (NO_3) concentrations of the other monitoring points that exceeded the drinking water standard (indicated by the yellow points) were less than 20 mg/l and can be described as marginal water quality.



Source: Clean Stream Scientific Services (2008)

Figure 35: Spatial variation of NO_3 concentration across the hydrocensus area

Health effects associated with high nitrate NO_3 (>20 mg/l) concentrations are impaired concentration, lack of energy and the forming of methaemoglobin in blood cells. Individuals at risk are specifically infants under the age of 1 year as the methaemoglobin in blood cells can lead to the death of youngsters. This condition is commonly being referred to as the blue baby syndrome

From the hydrocensus analyses the water quality can be summarised as follow:

- High salinity concentrations were recorded on farms south and north east of the project area.
- Very saline water quality (EC) together with high chloride (Cl) and sulphate (SO_4) conditions were recorded on a farm south of the project area.
- The salinity increased towards the southern part of the hydrocensus area.
- Most of the monitoring points were non–compliant to the drinking water standard for Total Hardness. Extreme hardness in excess of >600 mg/l were recorded on one farm part of the project area and at a couple of farms south of the project area.
- Dangerous nitrate (NO_3) concentration was recorded at a borehole on the south western side of the hydrocensus area. The land owner was informed not to use the water even for livestock watering. All the other monitoring points had nitrate (NO_3) concentrations less than 20 mg/l.

Overall the results showed that the water quality at the project site except for the hardness at the one monitoring point were on average better than that on the adjacent farms. The results indicated that there was no pollution present on the project site and as a result a good baseline dataset was obtained during the hydrocensus.

9.2.10 Database

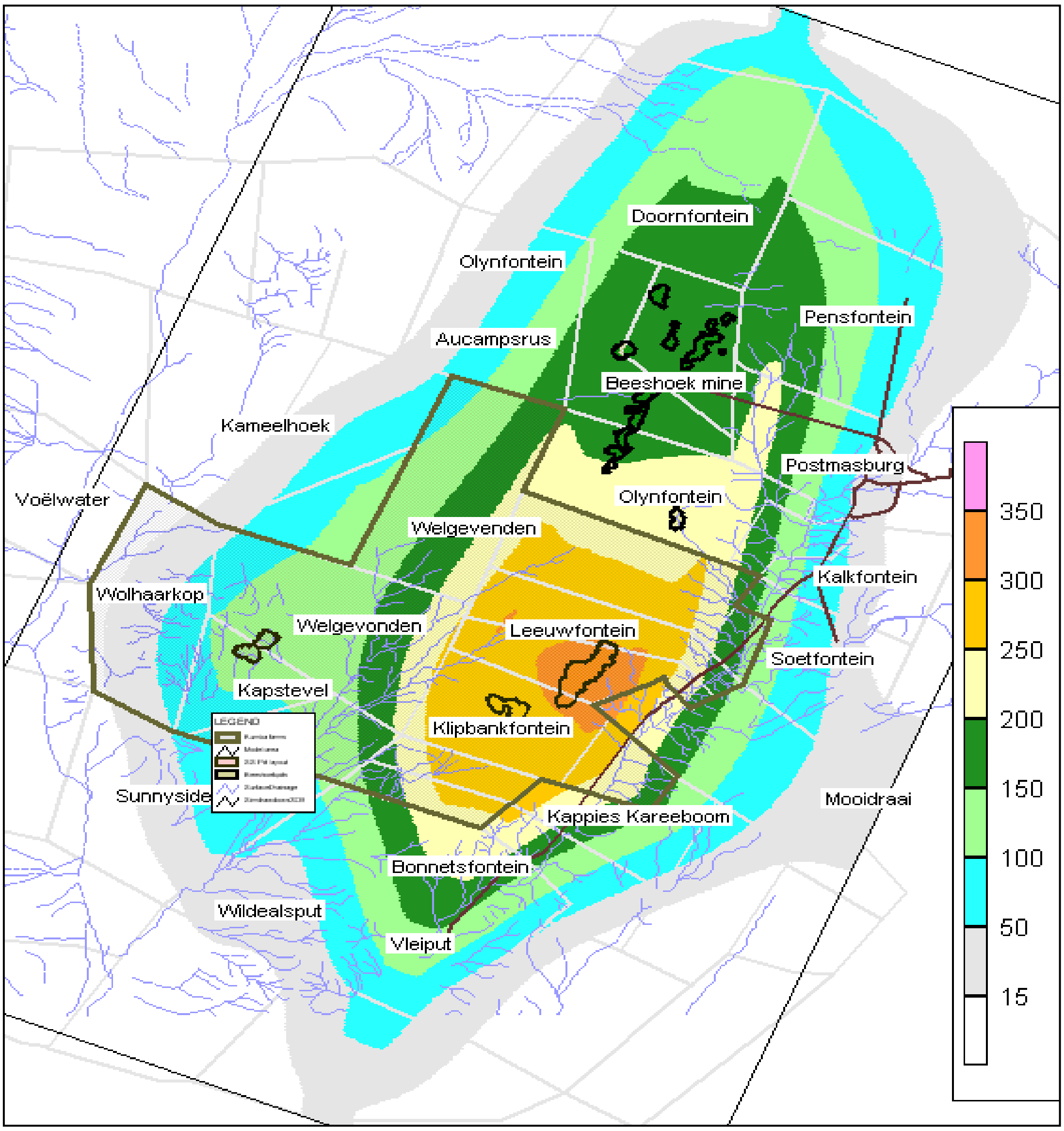
As mentioned the hydrocensus was performed over the period stretching from June to October 2008. Care was taken to capture the data into the database after completion of each day's fieldwork. By doing this the data could be captured in its full extent and in the right context. The data was incorporated into the database of the project site that's been in use since 1999.

It is of the utmost importance that data must be captured and stored as a lot of time and money is spent during a hydrocensus for the collecting thereof. It is also important to ensure that the data is stored in a secure environment within the company's database network. In this way the data can be retrieved at any time and the files can't get corrupted or lost as this can easily happen when the data is only being stored on a computer's local drive.

9.2.11 Numerical Modelling

On completion of the hydrocensus the water level, water quality and rainfall data were incorporated into the existing numerical model that was constructed in 2005 as discussed under point 8.2.3.

With the new data available the model was once again calibrated and simulations were done to determine the dewatering volume needed to ensure that the pit areas will be kept dry for the mining activities to proceed in a safe manner. Simulations were also done to get an idea of the area expected to be impacted upon with the combined dewatering activities of the neighbouring mine and the Sishen South project, Figure 36.



Source: Steenekamp (2005)

Figure 36: Maximum expected zone of impact

Comparing the 2005 and 2009 model simulations (Figures 22 and 36 respectively) one can clearly see the zone of impact extended in a north south direction. More prominently however is the expansion of the impact zone towards the eastern side while little to minor expansion of the impacted zone is perceptible in the western and north western areas respectively.

The change in depth of the pit layouts were the main reason for the extension of the impacted zone as determined by the 2009 model simulations.

9.2.12 Monitoring network

On completion of the hydrocensus the water levels and water quality were evaluated as discussed under points 9.2.7 and 9.2.9. Based on the outcome of the analyses a network was designed for future monitoring that comprised the water level monitoring of 35 boreholes and 2 fountains on a quarterly base.

As noted (under point 9.2.7) it was found that the hydrocensus area was covered sufficiently in terms of the number of water levels that were measured as well as the spatial distribution of the boreholes over the area thus no monitoring boreholes was drilled at that stage.

The selected monitoring points were distributed over the entire hydrocensus area (Figure 37) but on the north western and especially the north eastern side of the project area more boreholes were selected as irrigation activities were practised in those areas.

In addition to the quarterly monitoring it was decided that the hydrocensus would be repeated yearly to capture the water levels of all the boreholes (Figure 26) that were covered during the 2008 survey.

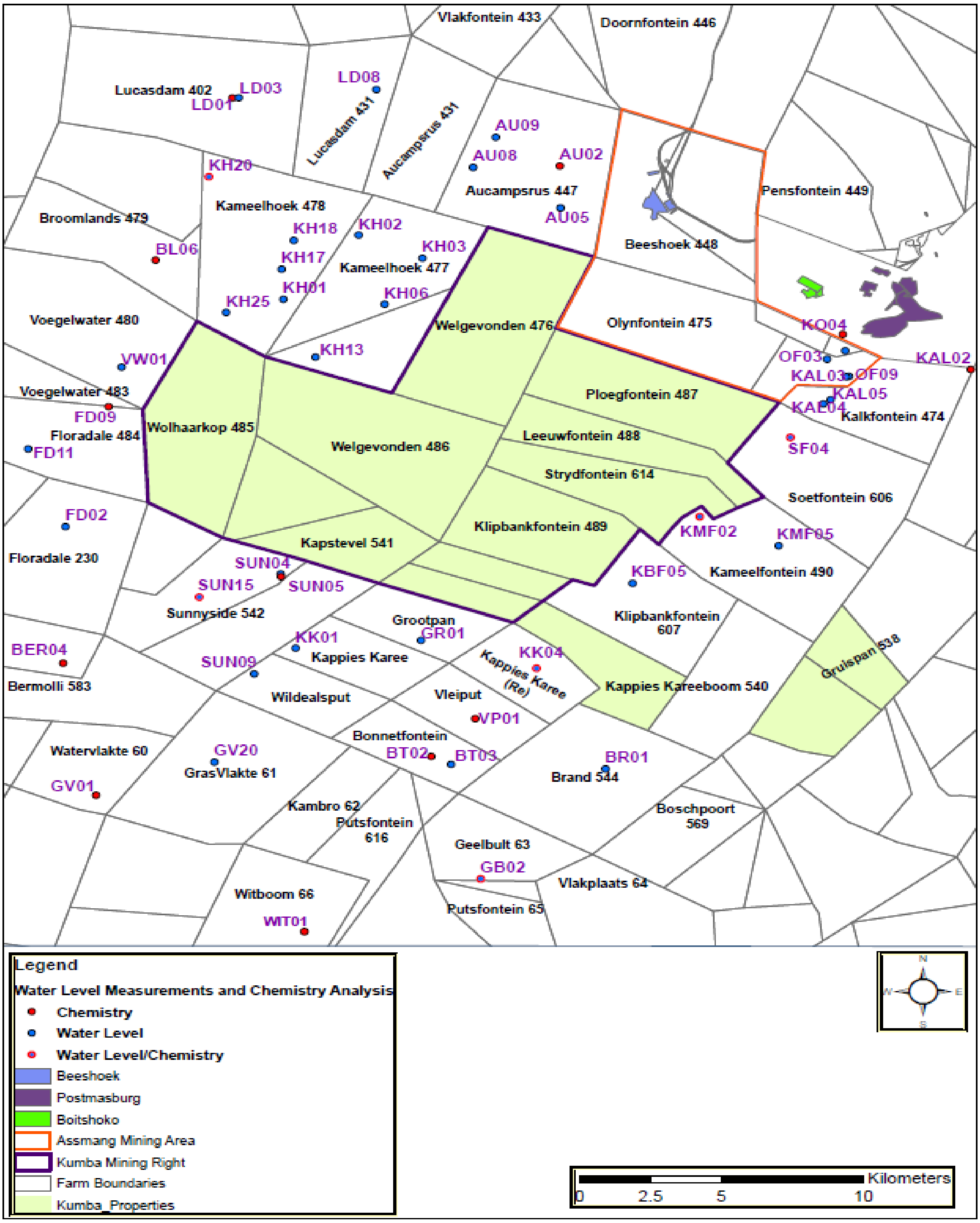


Figure 37: Position of groundwater level / quality monitoring points for regional area

When the dewatering started it was decided to drill three sets of boreholes in triangular form on the northern, eastern and southern boundaries of the mine properties (Figure 38). The main reason for these monitoring boreholes was to determine the direction of the groundwater flow and hydraulic gradient as it would then be possible to determine when the cone of depression caused by the dewatering extends beyond the mine properties onto private land.

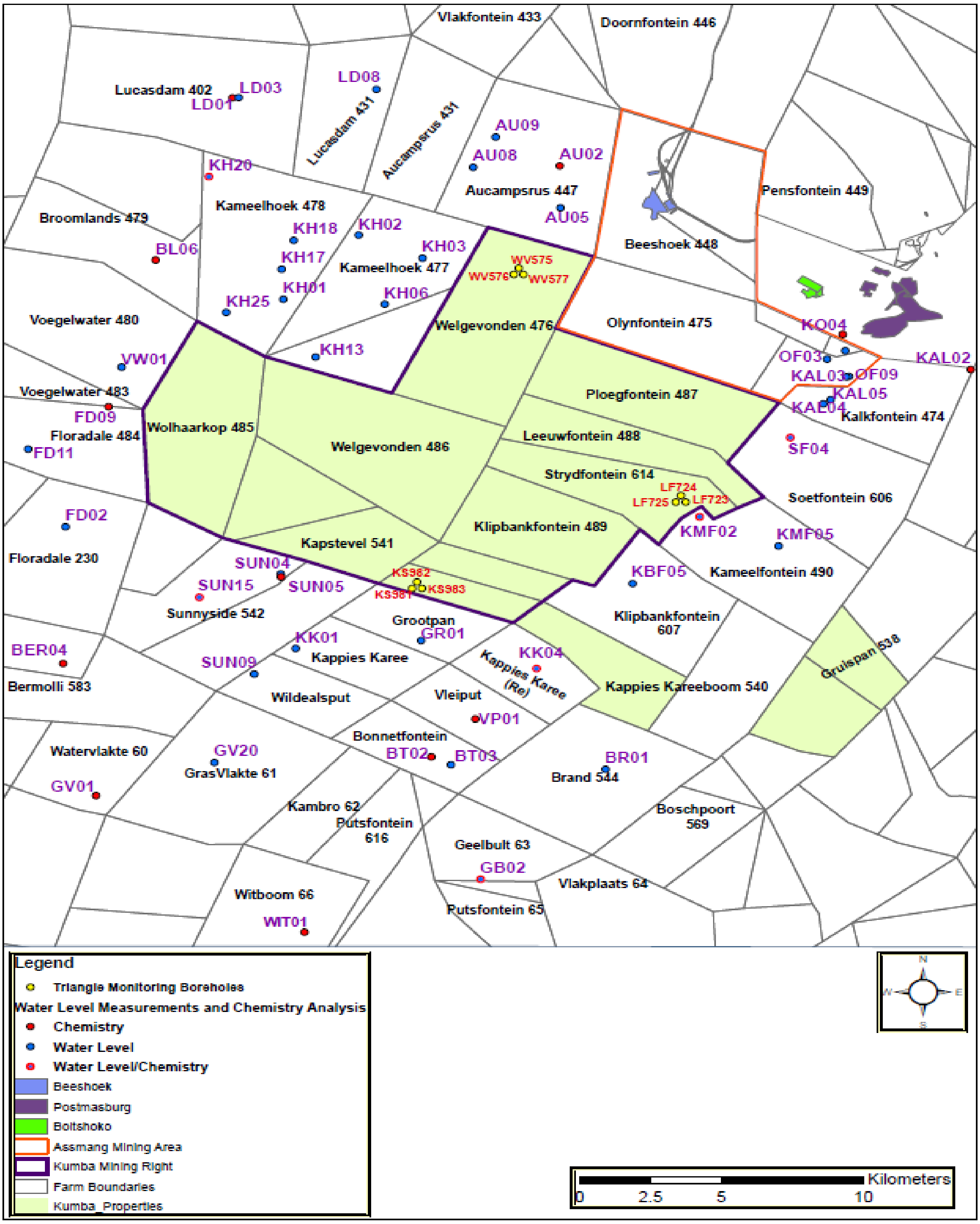


Figure 38: Position of triangular monitoring boreholes drilled on mine property

For the chemical monitoring fifteen (15) boreholes were selected for sampling at the following year's hydrocensus survey. The boreholes were selected in such a way that the entire hydrocensus area was covered but it also included the boreholes with the anomaly values.

From Figure 37 it can be seen that about two thirds of the chemistry monitoring boreholes are situated in the area south of the project area due to the poor water quality measured in this area comparing to the northern side as discussed under the water chemistry at point 9.2.9.

At this point in time quarterly monitoring was not scheduled for the regional boreholes as the degrading of the regional water quality due to the activities on the project site seems highly unlikely as the analyses indicate that no pollution occurs on the project site and in overall the water quality was better than that of the regional area.

The quarterly monitoring on the project site still continued and was seen as adequate to indicate any signs should pollution occur in which case adjustments could then be made to the monitoring interval on the adjacent farms.

The setup and development of a monitoring network is not a once off occasion but an iterative process that must be evaluated on a continue basis. After each hydrocensus the water level and chemical results were analysed and the monitoring network was adjusted when the following situations manifest:

- When a decline or rise of more than 3 meters in the water levels comparing to the previous readings were observed the specific boreholes were moved from the yearly hydrocensus to the quarterly monitoring. Most of the boreholes (about 90 percent) that were moved to the quarterly monitoring are open boreholes as a variance of 3 meter in water level for an equipped borehole is not that uncommon between readings.

- When new boreholes were drilled by either Kumba or the land owners on the farms they were added to the list of boreholes for the next year's hydrocensus and subject to the collecting of all information as discussed under point 9.2.

- If the chemical analysis of a borehole deviated in a great way of the previous results, for example a number of parameters don't comply with the drinking standards as was the case with the previous analyses the borehole would be subject to quarterly sampling instead of the yearly hydrocensus analysis.

The water quality monitoring programme that was set up comprised only the testing of the inorganic parameters. Local conditions must be kept in mind in this regard as it plays an important role in the selection of the type of analysis as well as the monitoring interval.

For example at coal and base metal mining operations the impacts on groundwater quality will be caused by chemical reactions such as ion exchanges, mobilization and precipitation of ions or groups of ions.

Sulphate (SO_4) related chemical reaction is one of the most important reactions in this regard and is a fair representation of pollution in coal mines. The SO_4 related reactions take place when it enters the groundwater through oxidation of pyrite through chemical weathering, mining and washing activities and percolation through stockpiles. An example of a reaction is:

$2FeS_2$	+ $7O_2$	=	$2FeSO_4$	+ $2H_2SO_4$
Pyrite	+ oxygen	=	iron sulphate	+ sulphuric acid

The reaction doesn't apply to iron ore mining as pyrite and sulphides do not occur in significant amounts and the dolomitic and calcrete aquifer host rocks cause the groundwater pH to be rather alkaline than acidic. Analyses at the nearby Sishen Mine indicated that very limited contamination occurs in the haematite iron ore mining environment. The iron ore and host rock are chemically inert preventing the acid mine drainage and related contamination found in the coal and base metal mining industry.

As explained above the site specifics of an area and the commodity to be mined will determine the pollution that will result during the mining operation. It is thus of the utmost importance that these factors are taken in consideration right from the start of implementing the chemical monitoring to ensure that the parameters that need to be monitored are included in the monitoring programme from the start to ensure that the correct base line data is in place before the mining activities commenced.

After the 2008 hydrocensus the quarterly water level and quality monitoring programme on the project site continued as since 2002 (Figure 20), with the only exception that a couple of boreholes on the western side of the project area were added to the monitoring programme.

In 2010 the monitoring network was totally transformed to include all aspects of the mining operations as described under point 7.8, "Monitoring of the water resources".

9.2.13 Frequency of monitoring

The cost of monitoring is related to the number of monitoring points and the frequency of the monitoring programme. It is important that the aspect of cost and the amount of information the hydrogeologist can gain from the monitoring programme be optimised.

Factors such as distance and accessibility to the monitoring points were also taken in consideration when the decision was made on the monitoring frequencies of the water level and chemical monitoring.

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Another aspect that was taken into consideration was the concept of data versus information as one might add data to a database but not necessarily information and thus knowledge about the hydrological system. The cost of the monitoring must be commensurate with the value obtained from the monitoring programme. The water level and sampling frequency of boreholes in the regional area must thus be less intense than the monitoring interval of the boreholes next to the intended mining area were impacts from the dewatering and pollution from the mining activities might originate.

9.3 ADDITIONAL MEASURES

In addition to the general borehole information, water levels, rainfall data and water quality analyses that were obtained during the hydrocensus it was deemed important to pump test the boreholes that were used for irrigation in the hydrocensus area.

Not only would the pump testing provide information on the sustainable yields of the boreholes that would be of great assistance in future should these boreholes be impacted upon, but it also provide characteristics of the regional aquifer (transmissivity (T) and storativity (S) values) that is essential in refining and calibrating the numerical model.

The Environmental Forum specifically focussed in setting up communication channels between the project team and the Interested and (potential) Affected Parties (I&AP) to establish good relations between the parties before the construction and mining activities commenced.

Although not all of the measures discussed below are a requirement it does add value and assist in getting the bigger hydrological picture of an area and at the same time set a good platform for interaction between the land owners and the project team.

9.3.1 Environmental Forum

With the start of the hydrocensus in June 2008 it was realised that there was a need for communication with the land owners to inform them on the processes that were soon to follow after the mining rights and water licences were awarded in May and June 2008 respectively.

As groundwater is the corner stone of the farming activities in this semi-arid area it was highlighted by the land owners as their main concern of being impacted upon when the mining activities would commence.

On request of the company's hydrogeology team the Environmental Forum meeting was established by the environmental consultants that assisted the project team in securing the mining, environmental and water licences. The consultants also chaired the meetings which proved to be very effective as they were on par with all the activities on the project site, the environmental laws and the application processes for obtaining the various licenses.

At the meetings the consultants have the responsibility to create an environment where everyone would feel at ease to participate in the discussions and raise their concerns. They should also call the meeting to order should the discussions get heated and make sure that the discussions stay focussed on the aspects of concern.

The fact that the meetings were not chaired by the project team and held at one of the land owners farm created a relax atmosphere where the I&AP didn't felt being intimidated and manipulated by the project team as that can easily happened if not correctly administered.

The success of such a forum lies in creating an atmosphere where anyone feel at ease to raise their thoughts and concerns and know that it will get the necessary consideration and attention.

The first meeting took placed at the end of July 2008 and was held every two months until the end of 2010 where after the scheduling was change to quarterly. The meetings were focussed on the engagement with the land owners but were an open forum that was also attended by some residents of the town of Postmasburg, the local Municipality and also the neighbouring mining company. The Department of Water Affairs was also invited to attend the meetings.

The water aspects were the main discussion point at the meetings but other aspects such as the construction of the mine facilities, the housing developments in town and the upgrading of infrastructure in the municipal area were also discussed and feedback regarding the progress on these aspects was given on a regular basis.

At the Forum meetings the hydrocensus results and quarterly monitoring were communicated and discussed. The hydrocensus reports were also distributed to the I&AP via email and also made available at the meetings in compact disc (CD) format.

As the monitoring and administrating of the water resources of the area and a good relation with the land owners was seen in a serious light the suggestion was tabled at one of the meetings that the land owners can nominate a hydrologist to represent them; the mine will then appoint and pay for the services delivered on his behalf to the agricultural community. The land owners accepted the proposal and nominated a hydrogeologist to represent them in the future.

A procedure for the handling of water related complains was also developed and agreed on at the Environmental Forum meeting. The procedure was as follow:

- Complaints to be received in writing where after it will be captured on the project site's complaints register and a number be allocated to the complaint. The I&AP were encouraged to fill in the complaint form at the project's office in town.
- At the meetings the contact details of the person at the project's office was also given should a person want to call or send an email. Complaints could also be submitted at the forum meetings. After the construction phase the mine's Public Affair Department took over the responsibility in handling the complaints procedure.
- After receiving of the complaint an independent hydrogeologist (appointed by the company) would visit the farm to investigate and capture all information at the site and from the land owner.
- The complaint would then be evaluated based on all available information obtained from the land owner, the field visit, the Department's NGDB and info from the various hydrocensuses and monitoring programmes.
- The independent hydrogeologist would then draft a technical report indicating whether an impact is identified. If an impact is identified the following must be noted:
    - Loss of water from the boreholes must be estimated in terms of the boreholes usages as noted during the hydrocensus of 2008.
    - Recommendations regarding assistance to be made.
- The report is then to be reviewed and approved by the company's hydrogeologist and the hydrogeological representative of the agricultural community.
- If all the parties are in agreement the report is finalised by the independent hydrogeologist and submitted to the land owner.
- Discussion is then held with the land owner regarding the outcome of the investigation and the assistance to be implemented should the farm found to be impacted upon.
- If agreement is not reached between the parties on the outcome of the report an action plan is to be compiled to obtain the necessary information in order that consensus can be reached. It was agreed that during this time the mine will give assistance until the investigation was completed and an answer could be provided whether there is an impact or not.

The value of the Environmental Forum meetings cannot be emphasised enough. Using this platform to communicate and provide feedback to the I&AP on the aspects relevant to the area will secure a good relationship between the parties although differences of opinion on certain aspects will always be a reality.

The company's personnel attending the meetings must always be well prepared to ensure that feedback and presentations are done in a clear and intelligible manner. This reflects heavily on the professionalism of the personnel. The way in which the communication is done will also determine the trust the I&AP will have in the company to address the environmental aspects.

The Environmental Forum forms the instrument for communication between the I&AP and the company. If administered correctly a good relationship between the parties can be established through this medium.

9.3.2 Hydrogeological Representative

The scope of work for the hydrogeologist nominated to represent the community was summarised as follow:

- Evaluate all monitoring information obtained with the quarterly monitoring and yearly hydrocensuses. Feedback in this regard to be done bi-annually at the Environmental Forum meetings.
- Should irregularities be identified in the data or areas where additional data need to be obtained a scope of work must be compiled in conjunction with the company's hydrological team.
- Review reports on water complaints investigated by the independent hydrologist and should an impact be identified valuate the remediation measurements to be put in place.
- Discussions with land owners regarding the outcome of an investigation explaining the science and rationale behind the finding of the investigation.
- Act as technical specialist on behalf of the land owners should conflict situations arise.
- Be accessible for answering water related questions and provide advice where applicable for better management of the water resources on farms.
- If necessary visit farms where water and water quality problems were reported and submit report on outcome of investigation.

With the appointment of the hydrogeological representative the land owners had the assurance that all the hydrogeological aspects and monitoring is handled in the correct way and that they have access to expertise advice on any water related aspect in the area.

9.3.3 Water infrastructure survey

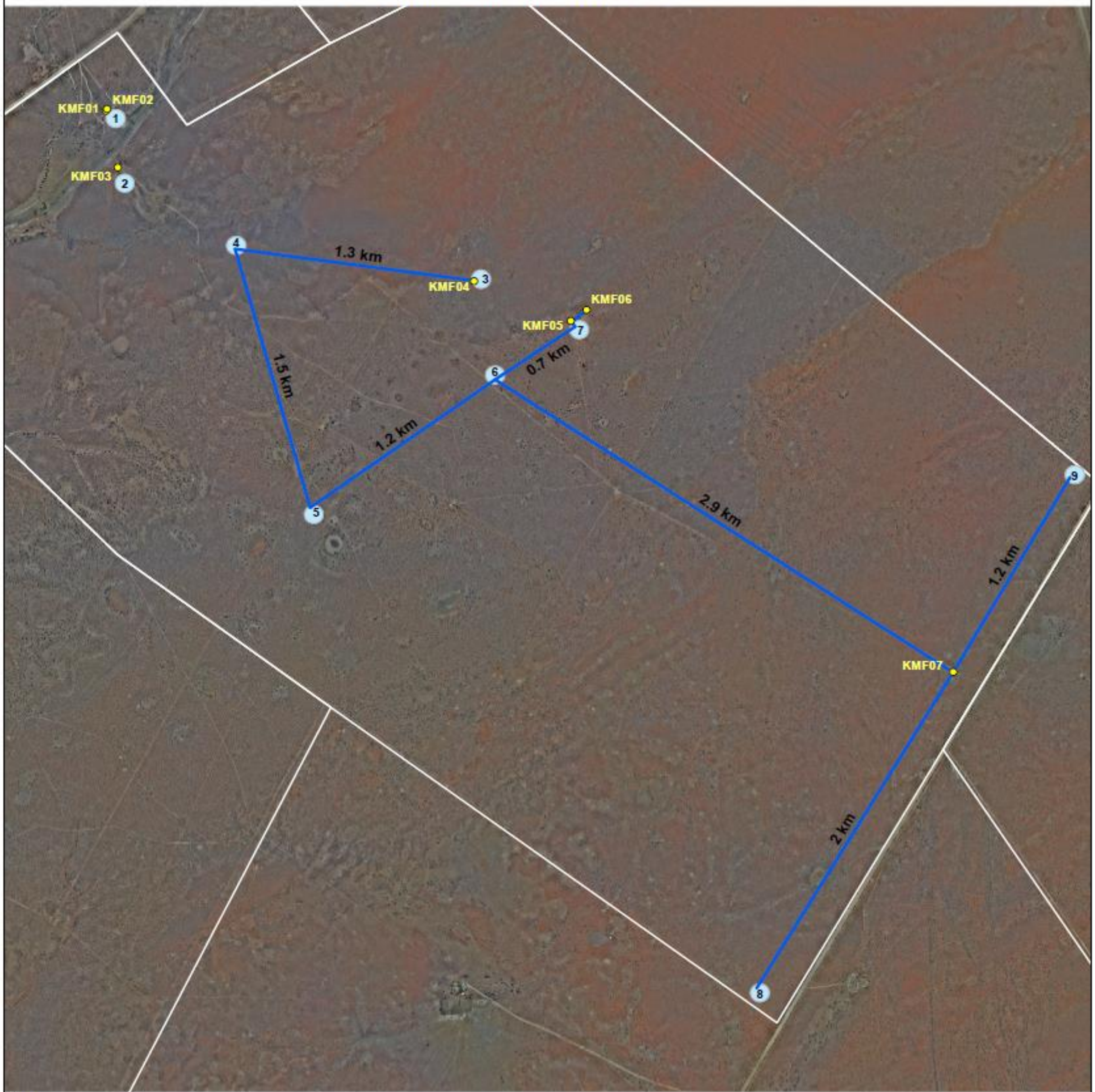
A considerable amount of time was spent on recording the water infrastructure on the farms. This was seen as an import aspect to get a complete reflection of the water distribution network on the farms before dewatering commenced.

In consultation with the land owners the following were recorded during the water infrastructure survey:

- The pipeline distribution network from the boreholes to the different end users indicating whether it's for domestic, livestock or irrigation use.
- The position of the dams and water troughs for livestock watering.
- The pipeline distances from the boreholes to the dams and water troughs. The distances were not physically measured and thus not hundred percent accurate but the land owners were able to provide a fairly good indication of the distances.
- The number of camps and livestock the specific boreholes supply water too.
- The dam sizes were also noted.

After the survey maps were drawn indicating the water infrastructure on the farms. This was done in geographic information system (GIS) format. Figures 39 and 40 indicate the survey data that was collected on the farms Kameelfontein and Bonnet respectively.

Kameelfontein 490



300 Sheep on the Farm
The sheep get water from Dams 3-9
Area = 1982 Ha

ID	Description
1	6.1mx1.2m- Domestic Use
2	6.1mx1.2m- Cement Dam
3	3mx1.8m- Zinc Dam/Sheep
4	3mx1.8m- Zinc Dam
5	6.1mx1.8m- Zinc Dam
6	6.1mx1.8m- Zinc Dam
7	9.1mx1.2m- Cement Dam/Sheep
8	6.1mx1.2m- Zinc Dam
9	4.6mx1.2m- Zinc Dam/Bricks on Outside

BH	X_Axis	Y_Axis	Description
KMF01	-28.402778	23.007117	Wind Pump/Domestic
KMF02	-28.402678	23.007183	SP/Domestic/Garden/Workers/BH Drilled KIO 45m
KMF03	-28.405602	23.007770	Wind Pump
KMF04	-28.411258	23.026942	Wind Pump/BH Drilled by KIO 60m
KMF05	-28.413245	23.032155	Wind Pump
KMF06	-28.412692	23.033008	Wind Pump/BH Drilled by KIO 60m
KMF07	-28.430738	23.052767	Wind Pump/BH 22m

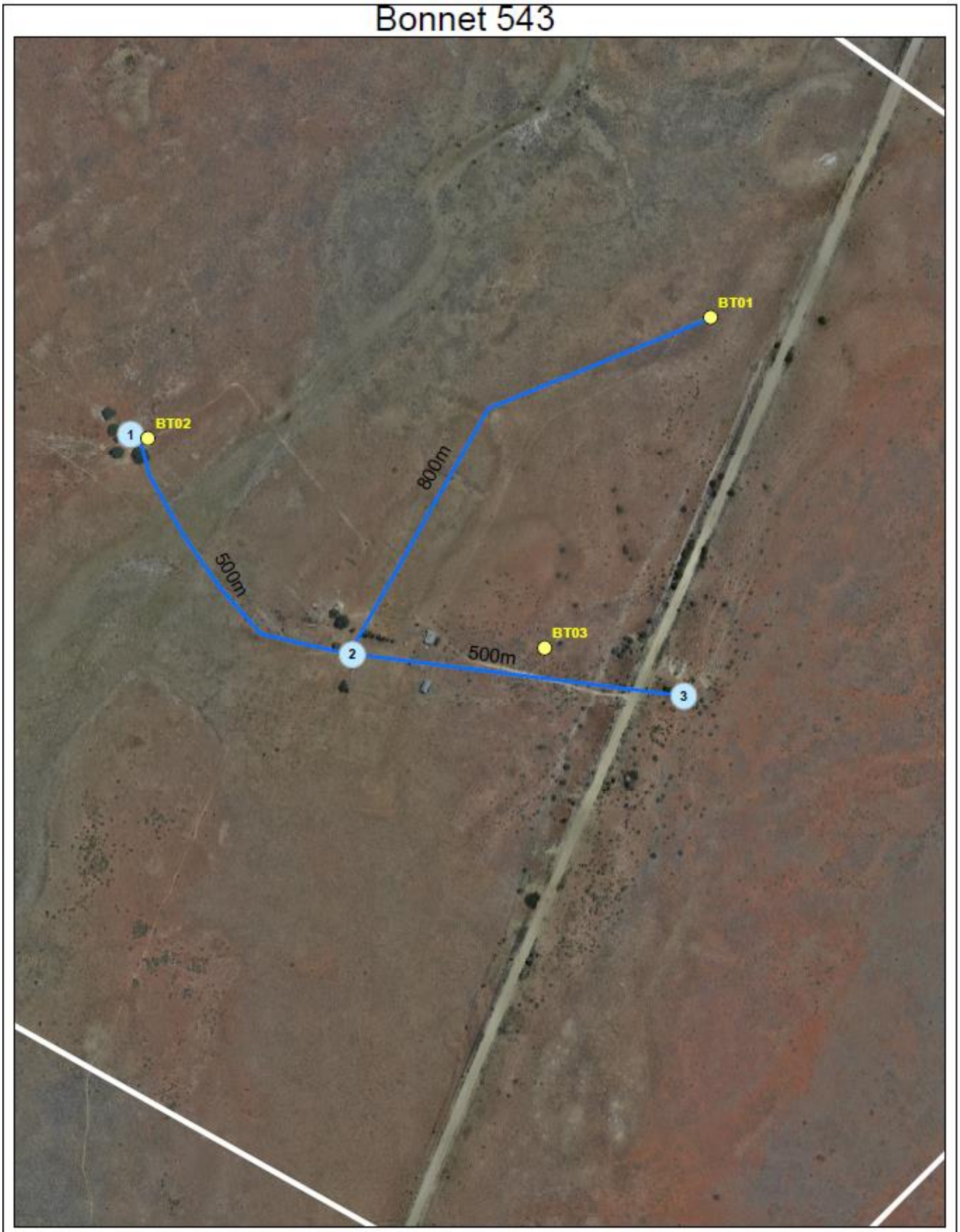
Legend

- Boreholes
- Pipelines
- Dams

0 250 500 1,000 Meters

N W E S

Figure 39: Water infrastructure on farm Kameelfontein



200 Sheep + 200 goats on the farm
400 livestock get water from Dams 1 & 3
Area = 890 Ha

ID	Description
1	5mx1.8m - Sheep
2	12mx1.8m - Domestic Water
3	5mx1.5m - Sheep

BH	X_Axis	Y_Axis	Description
BT01	-28.487845	22.931073	WP
BT02	-28.489510	22.922272	Well
BT03	-28.492410	22.928475	Open BH

Figure 40: Water infrastructure on the farm Bonnet

The infrastructure maps of the farms were distributed to the respective land owners for review whereupon, where necessary, corrections were made on the GIS database. The land owners were also asked to update the maps and submit the data should the distribution network on the farms change due to boreholes and pipelines taken out of production or new ones added to the system, or should there be an increase in the water use from a specific borehole over time.

With this survey the water distribution networks on the farms were captured prior to any impacts. If an impact should later be confirmed the survey data will come in handy in determining the extent of the assistance to be implemented as reference then exists on the usage and infrastructure associated with every borehole.

In this way the volume of water needed to replace an impacted borehole is known and the necessary actions can be done in addressing the water shortfall in the specific areas that was previously serviced by the impacted borehole/s.

9.3.4 Pumping test of irrigation boreholes

The capturing of the borehole information on the water usages (during the hydrocensus) indicated that many boreholes were used for irrigation in an area classified as being semi-arid; this is quite remarkable. At the time the land owners raised their concern that should these boreholes be impacted on by the dewatering activities of the mine in the future it would have a hugely negative effect on their financial stability.

Taking the potential financial impact on the land owners in consideration should the irrigation practices being impacted upon by the dewatering the decision was taken to conduct yield tests on these boreholes prior to the mining operations to determine the maximum utilisation of the groundwater resources surrounding the project area.

The results were used as a baseline to determine each borehole's contribution to the irrigation practices on the respective farms. Should any borehole be impacted upon it would be possible to negotiate with the land owner on the volume of water to be replaced as baseline data exist.

Should it not be possible to supply the volume of water either from new boreholes to be drilled on the farm or from a pipeline it would also be possible to determine the loss of income from crops that no longer can be produced due to the loss of water from the specific boreholes.

A pump testing contractor and a hydrogeological consulting firm were appointed for the scientific testing of the borehole yields and the analysing of the pumping test results respectively.

The reason for the appointment of a professional contractor and consultant was to ensure that the integrity of the data and analyses would not be questioned by third parties as such a situation can arise should the testing and analysing be conducted by the mining company.

Before the testing started the information on the Department of Water Affairs database regarding the licencing for irrigation in the area was obtained. From the information it could be confirmed whether a farm is registered for irrigation as well as the registered volume. Only the boreholes that were at that time or in the past being used for irrigation on the farms that were registered at the Department were tested.

Yield testing of the boreholes started in June 2009 and was completed in September 2009. In total 24 boreholes were tested (see Figure 41 for the locality of these boreholes). The boreholes were first submitted to a step drawdown test (SDT) consisting of between three and five steps in most cases, where the discharge rate was increased at hourly intervals. This was followed by a recovery test of similar duration or till full recovery has occurred, which ever was first.

The SDT gave an indication of the discharge rate to be used for the constant discharge test (CDT) which followed the SDT's recovery test. The CDT's was performed over 72 hours followed by a recovery test. The yield of the CDT's ranged between 1.26 to 20.20 L/s.

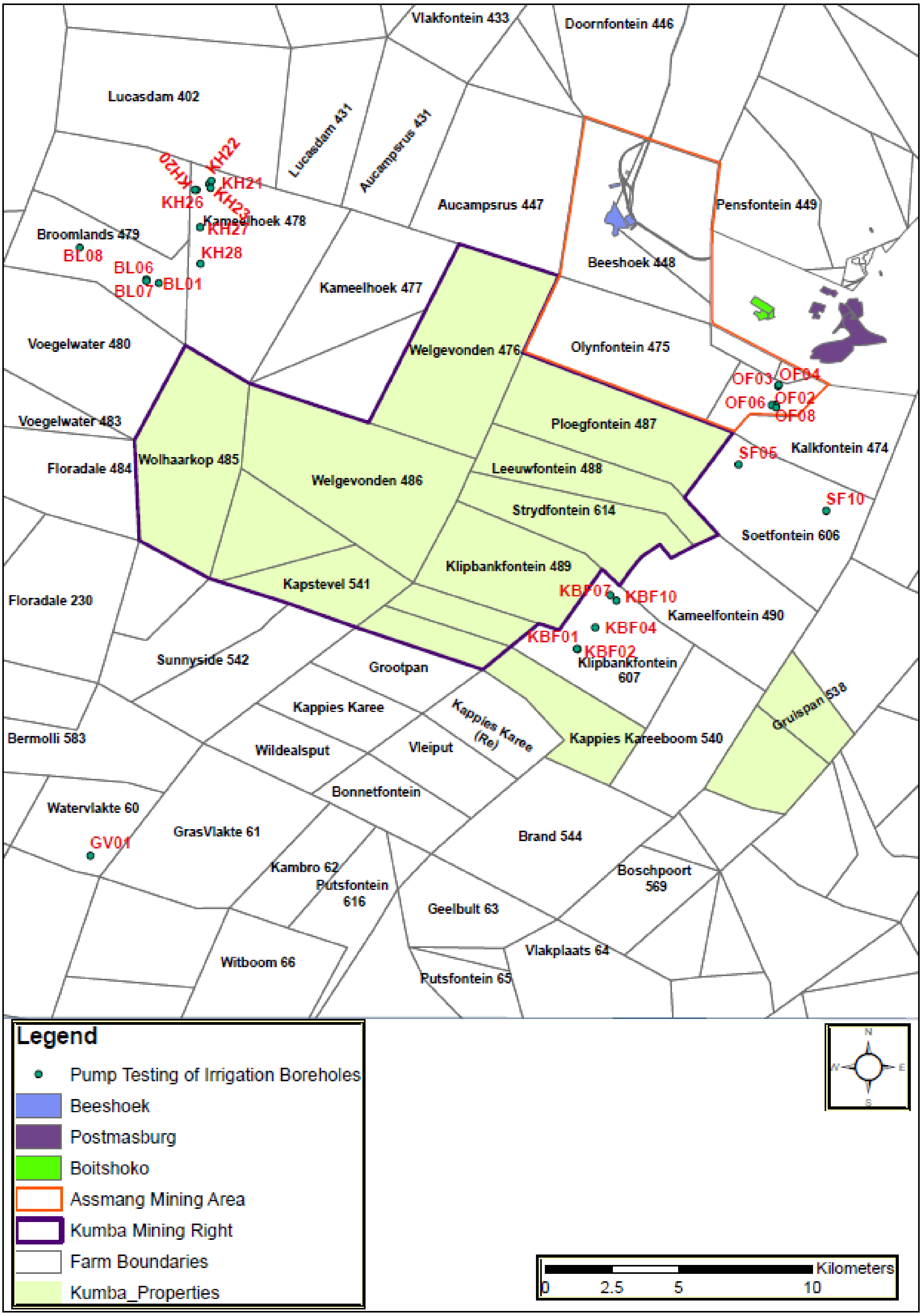


Figure 41: Locality of pump tested irrigation boreholes

The yield test data was analysed by means of the FC-method, which has been specifically developed (van Tonder *et al.*, 1999) for determining sustainable yields of boreholes penetrating fractured rock aquifers. The data was also analysed with the conservative recovery method which uses the rate of recovery after the test was stopped to determine the safe yield of the borehole.

The recovery method is calculated as follows:

Q = AV / ((PT+RT)/1440) where

Q = Calculated long term sustainable yield of borehole in m^3/d
AV = Volume of groundwater abstracted during yield test in m^3
PT = Total pumping time in minutes
RT = Total recovery time in minutes

The yield test results obtained with the two methods are summarized in Table 3. Although there are some differences in the sustainable yields between the Recovery and FC methods for individual boreholes the total sustainable yield of all the tested boreholes as calculated by these two methods differ by less than 4%.

TABLE 3: SUMMARY OF YIELD TEST RESULTS OF RECOVERY AND FC METHODS

Bh No	Farm	Coordinates (WGS84)		Depth (mbgl)	Sustainable yield				Comments
					Recovery Method		FC-Method		
		Latitude (DD)	Longitude (DD)		ℓ/s @ 24h/day	m^3/d	ℓ/s @ 24h/day	m^3/d	
BL1	Broomlands	-28.31105	22.83913	36.40	0.76	65.66	0.60	51.84	
BL6	Broomlands	-28.30973	22.83502	40.60	5.58	482.29	5.60	483.84	
BL7	Broomlands	-28.31026	22.83504	28.42	1.87	161.57	0.00	0.00	Pump suction - test abandoned - Not to be used
BL8	Broomlands	-28.31103	22.83922	32.60	1.26	108.81	1.10	95.04	Very quick recovery
GV	Grasvlakte	-28.50132	22.82777	17.00	2.77	238.97	3.40	293.76	Pumped yield too low to use recovery method
KBF1	Klipbankfontein	-28.43411	22.98018	37.85	5.74	495.91	5.50	475.20	
KBF10	Klipbankfontein	-28.41781	22.99312	22.40	1.36	117.81	1.20	103.68	
KBF2	Klipbankfontein	-28.43405	22.98019	99.50	9.51	821.96	10.90	941.76	
KBF4	Klipbankfontein	-28.42681	22.98595	100.00	5.13	443.17	6.40	552.96	
KBF7	Klipbankfontein	-28.41596	22.99106	16.82	1.18	101.55	0.00	0.00	Low yielding borehole - test abandoned - Not to be used
KH20	Kameelhoek	-28.27963	22.85188	30.80	1.25	107.88	1.70	146.88	
KH21	Kameelhoek	-28.27779	22.85619	40.10	2.95	254.62	1.70	146.88	FC allows for abstraction from other production bh's
KH22	Kameelhoek	-28.27665	22.85684	40.53	3.95	340.85	3.80	328.32	
KH23	Kameelhoek	-28.27915	22.85697	37.40	1.74	150.02	2.00	172.80	
KH26	Kameelhoek	-28.27918	22.85170	33.00	1.35	116.39	1.10	95.04	FC allows for abstraction from other production bh's
KH27	Kameelhoek	-28.28377	22.85417	31.50	3.67	316.77	2.00	172.80	Very quick recovery
KH28	Kameelhoek	-28.30453	22.85320	160.83	1.81	156.46	0.50	43.20	
OF2	Olynfontein	-28.35197	23.04680	42.09	5.29	456.69	4.30	371.52	FC allows for abstraction from other production bh's
OF3	Olynfontein	-28.34567	23.04749	35.35	3.18	274.97	2.00	172.80	
OF4	Olynfontein	-28.34519	23.04780	67.76	1.95	168.77	10.00	864.00	Recovery data affected by nearby pumping
OF6	Olynfontein	-28.35200	23.04540	21.21	2.90	250.28	2.00	172.80	Limited drawdown yields conservative FC-values
OF8	Olynfontein	-28.35345	23.04648	90.60	14.40	1,244.04	9.00	777.60	
SF10	Soetfontein	-28.38759	23.06372	115.43	2.57	221.81	5.00	432.00	
SF5	Soetfontein	-28.37207	23.03450	128.00	6.69	577.75	3.00	259.20	
				TOTAL	**85.79**	**7412.10**	**82.80**	**7153.92**	Bh's KBF7 & BL7 ignored in Recovery method Total
	Coloured cells indicate that recovery method allows for abstraction from nearby boreholes								

Source: SRK Consulting, Engineers and Scientists (2009)

The recommended yields of the tested boreholes are shown in Table 4. The sustainable yields as determined by the FC method (Table 3) were taken as the recommended yield for the boreholes. The main reason why the yields of this method is preferred is that the yields determined by the FC method for boreholes that are situated close to each other are more conservative as the abstraction of the nearby boreholes can be taken into account which cannot be done with the calculations of the Recovery method.

If a pump yield of a borehole is determined without taking the abstraction of nearby boreholes into account the yield of the borehole will not be sustainable over the long term and the borehole will be “damaged” and might most probably not be as productive in yielding the volume of water as before.

A sustainable yield was not assigned to boreholes BL07 and KBF07 as these two boreholes were not subjected to CDT’s. The reasons being that only a small head (distance from water level to bottom of borehole) were present and the step drawdown tests confirmed that the boreholes were low yielding. The boreholes were therefore not seen as suitable to be used for irrigation.

TABLE 4: RECOMMENDED YIELDS OF BOREHOLES

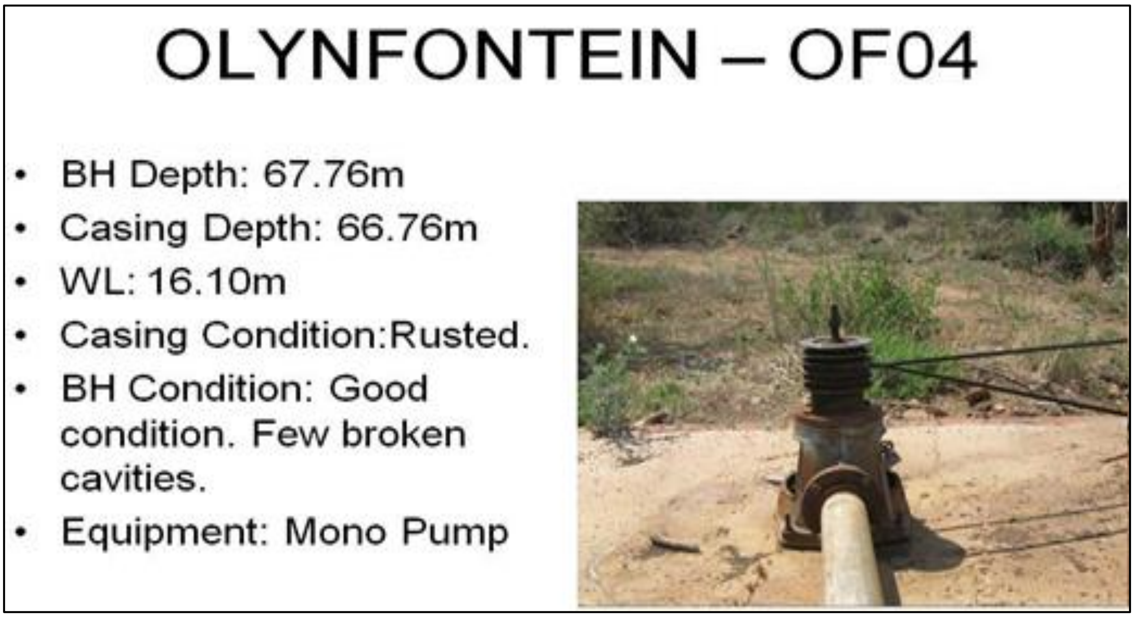
Bh No	Farm	Coordinates (WGS84)		Bh Depth (mbgl)	Rest water level (mbgl)	Recommended sustainable yield		Max rest water level (mbgl)	Comments
		Latitude (DD)	Longitude (DD)			ℓ/s @ 24h/day	m^3/d		
BL1	Broomlands	-28.31105	22.83913	36.40	8.47	0.60	51.84	16.00	
BL6	Broomlands	-28.30973	22.83502	40.60	11.12	5.60	483.84	22.00	
BL7	Broomlands	-28.31026	22.83504	28.42	11.55	0.00	0.00		Pump suction - test abandoned - Not to be used
BL8	Broomlands	-28.31103	22.83922	32.60	11.30	1.10	95.04	19.00	Very quick recovery
GV	Grasvlakte	-28.50132	22.82777	17.00	8.57	3.40	293.76	13.00	
KBF1	Klipbankfontein	-28.43411	22.98018	37.85	9.59	5.50	475.20	18.00	No inflection point reached during tests
KBF10	Klipbankfontein	-28.41781	22.99312	22.40	12.37	1.20	103.68	15.50	
KBF2	Klipbankfontein	-28.43405	22.98019	99.50	9.41	10.90	941.76	20.00	No inflection point reached during tests
KBF4	Klipbankfontein	-28.42681	22.98595	100.00	11.95	6.40	552.96	25.00	No inflection point reached during tests
KBF7	Klipbankfontein	-28.41596	22.99106	16.82	12.88	0.00	0.00		Shallow, low yielding borehole - No CDT - Not to be used
KH20	Kameelhoek	-28.27963	22.85188	30.80	5.38	1.70	146.88	13.50	
KH21	Kameelhoek	-28.27779	22.85619	40.10	7.35	1.70	146.88	15.75	
KH22	Kameelhoek	-28.27665	22.85684	40.53	7.36	3.80	328.32	11.00	No inflection point reached during tests
KH23	Kameelhoek	-28.27915	22.85697	37.40	7.35	2.00	172.80	14.85	
KH26	Kameelhoek	-28.27918	22.85170	33.00	7.05	1.10	95.04	12.60	
KH27	Kameelhoek	-28.28377	22.85417	31.50	7.05	2.00	172.80	20.00	Very quick recovery - No inflection point reached
KH28	Kameelhoek	-28.30453	22.85320	160.83	12.37	0.60	51.84	19.00	Inflection point at 19.3 mbgl
OF2	Olynfontein	-28.35197	23.04680	42.09	15.42	4.30	371.52	20.50	No inflection point reached during tests
OF3	Olynfontein	-28.34567	23.04749	35.35	15.31	2.00	172.80	16.20	Inflection point at 16.21 mbgl
OF4	Olynfontein	-28.34519	23.04780	67.76	15.79	10.00	864.00	19.50	No inflection point reached during tests
OF6	Olynfontein	-28.35200	23.04540	21.21	13.57	2.00	172.80	14.50	No inflection point reached during tests
OF8	Olynfontein	-28.35345	23.04648	90.60	23.50	9.00	777.60	35.00	No inflection point reached during tests
SF10	Soetfontein	-28.38759	23.06372	115.43	34.78	5.00	432.00	47.00	No inflection point reached during tests
SF5	Soetfontein	-28.37207	23.03450	128.00	8.45	3.00	259.20	20.00	Inflection point at 58 mbgl
					TOTAL	**82.90**	**7,162.56**		

Source: SRK Consulting, Engineers and Scientists (2009)

After the pump tests camera logging and an electrical conductivity (EC) and pH profile log was done on all the boreholes except BL07 and KBF07 as these boreholes were not subjected to CDT'S and not seen as suitable for irrigation use.

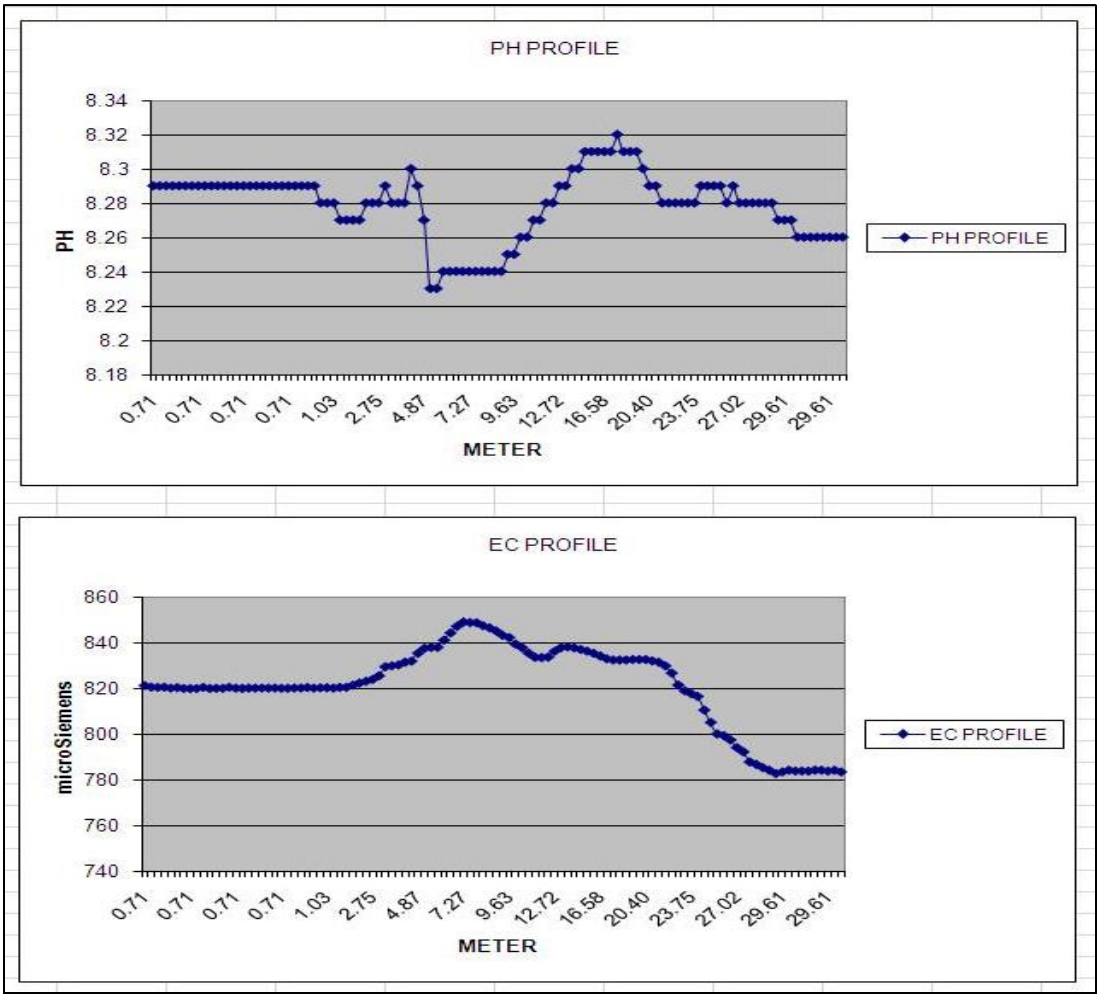
Photos of the boreholes were also taken and the information obtained during the camera logging, for example the depth of the casing, the casing and borehole condition was noted.

Figure 42 display the photo and information obtained with the camera logging of borehole OF04 of the farm Olynfontein while the electrical conductivity (EC) and pH log of borehole BL06 (farm Broomlands) are displayed in Figure 43.



Source: Van Niekerk (2010)

Figure 42: Camera logging of borehole OF04



Source: Van Niekerk (2010)

Figure 43: EC and pH profile log of borehole BL06

All the borehole information obtained with the camera logging, electrical conductivity (EC) and pH profiling are displayed in Table 5. The electrical conductivity (EC) and pH logs were done to see whether the depths of the water strikes/water bearing fractures could be identified in the borehole profile.

The method proved to be successful and in most of the boreholes good comparison was obtained between the electrical conductivity (EC), pH profiling and the camera logging methods in determining the fracture depths, Table 5.

From the electrical conductivity (EC) and pH log (Figure 43) the water strikes/fractures was interpreted to be at depths 0.71, 7.97 and 18.63 meters respectively. Positioning the fractures at the right depth below ground level the water level (10.31m) as measured at the time of the logging must be added to the depths of the fractures as interpreted on Figure 43, thus the depths of the fractures are at 11.02, 18.99 and 28.94 meters respectively (Table 5).

The reason for identifying the depth of the fractures was to determine the position of the fractures in relation to the water level. With the depth of the fractures known and the water level data from the quarterly and yearly hydrocensus monitoring at hand, a close eye can be kept on the “life expectancy” of the boreholes as it will be seen from the monitoring data which of the boreholes are heading to dry up should a decline in the water levels occur.

The pumping test and camera logging data will most definitely help in the investigation should a complaint be received stating that the yield of an irrigation borehole declined. On repeating the camera logging it will be possible to see whether the borehole had collapsed. It will also be possible to see if closing (maybe due to over utilisation) or calcification of the fractures occurred, all possibilities which individually or in combination will have a negative impact on the yield of a borehole.

TABLE 5: BOREHOLE DATA OBTAINED WITH CAMERA, EC AND pH PROFILING

						WATER STRIKES - CAMERA vs EC PROFILE					
						WATER STRIKE		WATER STRIKE		WATER STRIKE	
BH No	WL	SOLID CASING DEPTH	SLOTED CASING DEPTH	CASING DEPTH	BH DEPTH	CAMERA	EC PROFILE	CAMERA	EC PROFILE	CAMERA	EC PROFILE
KAMEELHOEK											
KH20	5.75	29.62	n/a	29.62	30.17	SOLID CASING	24.51	n/a	n/a	n/a	n/a
KH21	7.68	0.73	n/a	0.73	27.34	12.10 - 14.31	10.72	n/a	14.87	n/a	n/a
KH22	7.43	2.55	n/a	2.55	39.95	12.13	8.35 - 10.88	13.86	14.12	16.45	17.12
KH23	7.52	0.71	n/a	0.71	37.58	9.08 - 10.73	12.17	12.43	12.47	14.5	14.21
KH26	4.57	12.71	n/a	12.71	32.46	20.11	13.19	n/a	27.88	n/a	n/a
KH27	6.21	6.01	9.99	9.99	30.84	19.84	30.41	n/a	n/a	n/a	n/a
KH28	12.52	13.71	n/a	13.71	162.27	14.98 - 19.23	76.3	28.52	n/a	40.63 - 47.33	n/a
BROOMLANDS											
BL01	8.13	5.8	n/a	5.8	36.39	8.27-8.50	8.37	15.71	15.75	19.9	19.97
BL06	10.31	16.2	n/a	16.2	40.59	9.13 - 11.87	11.02	17.41 - 19.03	18.99	27.41	28.94
BL07	10.55	9.66	n/a	9.66	28.42	n/a	n/a	n/a	n/a	n/a	n/a
BLO8	10.54	9.63	n/a	9.63	34.87	10.97-11.43	11.24	12.31	12.31	14.2	14.24
SOETFONTEIN											
SF05	8.5	40	n/a	40	128	n/a	n/a	n/a	36.55	n/a	64.08
SF10	34.9	7.13	n/a	7.13	82.32	53.29	83.39	83.88	n/a	n/a	n/a
KLIPBANKSFONTEIN											
KBF1	9.33	n/a	37.4	37.4	37.85	Cased	9.36		10.2	n/a	n/a
KBF2	8.9	24	43.03	43.03	99.97	64.03	14.71	66.32	66.2	n/a	n/a
KBF4	11.33	12	23.01	23.01	100.31	33.34	32.93	n/a	n/a	n/a	n/a
KBF7	12.88	n/a	n/a	2.34	16.82	n/a	n/a	n/a	n/a	n/a	n/a
KBF10	12.57	n/a	n/a	n/a	22.4	n/a	19.77	n/a	n/a	n/a	n/a
GRASVLAKTE											
GV01	7.2	2.2	n/a	2.2	16.6	8-16.6	7.9	n/a	n/a	n/a	n/a
OLYFONTEIN											
OF02	18.61	5.09	n/a	5.09	42.09	6.13 - 8.41	5.84	19.14	n/a	27.11 - 34.12	n/a
OF03	15.54	3.26	n/a	3.26	34.31	16.52 - 19.34	17.71	26.3	26.27	29.74	28.95
OF04	16.27	6.76	n/a	6.76	67.76	n/a	21.9	n/a	29.55	n/a	41.52
OF06	13.89	5.45	n/a	5.45	21.51	19.53 - 21.51	19.1	n/a	n/a	n/a	n/a
OF08	24.45	14	n/a	14	90.6	19.5	20.02	41.10 - 45	44.81	49 - 51	50.34

SF5 :Obstruction in borehle at 89 meters, lot of cavities inside boreholes wich look very unstable.

BLO7 : Camera & EC profiling not done.

KBF7 : Camera & EC profiling not done.

Source: Van Niekerk (2010)

With this detailed information available on the boreholes the company was placed in a position to act proactively should it be observed that an impact from the dewatering is starting to manifest on the boreholes used for irrigation.

9.3.5 Pumping test of boreholes for future expansion

After the pump testing of the irrigation boreholes and determining of the sustainable yields thereof a request was received from a number of land owners asking whether pump tests could also be performed on their boreholes as well.

The land owners indicated that they either intend to expand the use of these boreholes in future, or start to use them in an intensive capacity for their farming activities. As the yields of these boreholes were unknown it was decided to pump test the boreholes - the data could then serve as reference should any dispute arise in future on these boreholes being impacted upon.

As these boreholes didn't have the ''status" of the irrigation boreholes the pump testing were not done in the extensive way the tests were performed on the irrigation boreholes. The testing was co-ordinated by the hydrogeological representative of the land owners.

The testing started at the end of November and was completed in December 2010. No step drawdown tests were performed and the CDT's interval ranges between only 1.25 and 3 hours. For the open boreholes a relative small pump (yield of 2 L/s) was used while the pumps on the equipped boreholes were used to perform the pump tests on those boreholes.

In total 9 pumping tests were performed (Figure 44) of which 6 and 3 tests were performed on boreholes and wells respectively. The pumping test information and yield results are summarised in Table 6.

TABLE 6: SUMMARY OF PUMPING TEST INFORMATION AND YIELD TEST RESULTS

Borehole Number	Constant drawdown test performed (L/s)	Time of constant drawdown test performed (hours)	Recommended sustainable yield (L/s for 24h/day)
BP01	10.0	2.00	35.0
FD15	2.0	1.25	9.0
HK16	2.0	2.00	5.0
KH01	2.0	3.00	5.0
LD01 (well)	2.0	1.50	4.0
LD03 (well)	2.0	2.00	6.0
LD04 (well)	2.0	1.50	6.0
SUN01	2.0	2.00	10.0
SUN11	2.9	2.00	7.0

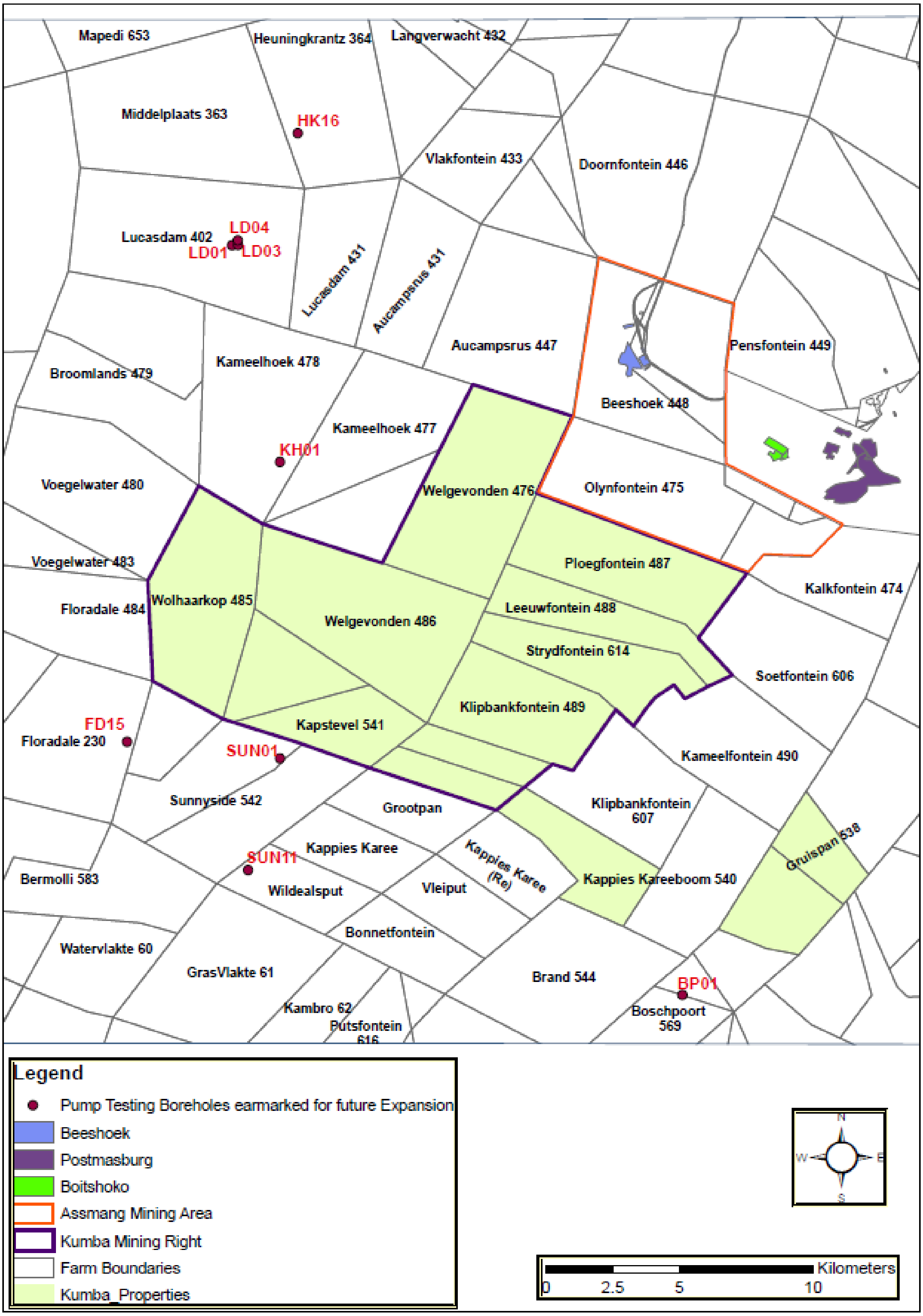


Figure 44: Pump testing of boreholes for future expansion

The FC program was used to analyse the data in order to determine the sustainable yields and the aquifer parameters of these boreholes. As can be seen from the recommended yield results the boreholes as well as the wells have fairly good yields ranging from 4 to 10 L/s with borehole BP01 having an extraordinary high yield of 35 L/s.

As can be seen from Table 6 all the recommended yields are higher than the rate at which the boreholes and wells were pumped during the testing period. The reason for this can be ascribed to the fact that the data analyses of all the pumping tests indicated high to very high transmissivity values and also indicated that no borders were reached during the pumping tests. It must however be stressed that the testing times were very short.

In conclusion Vermeulen *et al*. (2011) mentioned that the sustainable values as determined only serve as indicators for future reference and that prolonged tests must be done to determine the exact yields should these boreholes and wells being utilized in future development.

9.3.6 Water level meters

At the Environmental Forum meetings the importance of water level monitoring was emphasise and land owners were encouraged to take part in the monitoring thereof. Kumba committed in supplying water level meters to the land owners who indicate willingness in monitoring the water levels of their boreholes.

At the end of 2009 five water level meters were distributed which was followed with nine and thirteen meters during 2010 and 2011 respectively. Water level meters were not only distributed to land owners in the hydrocensus area but also further away (between 3 and 12 farms from the mine properties) who showed interest to monitor the water levels of the boreholes on their farms.

On delivery of the water level meters the land owners signed a form acknowledging receipt thereof. The signed forms were kept by Kumba and a copy of the signed form was given to the land owners. The following was noted on the forms:

- A short discussion explaining the reasons for water level monitoring and the importance thereof.
- Mention was made that all data will be incorporated into the mine’s database and be used for discussion at the Environmental Forums.
- Request that the water levels of the boreholes be measured on a monthly base and the data submitted to Kumba either via email to the hydrogeologist or at the Environmental Forums or at any ad hoc water meeting that is being held.

- Should the data be submitted at meetings it was requested that it must be in writing, in this way the integrity of the data will be retained.
- The contact details (email and cell phone) of the Kumba hydrogeologist were provided for submitting of the data and discussion of inquiries.

Unfortunately only a small number of land owners who received a water level meter were committed in measuring the water levels on a monthly base and submitting the data to the mine.

Most of the land owners monitor and submit the data on an ad-hoc base although situations also occur where some land owners have not submitted any data at all; this is mostly the situation experienced with the farms the furthest away from the mine properties.

The distribution of water level meters is still done. The land owners are asked to submit an application therefore as it is experience that when effort is being made in obtaining a water level meter, the land owners see the monitoring in a serious light and are committed in performing their part of the deal.

When the decision was taken that the Sishen South project would be developed as a mining operation it was decided that a detailed hydrocensus had to be performed to ensure that a proper base line is obtained that reflect the hydrogeological conditions of the regional area.

The objective of the hydrocensus was not only to obtain water level data but all information regarding the boreholes and water infrastructure on the private properties. Samples were also taken for chemical analysing and pump testing was conducted on boreholes used for irrigation.

After evaluation and analysing the data collected during the hydrocensus a monitoring network for both the project and regional areas was designed and implemented. As communication with the land owners was seen as a priority a Forum was established. The water aspects formed the main discussion point at the meetings but the Forum was also used to discuss and provide feedback on other environmental aspects as well.

The main objective of the hydrocensus was to obtain the necessary information that informed decisions can be taken to manage and protect the groundwater resources in an efficient manner.

Chapter 10

GUIDELINE FOR SET-UP OF PRE-MINING GROUNDWATER MONITORING NETWORK FOR OPEN PIT MINES

10.1 INTRODUCTION

In general a monitoring programme can be seen as the routine collection of water levels, water quality and water use in order to gain a record of the aquifers response over time. Monitoring programmes will assist in obtaining the necessary data/information needed to develop the water management and monitoring programmes for the mining operation and to obtain the pre-mining hydrogeological situation of the aquifers in the regional area. Monitoring forms the foundation on which the managing and protection of water resources are being built on.

The literature review highlighted a number of aspects to be taken into account when a groundwater monitoring programme is designed. The following aspects were emphasised:

- The monitoring objectives must be clearly defined.
- A sound understanding of the geological, hydrogeological and geochemical setting of the area is essential before the monitoring program can be developed.
- All the aquifers must be monitored including the interaction between surface and groundwater in areas where it is applicable.
- Development of a conceptual hydrogeological model.
- The frequency of measurement and sampling must be chosen with respect to the objectives.
- The monitoring programme must periodically be evaluated and adjusted should changes to the groundwater system occur.

Taking the monitoring aspects highlighted in the literature review and the first-hand experience gained in the case study in consideration, the following stages are proposed in the setting up of a holistic and representative pre-mining monitoring programme as illustrated in Figure 45 below.

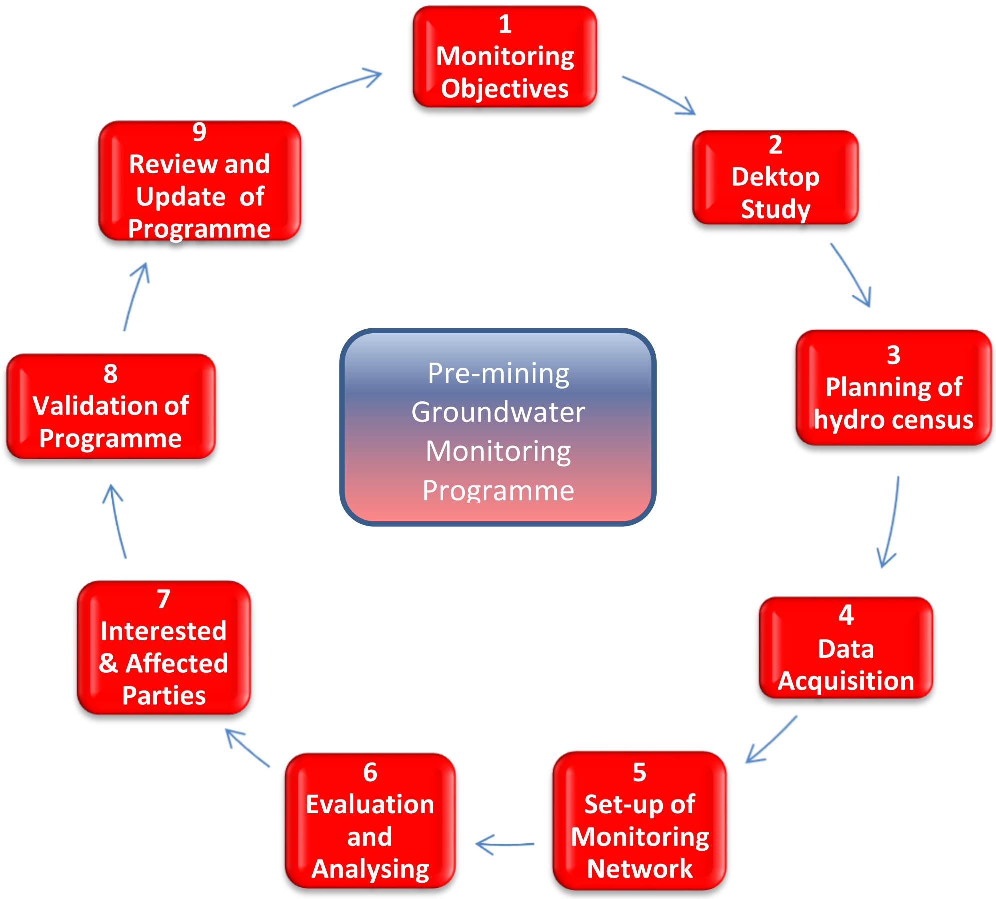


Figure 45: Stages in setting pre-mining groundwater monitoring programme

A successful monitoring programme can be described as where an adequate number of boreholes are present to monitor the groundwater at specific locations and depths. The monitoring positions must be within and outside of the expected impacted area.

The monitoring programme must also include a sufficient number of groundwater quality sampling points. The monitoring positions must be spread over the whole area covering the down and upstream areas around the proposed mining facilities.

10.2 MONITORING OBJECTIVES

Before a monitoring programme is commissioned it is important that clear objectives are set of what exactly needs to be achieved with the monitoring. The objectives must be set with the focus on efficiency and practicality. In order to set these objectives the following question should be kept in mind:

Why is it important that the groundwater needs to be monitored? Does the company only want to comply with the legal compliances of the water use licence and the company's policies and standards for example the Environmental Management Plan Report (EMPR)?

The monitoring programme of a company taking only the above in consideration will significantly be less comprehensive from that of a company that also see themselves as a responsible stakeholder and want to promote sustainability and be integrally part of the community where-in they operate.

In the latter case the monitoring needs to be comprehensive in order that a thorough understanding of the hydrogeological characteristics of the aquifers of the area is gained. By doing this the company will be empowered to take informed decisions to effectively protect and manage the water resources.

To set up a groundwater monitoring programme that complies with the above the following stages must be followed as described in this chapter.

10.3 DESKTOP STUDY

Before the hydrocensus is planned a desktop study must be performed. All the available geological and hydrogeological reports, data and information of the area must be sourced; usually this can be obtained from:

- Internal reports of studies and investigations undertaken by the company.
- The company's database of previous monitoring in the area.
- The NGDB of the Department of Water Affairs.
- If other mining operations are in the area they usually are willing to share water level data but not geological data.
- The internet for any studies/investigations undertaken by other institutions in the past for instance the Water Research Commission, The Council for Geosiences and Universities.
- Water User Association if present in the area.

If a Water User Association (WUA) is present in the study area it will be a good source in providing background information as the general objectives of a WUA can be defined as the;

i) management of the water resources to the benefit of the ecology and all water users and

ii) to monitor and control the use of the water resources within its operational area

In some instances they have a comprehensive database with the data of all the role players in the area together with the reports of studies and investigations done in the past.

10.4 PLANNING OF HYDROCENSUS

Depending on the amount of data sourced during the desktop study ample time must be set aside to evaluate and interpreted the data to create a conceptual model of the hydrogeological conditions of the area. The conceptual model will provide a good indication what to expect during the hydrocensus and also give guidance in demarcating the area that needed to be surveyed during the hydrocensus.

If a numerical model is already developed the simulations will provide a good indication of the areas where impacts might occur over time and thus assist in determining the area to be covered by the hydrocensus. If a numerical model is not available and the proposed mining operation is in an area where there is no big scale water abstraction the radius of the hydrocensus should extent to include at least two rows of farms around the proposed mining area.

If for instance impacts are already being observed in the area due to abstraction from mines, municipalities or irrigation schemes, the radius of the hydrocensus area need to be enlarged especially in the direction where the impact is manifesting.

In the case of areas around rivers (both perennial and non-perennial) and drainage channels the hydrocensus area need to cover a couple of kilometres up- and downstream of the proposed mining area. The upstream water quality data will be informative in determining any deterioration in the downstream water quality and to quantify whether the deterioration is due to the mining operations or not.

It is important that the hydrogeologist must take the following site conditions and hydrogeological characteristics in consideration when the area for the hydrocensus is determined:

- the elevation of the water table and the hydraulic gradient across the site
- the potential of compartmentalisation within the different geology units
- the nature of the recharge boundaries or groundwater flow barriers
- the hydrogeological characterisation of the different geology lithologies
- the groundwater transmitting characteristics between the geological units
- the characterisation of the major structures, for example faults, dykes and sills
- the water chemistry

With the hydrocensus area determined all the landowners must be informed about the planned hydrocensus. Usually the names and telephone numbers of the land owners can be obtained from the mine's exploration division as they are familiar with the area and the land owners after years of exploration in the area.

In cases where the land owners do not permanently reside on the farms their contact details can be obtained from the farm workers or neighbouring land owners.

The following aspects are of great importance in the planning phase and will help tremendous with the set-up and execution of a hydrocensus and the monitoring actions thereafter in any area.

10.4.1 Communication with land owners regarding the hydrocensus

This aspect is of cardinal importance as this will determine right from the start the success of the hydrocensus and the co-operation from the land owners.

For the inaugural hydrocensus the land owners must be contacted well in advanced (at least two to three weeks) before the proposed survey to ensure the availability of the land owners. For follow up surveys communication can be done the week before the survey as the hydrocensus team can now function on their own as the localities of the boreholes are known.

Communication regarding the inaugural hydrocensus must preferable be done by the hydrogeologist of the mining company or a staff member involved with the hydrocensus.

If a consulting firm is contracted for the survey it is not recommended that the communication to the land owners are done by the consultant as this can easily be interpreted that the mining company does not have the time and respect for the community in which they are to operate.

The hydrogeologist or a staff member of the company must accompany the consulting firm during the first survey in order for the land owners to get acquainted with the mine personnel. Thereafter the consulting firm can take over the communication role in co-ordinating and executing the future monitoring surveys.

Where possible communication with the land owners (especially in the beginning when they are informed about the hydrocensus) must be done in the language spoken by them otherwise the danger exists that co-operation from the land owner's side might be jeopardised. It is also recommended that at least one of the hydrocensus team members can speak and understand the language when the farms are visited for the surveys.

The contact details of the farms foreman, where applicable, must also be obtained as some of the land owners do not permanently reside on the farms, or have other business interests and is not always available that access can be arranged. The cell and landline telephone numbers as well as email addresses (where available) must be obtained. The latter being the prefer medium for communication and the transferring of data between the parties.

The contact details of the mine hydrogeologist must also be given to the land owners to enable them to make contact should there be any questions or inquiries after the hydrocensus about the information gathered during the survey.

10.4.2 Time for (inaugural) hydrocensus

Make sure that sufficient time is allowed for the hydrocensus survey for each farm. When the land owners are contacted for appointments it is important to ask how many boreholes are on the farm as well as the size of the farm, as this is essential in the planning of the hydrocensus schedule.

From experience it was found that a maximum of 2 neighbouring farms (each smaller than 2000 ha in size) with approximately 10 boreholes each can be surveyed during a day if started at 7:00 continuing until 18:00. If no delays are experienced during the day one should be able to survey the 2 farms that includes the numbering of the boreholes, water level measurements, sampling and noting of the borehole information as discussed under point 10.5.

If the water infrastructure survey is also conducted (as described under point 10.5) a whole day would be necessary for one farm. Also take in consideration other time consuming aspects like the drilling of holes in the base plates to gain access for the water level meter probe to measure the water levels. The drilling of a hole can easily take half an hour up to an hour depending on the thickness of the base plates. When the land owners are contacted for the appointments it must be asked how many boreholes are equipped in order to get an idea of how many base plates probably needed to be drilled.

With a few exceptions the land owners are very hospitable and on arrival one is usually invited for coffee and cookies, sometimes even for lunch. Make provision for at least an hour for discussion as the land owners usually have a couple of questions and concerns regarding the water aspects to discuss. This time is very important as it set the foundation for good communication between the two parties for the future, and one also gets a good idea of the aspects that are of concern to the land owners.

The above being the rationale why the hydrogeologist or mine staff member must accompany the hydrocensus team in order that a good relation can be built between the mine and the land owners. If the mine's personnel is not accompanying the survey team this opportunity will be jeopardised in a way and reflect negatively on the image of the mining company. The consultants will also not be in a position to answer all the questions and concerns of the land owners in a satisfactory manner.

Taking all the above in consideration it will be better to make only one appointment per day especially if the farms sizes are in the region of 2000 ha with 10 plus boreholes to survey. If time is available after the day's survey it can be used to record all the data and information into the hydrocensus database.

It is also very important to be on time for the scheduled appointments, if uncertain of the routes to the farms get beforehand the road directions from the land owners.

The follow up surveys (water level and sampling) can be executed in approximately a third of the time span from that of the inaugural survey as describe above.

10.5 DATA ACQUISITION DURING HYDROCENSUS

A hydrocensus should not only consist of obtaining water level data but all information regarding the boreholes for example the water strikes and depths of the boreholes, yield and usage. Rainfall data as well as information on the water infrastructure network and the number of stock dependant on a watering point is also important to be noted during the survey.

The data acquisition during the hydrocensus comprises the following:

10.5.1 Borehole numbering

The numbering of boreholes is an aspect that needs some thought and planning. To prevent confusion and eliminate frustration the following is recommended:

- If a numbering system already exists from previous hydrocensuses (usually this is the case when there are more than one mining company operational in an area) it would be best to use the existing numbers assigned to the boreholes and also continue with that specific numbering sequence if new boreholes are drilled on the farms.
- Where numbers must be assigned to boreholes it is good practice to use the first and last letter of the farm name together with a numerical number for the borehole numbers, for example boreholes on the farm Bestwood would be numbered BD01, BD02.

If another farm name begin and ends with the same letters for instance Bishopswood, include a middle letter of the farm name in the borehole numbers as well, BPD01.

- At some farms the Department of Water Affairs have monitoring boreholes that form part of their regional monitoring network. Number these boreholes according to the numbering system of the other boreholes on the farm but also note the Department's number (for example GO102NC) next to the hydrocensus number allotted to the borehole.
- The land owners must also be consulted on the numbering system they use but usually they use descriptive naming for the boreholes like "borehole behind house" and "borehole in game camp". In such cases it would be best to number the boreholes according to the first and last letter principle. Note the land owner's naming of the boreholes as well to eliminate confusion during data exchange.

The numbers must preferable be on the borehole casings but unfortunately this is not always possible. In such cases the numbering must be done on either the windmill structure, the pipeline of the installed pump at the borehole, pump house, dam or any infrastructure close to the specific borehole.

Unfortunately infrastructure like windmills and pipelines are sometimes moved to other boreholes, thus it is best to place the borehole number on a permanent structure at the borehole where possible.

The numbering must be done in such a way that it is clearly visible and easily readable. A bright ink pen or spray paint can be used for the numbering but consult with the land owner beforehand with what, the size and on which infrastructure the numbering will be done as it can lead to dissatisfaction if a borehole number is spray painted in large format on the side of a zinc dam for example.

10.5.2 General borehole information

All boreholes must be visited whether the boreholes are operational, dry, blocked or never been used. The status of the boreholes must also be recorded. This is an important aspect as the status of some of the boreholes change over time from operational to not being in use and vice versa. The change in status usually reflects in the behaviour of the water levels of the boreholes and in such cases the water level behaviour can be explained with more certainty if the status were recorded during the surveys.

It is important that an effort be made to obtain as much information as possible of the boreholes during the hydrocensus. If available the following information must be collected:

- **Year when the boreholes were drilled.** This information is not commonly available but some of the land owners are able to provide the dates when the boreholes were drilled. In some instances the drilling dates are engraved in the cement block situated around the borehole. The drilling date is of importance, if the yield and water level of the borehole at the time of drilling was noted this can provide a good reference of what happened over time.

- **Depth of boreholes.** If the land owners cannot provide the depth of the boreholes, attempts must be made to measure it.

  For the depth measurement a weight can be taped to the probe of the water level meter and lowered down the hole. The batteries are to be taken out to prevent the instrument from making noises as the probe is lowered down into the water column of the borehole. At the point where the tape indicates signs of getting slack the reading must be taken where the tape crosses the top of the borehole casing.

  The depth of the boreholes can also be measured by using a measuring tape or a rope with a weight tied at the one end. This method is recommended as the water level meter is expensive and can get damaged during the process.

  Measuring the depth by these methods is not hundred percent accurate but will give a good indication of the borehole depth. For a hydrocensus survey this is usually sufficient but should greater accuracy be needed or when it is not possible to gain access to the borehole with the above methods as the borehole is equipped and it is critical to get the borehole depth then it will be necessary to lower pipes down to the bottom of the borehole in order to measure the depth. This will require the use of a tripod or mechanical equipment that is normally used for the installation of the equipment for the pump testing of a borehole.

  The borehole depth can also be determined by doing a camera survey; the advantage of this method is that the water strikes can then also be recorded.

  If the original borehole depth is known it is important that the depth is measured during the hydrocensus as it will indicate whether a borehole has collapsed over the years. This phenomenon can contribute to the declining in yield of the boreholes over time. The drilling of farm boreholes is usually ceased within a couple of meters after a water strike and when collapsing occur the water strike area can be neutralised in a great way as the farm boreholes are seldom equipped with casing to the bottom of the borehole.

- **Depth of the water strikes.** This information is usually not available but some land owners do keep documentation of the boreholes while being drilled. With the water strike and water level known it will be possible to determine when the borehole will become dry should the water level decrease over time. The mining company can thus act pro-actively in replacing the borehole should it been impacted upon.

- **Borehole equipment.** The type of equipment that a borehole is been equipped with, being a windmill, mono or submersible pump must be noted as well as whether the equipment had been up or down graded over the years, and if so the reasons therefore. The depth at which the equipment is installed must also be noted. The model and size (kilo watt) of the mono or submersible pumps must be documented as the yield of the borehole can be derived from the pump capacity.

- **Borehole use.** The use of the boreholes must be documented, for example are the boreholes been used for human consumption, livestock watering, irrigation or a combination thereof.

  If boreholes are used for irrigation the following must also be obtained:
    - hectares currently under irrigation
    - number of months irrigation is done
    - crops that are cultivated
    - hectares previously irrigated and the years when this was done

- **Boreholes yields.** In most cases land owners are able to give an idea of the yield of the boreholes which are either derived from the yields delivered by the installed equipment or from the observations made by the driller during the drilling of the boreholes (normally from the blow yield). Although this is not a hundred percent accurate reflection of the borehole yields it does provide acceptable figures for the purpose of a hydrocensus survey.

  In areas where irrigation is done land owners usually have some sort of documentation on the yields of the boreholes as the boreholes most likely have been tested before being equipped.

  The yields of some of the Department's monitoring boreholes are also documented in the NGDB. In some instances the yields might not be accurate as they are blow yields measured when the boreholes were drilled, but at least provides an indication of the yield of the boreholes at the time.

- **Photographs.** It's good practice and highly recommended to take photos of the boreholes as it can be very useful to identify a specific borehole during later surveys as it happens that infrastructure with the boreholes numbers on are removed at times. The photographs will also be of great help where land owners refused that the borehole numbers be placed on the infrastructure especially if boreholes are closely spaced.

10.5.3 Water levels

During a hydrocensus the water levels of all the boreholes (where practical possible) must be measured. In most situations the water levels at equipped boreholes can be measured by moving the base plates with a crow bar to create just enough space for the water level meter probe to be lowered down the borehole.

There may be boreholes where the base plates cannot be moved; in such cases holes for the water level meter probe must be drilled in the base plates to gain access for the measuring of the water levels.

For the drilling of the base plate holes a generator and a high Watt (industrial) drill are required. It's recommended that tungsten drill bits of different sizes be used, to drill firstly an 8 mm hole, followed by a 12 mm and ending with an 18 mm hole as the water level meter's probes are normally 16 mm in diameter.

As a standard the water level meter readings are measured at the top of the borehole casing and the length of the casing above ground level must also be measured in order that the correct water level readings can be calculated.

At wells the position where the readings are taken must be marked to ensure that follow up measurements would be taken at the same position. If this procedure is not followed the readings may be taken at a different position as the circumferences of the wells are usually a couple of meters and significant height differences can occur around the circumference of a well that will influence the accuracy of the readings.

When water levels of boreholes equipped with mono or submersible pumps are measured, it must be noted whether the borehole was pumped at the time or not. If a borehole was not pumped when the water level was measured it must also be noted how long before the reading was taken the pump was switched off. In this way variances in water levels taken over time can be explained.

For boreholes equipped with windmills it is advisable to note whether the wind was blowing when the readings was taken and also indicate the strength of the wind at the time being moderate, strong or very strong as this can have a huge influence on the water levels especially in the case of low yielding boreholes.

The land owners must be asked whether they have historic water levels of their boreholes as some of them do monitoring from time to time. If any data are available it must be recorded during the hydrocensus as well.

A list with the boreholes as numbered during the hydrocensus together with the measured water levels must be submitted to the land owners. This will ensure that both parties are on the same page regarding the boreholes for future monitoring and reference.

On the mining properties the water levels of the exploration boreholes must be recorded. If there are numerous boreholes a couple must be selected covering the entire mining area, also identify a number of additional boreholes around the proposed pit areas to be monitored. Study the mine plans before selecting these monitoring boreholes to ensure that the boreholes will not be demolished by the mine activities and infrastructure developments.

10.5.4 Borehole co-ordinates

The co-ordinates of all the boreholes whether in production, not in use, dry or blocked must be taken. Although the Z co-ordinate or elevation of hand held global positioning systems (GPS's) are usually inaccurate for a couple of meters the Z co-ordinate must be recorded as it can still provide a fairly accurate reading of the water situation of an area when presented as water levels above mean sea level.

Before any fieldwork is done a decision must be taken regarding what co-ordinate system is to be used not only for the hydrocensus at that time, but also for future surveys as it can get a bit confused and accuracy are lost if co-ordinates are taken in different formats and conversions have to be performed each time. It is also preferable that the same co-ordinate system is used for the hydrocensus as the one being used by the mining company. Where possible it's recommended that WGS84 is used as it is the most widely used system.

All the information as discussed above must be recorded on a field report form, an example can be seen under Appendix A.

10.5.5 Geological information

Normally the land owners do not have any geological profiles of the boreholes on their properties but in some instances they can provide an idea of the geology as was encountered during the drilling.

The information must be recorded and stated that the observations were obtained from the land owner and as such will most probably not be hundred percent correct.

During the desktop study the NGDB must be searched for any geological information on the monitoring boreholes of the Department.

10.5.6 Rainfall data

Rainfall plays a major role in the recharge mechanism of the groundwater in an area and provides insight in interpreting the water level behaviour especially over time. For most areas a data point or two (either in the hydrocensus or in the nearby area) will be found on the web page of the Weather Bureau.

The land owners are usually a good source of rainfall data and at some farms recording are done by generations stretching over decades. If ”old” data (usually up to the 1970’s) is obtained make sure to ask if the data has been converted to millimetres as the old data was measured in inches and later in points. Converting the data measured in inches and points to millimetres it must be multiplied by 25.4 and divided by 4 respectively. Request the land owners to continue with the rainfall monitoring.

10.5.7 Water chemistry

The monitoring of the water chemistry forms an integral part of any hydrocensus and it is essential that a base line is established before any mining activities commenced. The baseline is important as it is used for reference to compare the water chemistry over time as the mining activities continue to develop in the area.

During the inaugural hydrocensus the ideal would be to sample, where practically possible, all the boreholes that are recorded during the hydrocensus. If a significant number of boreholes are in the hydrocensus area the financial implication thereof normally restrain the number of samples to be taken for analysing. If this is the situation care must be taken that the samples are representative of the farms and the hydrocensus area in a whole.

Where a number of boreholes are spaced closely to each other (approximately 50 to 100 meters) it will be sufficient if only the operational boreholes are sampled. For the mining areas samples must be taken at all the boreholes visited during the hydrocensus.

Wells and open boreholes must be sampled by bailing while samples at equipped boreholes can be taken at dams where the water is being pumped too or at taps should it been installed on the pipelines from the boreholes.

Record the borehole numbers (with a permanent marker) on the sides of the sampling bottle as well as on the cap as the numbers on the sides sometimes smudge a bit due to handling and scouring against each other. The sampling bottles must be placed in a cool box and send to the laboratory as soon as the hydrocensus is completed.

10.5.8 Water infrastructure survey

The aim of the water infrastructure survey is to get a holistic view of the water distribution network on the farms before dewatering commenced. If an impact should later be confirmed the survey data will come in handy in determining the extent of the assistance to be implemented as reference exists on the usage and infrastructure associated with every borehole.

In this way the volume of water needed to replace an impacted borehole is known and the necessary actions can be done in addressing the water shortfall in the specific areas that was previously supplied with water by the impacted borehole.

In consultation with the land owners the following must be recorded during the water infrastructure survey:

- The pipeline distribution network from the boreholes to the different end users indicating whether the water is been utilised for domestic, livestock, irrigation or for a combination of the usages.
- The position of the dams and water troughs used for livestock watering. The dam sizes must also be noted.
- The pipeline distances from the boreholes to the dams and water troughs. It is not necessary that the distances be physically measured as it can be determined fairly accurate from maps where the positions of the dams and troughs has been plotted by the land owners.
- The number of livestock that is supplied with water from a specific borehole will vary over time due to the rotational grazing system that is used; it is thus important that the maximum number of stock that gets water from a borehole at a given time be noted.

After the survey maps must be drawn capturing the pipeline network, the position of the dams and troughs and indicating the maximum number of stock supplied with water from the various boreholes. It's recommended that the maps be done in GIS format; this way it can be updated when necessary.

The maps must be printed and distributed to the respective land owners for review where upon corrections must be made on the GIS system if necessary. The land owners must also update the maps and submit the data should the distribution network on the farms change due to boreholes and pipelines taken out of production or new ones added to the system or should there be an increase/decrease in the water use from a specific borehole over time.

10.5.9 Pumping tests

Usually during the exploration phase of a mining project a number of pumping tests are performed to determine the hydrological characteristics of the aquifers on the project site. The pumping tests are performed either to determine if sufficient water is availability to sustain the proposed mining operations or to determine the rate of dewatering required to lower the groundwater levels in order that the mining operations will be kept dry and safe.

If irrigation is done in the hydrocensus area it is recommended that pumping tests are performed on these boreholes to determine their sustainable yield before the mining operations and water abstraction commence. If it is not possible that all of the boreholes be tested then at least two boreholes per farm, a medium and strong yielded borehole.

Should it not be possible for any testing to be done the information obtained from the land owners regarding the borehole yields, pump capacity, the crops that are cultivated and the hectares that are under irrigation at a time must be used to make a best calculation on the sustainable yields of the boreholes.

The main reason for the pumping tests is to determine a baseline for the borehole's yields and each borehole's contribution to the irrigation practices on the respective farms in the hydrocensus area. Should any borehole be impacted upon at a later stage it would be possible to negotiate with the land owner on the volume of water to be replaced as baseline data does exist.

If the volume of water cannot be supplied by either new boreholes drilled on the farm or from a pipeline it will be possible to determine the loss of income the land owner must be compensated with for the crops that no longer can be produced due to the loss of water from the specific boreholes.

For the testing it would be best to appoint a registered pumping test contractor. In doing so the integrity of the testing results cannot be questioned by third parties as such a situation can arise should the tests be performed internally by the mining company.

Before the testing is to be undertaken it must be confirmed at the Department whether a farm is registered for irrigation as well as the volume therefore. It is recommended that only the boreholes on the farms that is at the time of the hydrocensus, or in the past, being used for irrigation (and are registered for irrigation), be tested.

If the boreholes that are to be tested being utilised shortly before (12 hours or less) sufficient time must be allowed for the recovery of the water level to its static level. A step drawdown test (SDT) consisting of between three to five steps must be done with the discharge rate to be increased at hourly intervals. If the borehole yield is unknown start with a relative low yield, for example 1 or 2 L/s to get an idea of the water level drawdown where after the yield can be increased significantly should the drawdown be only a couple of centimetres.

The available water head (distance between the static water level and pump equipment) must also be taken into account when the discharge rate is adjusted for the next steps as best results will be obtained if about two thirds of the available water head has been drawn down during the SDT series.

If after the third SDT the water head has only been drawn down for example less than a metre or to the pump inlet the SDT’s must be repeated with the SDT’s done at higher and lower discharge rates respectively. After the SDT’s the water level should be allowed to recover to at least 90% of the static water level before further testing should commence.

The SDT’s will give a good indication of the discharge rate at which the constant drawdown tests (CDT) must be performed. The SDT discharge rate that draws the water level down to just above the hallway mark of the available water head is usually a good rate for the CDT.

If time and cost is not a factor the CDT’s must be performed over 72 hours, if not possible a 48 hour or at least a 24 hour test. To get a proper indication of the sustainable yield of a borehole used for irrigation, it is recommended that CDT’s not shorter than 24 hours is performed.

In situations where an indication is required on the yield of a borehole to determine whether it can be equipped with a windmill or pump, CDT's shorter than 24 hours should be in order. After the test the water level recovery must be measured up to at least 90% of the static water level.

It is advisable that a camera survey be done together with electrical conductivity (EC) and pH profile logging on the boreholes as well. Information to obtain from the camera survey is the depth of the (water) fractures and the casing while the condition of the borehole sides and casing must also be noted.

The electrical conductivity (EC) and pH logs are done to determine whether the depths of the water strikes/water bearing fractures can be identified in the borehole profile and these are then compared with the camera survey's information. Usually a good comparison is obtained between the electrical conductivity (EC), pH profiling and the camera logging methods in determining the fracture depths.

With the water levels and depth of the fractures known it will be possible to make predictions on the "life expectancy" of the boreholes when evaluating the monitoring data, as it will give an indication which of the boreholes are heading to dry up should a decline in the water levels occur.

The pumping test and camera logging data will most definitely help in investigations should complaints be received stating that the yields of irrigation boreholes declined. On repeating the camera logging it will be possible to see whether collapsing of the borehole had occur and fractures were eliminated in the process. It will also be possible to see if closing (maybe due to over utilisation) or calcification of the fractures occurred, all possibilities which individually or in combination will have a negative impact on the yield of a borehole.

With this detail information available the company is placed in a position to act proactively should it be observed that an impact from dewatering is starting to manifest on the boreholes used for irrigation.

10.5.10 Database

One of the most important aspects of a hydrocensus or any investigation is the capturing of the data into a database after the day's fieldwork. In many instances this is being neglected until the end of the hydrocensus. By doing this there is always a chance that some data may be lost; it is thus best to capture the data after the day's fieldwork as the discussions being held is still fresh in one's mind.

It's recommended that the data be captured in a database customise for the display of hydrogeological characteristics for example the WISH database. The data fields of the database consist of the following:

- Basic information – borehole number, co-ordinates, farm name
- Borehole construction
- Geology
- Borehole yield
- Chemistry
- Rainfall
- Water level

The above is the main data fields but additional ones for example borehole discharge can be added into the database should the necessity exist. The WISH database is obtainable at the Institute for Groundwater Studies at the University of the Free State.

It is important that the data be captured as a lot of time and money are being spent during a hydrocensus for the collecting thereof. It is also important to ensure that the data is stored in a secure environment within the company's network. In this way the data can be retrieved at any time and the files cannot get corrupted or lost; this can easily happen when the data is being stored on a computer's local drive.

10.6 SET-UP OF A MONITORING NETWORK

The question around the exact number of monitoring points for a specific monitoring programme is always debateable. The site specific conditions play a major role and will be pivotal in determining the number of points needed for the monitoring programme.

Other factors such as the geological setting of the aquifers, the monitoring objectives and what is needed to be monitored will all influence the number of points for setting up a successful monitoring programme.

The practicality in which the monitoring programme can be executed must also be taken into account as the hindering of access to monitoring points by either the topography or absence of consent from the land owners can play a major role in the set-up of the monitoring programme.

Another important aspect to consider during the set-up of a monitoring programme is the monitoring frequency. The cost of monitoring is related to the number of monitoring points and the frequency of the monitoring programme.

It is important that the aspect of cost and the amount of information the hydrogeologist can gain from the monitoring programme be optimised.

Factors such as distance and accessibility to the monitoring points must also be taken in consideration when a decision is made on the monitoring frequency. In situations where monitoring positions are spread over a vast area or access to the monitoring points are problematic as it is difficult to get hold of the land owners or the monitoring points are in inaccessible areas it will be worthwhile to consider the option of installing loggers for water level monitoring.

The concept of data versus information must also be understood as one might add data to a database but not necessarily information, and thus knowledge about the hydrogeological system. The cost of the monitoring must commensurate with the value obtained from the monitoring programme.

10.6.1 Water levels

The site specific conditions will play the most defining role in determining the number of boreholes for the monitoring programme. An exact formulae to determine the number of monitoring points for a specific site cannot be given but from experience the monitoring programme should include about a fifth to a quarter of the hydrocensus boreholes.

Care must be taken that the selected boreholes are evenly distributed over the entire hydrocensus area. In areas where huge abstraction is done (for irrigation or town supply) it would be wise to add a couple of extra monitoring points close to those areas. If boreholes were drilled as indicated during the evaluation and analysing phase they must all be included in the monitoring programme.

Quarterly monitoring is a good start and it is recommended that this monitoring interval prevail for at least two years before scaling down is considered. If the monitoring interval is later scaled down to bi-annual or annual a couple of key boreholes must however still be monitored on a quarterly base to ensure that a good series of data are collected through the different dry and wet periods over the years.

In addition to the quarterly monitoring it is recommended that the hydrocensus will be repeated at least every four years.

If possible it would be of great value if a couple of boreholes (ones in strategically positions close to areas where huge water abstraction is done for irrigation or town supply or boreholes that are not easily accessible due to the topography) will be equipped with data loggers. The time interval for readings can be set at a reading per day.

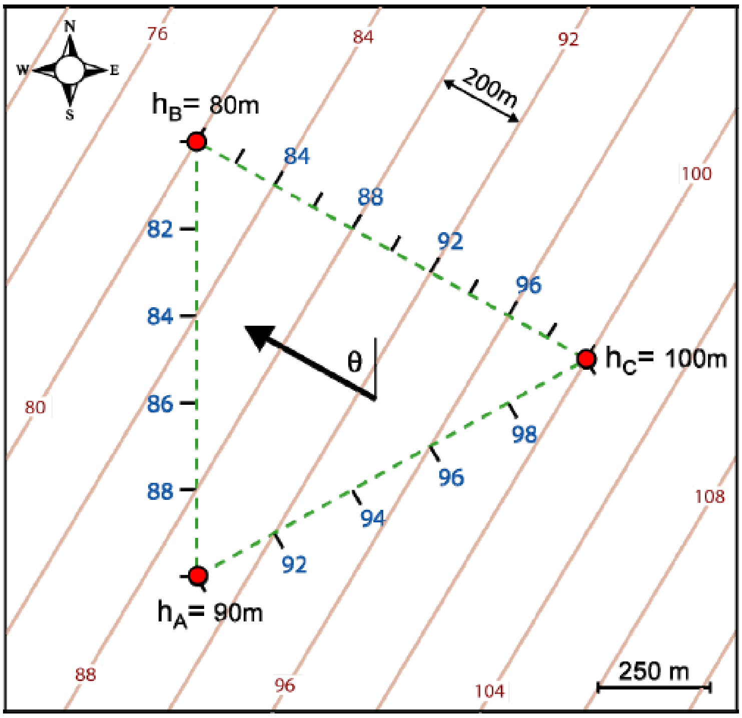
These boreholes can then be visited bi-annually or once a year for the download of the data instead of being visited quarterly for water level monitoring. Care must be taken for the protection of these loggers as they easily get stolen or vandalised. This is especially the case with boreholes close to public roads from where it is visible that a borehole is equipped with instrumentation.

Before any mining activities started the water level monitoring on the mining areas can also be done on a quarterly interval. If groundwater is abstracted on the mining site during the construction phase for the infrastructure and civil works, the monitoring interval must be change to monthly.

When dewatering or abstraction for the mining activities commences the monitoring for the abstraction and close by monitoring boreholes must be done two weekly or even weekly depending on the site conditions. The rest of the monitoring boreholes on the mining areas can still be monitored on a monthly interval.

The general assumption regarding groundwater flow is that it mimics the surface topography meaning as the topography rise or dip so does the water level. This assumption is in most cases a fair reflection of the groundwater flow but in areas where groundwater is abstracted at large scale the groundwater flow direction in certain areas will change towards the abstraction points and not follow the surface topography anymore. The areas where the flow directions change are indicative of being impacted by groundwater abstraction.

A couple of methods can be used to accurately determine the groundwater flow and hydraulic gradient, one being three boreholes drilled at equal distances from each other in triangular form. The methodology is described and illustrated (according to Dingman, 2002) in Figure 46.



Source: Dingman (2002)

Figure 46: Determining of groundwater flow and hydraulic gradient

Three boreholes are drilled 1000 m apart in a triangular position. The surface elevations of boreholes A, B and C are given as 95, 110 and 135 m respectively. With water levels at 5, 30 and 35 m the hydraulic head of the boreholes are calculated as follow:

$h_A = L_A - s_A$ = 95m – 5m = 90m

$h_B = L_B - s_B$ = 110m – 30m = 80m

$h_C = L_C - s_C$ = 135m – 35m = 100m

where *L* is the elevation of the boreholes at land surface

With the three hydraulic heads known, the heads of any points on the lines between them can now be found. Contours can now be drawn by connecting the points of the same heads. The contours must be parallel and equally spaced.

The direction of flow is perpendicular to the contours, θ=60° in the north-west direction. The hydraulic gradient can be expressed as:

$$\frac{dh}{ds} = \frac{4\text{ m}}{200\text{ m}} = 0.02$$

where *s* is the direction of flow

It's recommended that these sets of triangular monitoring boreholes be drilled at the edges of the mine properties in the four main directions that the groundwater flow direction can be determined. It would be best if these sets of boreholes can be drilled before abstraction is done at the mining area.

If an impact starts to manifest due to the abstraction at the mining site the flow direction of the triangular boreholes that indicated the groundwater flow direction away from the mining area when the boreholes were drilled will now indicate that the groundwater flow direction is towards the abstraction boreholes in the mining area. If this observation is being made and the triangular borehole set is at the edge of the mine property the impact will start to spread onto the adjacent private properties.

10.6.2 Chemistry

Where possible the boreholes as selected for the water level monitoring programme must be used for the chemistry monitoring as well as this will simplify the monitoring network and save time and cost during the monitoring surveys. The boreholes for domestic usage and the ones identified with anomalies exceeding the drinking water standards must be included in the monitoring network if they are not part of the boreholes selected for the water level monitoring programme.

In the regional area the sampling must be done on a bi-annual interval and the samples analysed for the major inorganic constituents. The bi-annual monitoring must continue for at least two years before the programme are to be revised. When the hydrocensus is repeated all the sampling points as covered during the inaugural hydrocensus must be sampled again.

On the mining sites all the hydrocensus boreholes must be sampled during the quarterly water level monitoring programme and analysed for the major inorganic constituents. On a bi-annual interval the samples must also be analysed for SOG and the VPH C10 to C40 range.

When the mining sites are developed dedicated monitoring boreholes must be drilled for monitoring around the workshops and plant infrastructure. These boreholes must be monitored quarterly for inorganic, SOG and VPH analyses.

When the mine's dewatering/abstraction boreholes are in operation the following analyses must be done:

- Quarterly monitoring of the inorganic chemical quality of the groundwater
- Bi-annually analysing for SOG and VPH, the VPH must include analyses for:

- GROs – Benzene, Toluene, Ethyl benzene, m+p Xylene, o-Xylen and MTBE
  - DROs (C10, C12, C14 & C16)
  - PAH – Acenaphthene, Acenaphthylene, Fluorene, Phenanthrene, Anthracene and Naphthalene
- Annual analysing for heavy metals

The drinking water points on the mine must be sampled monthly and subjected to inorganic and bacteriological analyses. The bacteriological analyses must comprise of total coliforms and E.coli.

Waste water from workshops that is diverted to oil separators must be analysed monthly for SOG. If a sewage plant is on site bacteriological and waste water analyses must be done on a monthly interval on the water before and after treatment. The analyses should include the following:

- Orthophosphate (PO_4) as P
- Ammonium (NH_4) as N
- Nitrate (NO_3) as N
- Nitrite (NO_2) as N
- Total Kjeldahi nitrogen (TKN)
- Total Phosphorus (TP)
- Chemical Oxygen Demand (COD) & (COD) filtered
- Suspended Solids (SS)
- Oil & Grease (SOG)
- Total Coliforms and E.coli
- Faecal Coliforms

Monthly inorganic analyses must also be done on samples at the different plant processes, the process return and slimes discard dams. If rivers or drainage channels cross or are close to the mining areas monthly samples must be taken for inorganic analyses. If the river or channel is not perennial sampling must be done whenever flow does occur. Sampling must be done up and downstream of the mining properties.

The site specifics and the commodity to be mined will determine the pollution that might result during the mining operation. It is thus of the utmost importance that these factors are taken in consideration right from the start of implementing the chemical monitoring, to ensure that the parameters that need to be monitored are included in the monitoring programme. This will ensure that the correct base line data is obtained before the mining activities commenced.

10.6.3 Rainfall

Whether the rainfall points are adequate will depend greatly on the site conditions of the area as discussed in the evaluation and analysing phase. A minimum of at least two measuring points are needed in the hydrocensus area, one in the low and in the high elevating areas respectively, and another monitoring point at the mining site.

If rainfall data are not available from the Weather Bureau or the land owners in the hydrocensus area rainfall stations have to be installed that record and send the rainfall data to a web site from where it can be electronically retrieved.

10.7 EVALUATION AND ANALYSING OF DATA

The evaluation and analysing of the data plays an essential role in understanding the hydrogeological characteristics that is indispensable in building the conceptual model of the area. The evaluation and analysing of the hydrocensus data comprise of the following.

10.7.1 Water levels

For the evaluation of the water level data the following must be taken into account to determine whether the data is sufficient and representative of an area:

- Are the boreholes evenly spread over the area or clustered in certain areas with no or only a few boreholes in some areas? If the latter is predominant it will be necessary to drill additional boreholes.
- Where boreholes are fairly spread over an area but significant distances occur between them it might be necessary (depending on the site specifics) that boreholes be drilled between the existing ones.
- If there are huge differences in the water levels (irrespective if the boreholes are spaced close or far from each other) it would be wise to consider drilling additional monitoring boreholes to get a better understanding of the hydrogeology and geology in that area.
- Another important aspect to take in consideration is whether there are one or two (or more) aquifers present in the area. Normally during the desktop study this will be interpreted from the geological and hydrogeological reports of the area. If a primary and secondary aquifer is present care must be taken in the evaluation of the data to determine which borehole represents which aquifer.

In an area where there is a primary and secondary aquifer about ninety percent of the farm boreholes usually represent the upper primary aquifer while the boreholes drilled by the mining companies predominantly measure the water level of the deeper secondary aquifers. If difficulty is experienced in classifying the boreholes to a specific aquifer a number of shallow and deep boreholes must be drilled to clear any misinterpretation that might result from the interpretation of the hydrocensus data.

When constructing the deeper boreholes care must be taken that the shallow aquifer is sealed off in a proper way otherwise the water level will not be presentative of the deeper aquifer but a mixture of the two aquifers. The hydrogeologist must be on site during the drilling of the shallow and deep boreholes and co-ordinate the construction of the boreholes.

The above evaluation of the water levels is applicable for boreholes on both the regional and mine site areas.

10.7.2 Chemistry

All the samples must be analysed for major inorganic constituents and the results evaluated against the Department of Water Affair's water quality guideline for domestic and irrigation use and livestock watering.

If the analyses indicate anomalies on the mine site areas further investigation needs to be done to find the reasons thereof. It is also recommended that the monitoring boreholes on the mining areas be analysed for SOG and VPH for the C10 to C40 range as there is a good chance of some sort of pollution due to diesel/oil spillage on especially the older exploration sites. If any pollution is detected by the analyses, remediation measures must immediately be put in place.

Although the mining company is not obliged for further investigations if the chemical analyses of the regional boreholes exceed the limits of the Department's water quality guidelines it will however be advantageous if it can be accommodated by the mining company to determine the reasons for the exceeding of the standards.

10.7.3 Rainfall

The number and position of the measuring points must be evaluated whether adequate data are obtained for the area. More data points will be necessary in hilly and mountainous areas as rainfall can vary significantly over small distances in these areas comparing to areas where there is not much difference in elevation over the study area.

Another factor to take in consideration when evaluating the representativeness of the data is the geology of the area. If the surface geology varies over the study area it would be advantageous to monitor the rainfall at each of these different geological areas as the recharge to the groundwater regime can vary significantly between areas of different geological contacts (for example where lavas and dolomite outcrops).

If rainfall data is available for the different geological areas it will assist in interpreting the water level behaviour and determining the recharge for the different areas. The latter is an important component in the compilation of the numerical model.

Sources for rainfall data are the Weather Bureau, the internet and the land owners in the hydrocensus area. If only limited data is available or the criteria as describe above is not met it is necessary that rainfall stations be installed over the area from where the data can be retrieved electronically from the office. At least one rainfall station must be installed on the mine site as well.

10.7.4 Pumping tests

As 90% of the South African aquifers are classified as fractured it is recommended that the pumping test data be analysed by the FC-method which has been specifically developed for determining sustainable yields of boreholes penetrating fractured rock aquifers in the South African environment.

The main reason why this method is preferred is that the yields determined by the FC-method for boreholes that are situated close to each other are more conservative as the abstraction of the nearby boreholes can be taken into account which can't be done with most of the other pump testing analyses.

If the yield of a borehole is determined without taking the abstraction of nearby boreholes into account the yield of the borehole will not be sustainable over the long term and the borehole will be "damaged" and will most probably not be able to yield the volume of water as before.

10.7.5 Conceptual and Numerical Modelling

On completion of evaluating and analysing the water level, chemistry, rainfall and pumping test data the conceptual model developed from the desktop study must be updated and adjusted where necessary. If a numerical model is not yet compiled the hydrocensus data together with the data obtained during the desktop study would provide a sound basis for the developing of such a model.

If dewatering needs to be done for the planned mining activities, model simulations must be done to determine the dewatering volume needed. This will ensure that the pit areas can be kept dry in order for the mining activities to proceed in a safe manner. Simulations must also be used to determine the areas where a decline in water level is expected due to the dewatering activities.

Mass transport is also an important aspect to be simulated in order to determine the extent of pollution plumes should pollutants be spilled or generated on the proposed mining areas. This aspect is of great importance in areas where surface water is prominent, especially if rivers flow through the proposed mining areas or are in close proximity thereof.

10.8 INTERESTED AND AFFECTED PARTIES

10.8.1 Environmental Forum

As mentioned under the planning phase communication with the land owners is of cardinal importance. The establishment of an Environmental Forum is recommended, this can be done before or after the hydrocensus but it is important that feedback are given as soon as possible after the hydrocensus is completed.

The Forum is ideal for the setting up of communication channels between the mine personnel and the land owners. The water aspects are usually the main discussion point at these meetings but other environmental aspects like dust, sound and vibration monitoring and information regarding the planned construction at the mine site, housing developments and upgrading of infrastructure in the municipal area must also be discussed.

The Forum is also the ideal place for the distribution of the hydrocensus and quarterly monitoring reports of the regional area as some of the Interested & Affected Parties prefer the reports in hard copy and not via email.

If an environmental consultant or firm is already appointed by the company it will be best if they can be tasked to chair the Forum meetings as they will be on par with all the activities on the project site, the environmental laws and the application processes for the mining, environmental and water licences.

It is not recommended that the meetings be chaired by mining personnel as it can easily result that the I&AP feel intimidated and that the meetings are being manipulated by the mining company. If possible the meetings should preferable not be held at the mining company’s offices but at a neutral venue.

If an environmental consultant or firm is to be appointed for the meetings the following can be used as a guideline:

- At least five years experienced as an environmental consultant.
- Knowledge of legal requirements regarding monitoring and standards for all the environmental aspects for dust, noise and blasting (vibrating) monitoring but especially for the water domain as this will form the focus point in eighty percent of the meetings.
- Track record of work done in the specific area.
- Experience in chairing similar meetings would be advantageous.

Consultants must have the ability to steer and control the meetings to ensure that everybody has the opportunity to give their inputs. In situations where discussions get heated the consultant must call the meeting to order, see to it that the discussions stay focussed on the aspect and is not directed to any individual in person.

The success of such a forum lies in creating an atmosphere where anyone feel at ease to raise their thoughts and concerns and know that it will get the necessary consideration and attention. It is suggested that the meetings be held quarterly but the scheduling can be determined by the attendees.

Although the aim of the meetings is to engage with the land owners the forum must be open for attendance by residents of the nearby towns, the local municipality and other stakeholders in the area as well. It is important that representatives of the regional office from the Department of Water Affairs and Sanitation attend the first meetings that questions regarding the water licence can be answered first hand. This will give assurance to the land owners that the Department is involved in the area and committed to oversee the fulfilment of the licence conditions by the mining company.

The company’s personnel attending the meetings must always be well prepared to ensure that feedback and presentations are done in a clear and intelligible manner. This reflects heavily on the professionalism of the personal. The way in which the communication is done will also determine the trust that the I&AP will have in the company to address the environmental aspects.

If questions from the I&AP cannot be answered during the discussions or if there is uncertainty around certain aspects mention that it will be followed up and feedback given at the next meeting and very important keep word by doing so.

The Environmental Forum forms the instrument for communication between the I&AP and the company. If administered correctly a good relationship between the parties can be established through this medium.

In using this platform to communicate and provide feedback on the aspects relevant to the area to the I&AP it will secure a good relationship between the parties although differences of opinion on certain aspects will always be a reality.

If possible at all such a Forum must be established before the mining activities commenced as this will eliminate the uncertainties in a great way and create a more positive outlook if the surrounding communities are informed in advance of the transformation the area will be subjected to in the future.

10.8.2 Hydrogeological Representative

The most concerning factor for land owners in close proximately of mining activities is about the water quantity and quality. One of the best ways to address these concerns is to appoint a hydrogeologist of their choice to represent the local communities in that area. By doing this the mining company will indicate their dedication in protecting and managing the water resources in the area to the benefit of everyone.

The scope of work for the hydrogeological representative can be summarised as follow:

- Evaluate all monitoring information obtained from the hydrocensuses and monitoring programmes. Feedback in this regard to be done bi-annually at the Environmental Forum meetings.
- Should irregularities be identified in the data or areas where additional data need to be obtained a scope of work must be compiled in conjunction with the company's hydrogeological team.
- Review reports on water complaints investigated by the independent hydrogeologist and should an impact be identified the remediation measurements to be put in place must be evaluated.
- Discussions with land owners regarding the outcome of an investigation explaining the science and rationale behind the finding of the investigation.
- Act as technical specialist on behalf of the land owners should conflict situations arise.
- Be accessible for answering water related questions and provide advice where applicable for better management of the water resources on farms.
- If necessary visit farms where water and water quality problems were reported and submit report on outcome of investigation.

If a hydrogeological representative is appointed the land owners will have the assurance that all the monitoring and hydrogeological aspects are handled in the correct way (by the mining company) and that they have access to expertise advice on any water related aspect.

10.8.3 Procedure for the handling of water complains

It's important that a procedure for the handling of water related complaints be developed at the Environmental Forum meeting with the input from all the parties. An example of a generic procedure is as follows:

- Complaints to be received in email or writing where after it will be captured on the company's complaints register and a number be allocated to the complaint. The contact details of the person to whom the complaint must be send to must be given at the Forum. Complaint forms should be made available at the mine's Reception or Safety Offices.
- It should also be allowed that complaints be submitted at the Forum meetings should this be preferred by a person. At the meetings the complaint can either be submitted via the complaint form or the complaint can be noted in the minutes of the meeting where after the complaint must be recorded in the complaints register by the mine personnel.
- It is not advisable that complaints be submitted via phone as there is always the chance that the complaint can be misunderstood and the follow up actions be directed in the wrong direction to the dismay of the complainant. Should the mine personnel neglect to note the complaint in the complaints register there is no paper trail as in the case of a complaint written in the complaints register from where the progress on the complaint can be traced.
- After receiving of the complaint an independent hydrogeologist (appointed by the company) would visit the farm to investigate and capture all information at the site and from the land owner.
- The complaint would then be evaluated based on all available information obtained from the land owner, the field visit, the Department's NGDB and info from the hydrocensuses and monitoring programmes of the mine.
- The independent hydrogeologist would then draft a technical report indicating whether an impact is identified. If an impact is identified the following must be noted:
    - Loss of water from the boreholes must be estimated in terms of the boreholes usages as noted during the hydrocensuses.
    - Recommendations regarding assistance to be made.
- The report must then be reviewed and approved by the company's hydrogeologist and the hydrogeological representative of the agricultural community.
- If all the parties are in agreement the report are finalised by the independent hydrogeologist and submitted to the land owner.
- Discussion is then held with the land owner regarding the outcome of the investigation. If an impact is confirm the different options for assistance is discussed till agreement is reached where after the assistance is implemented.

- If agreement is not reached between the parties on the outcome of the report an action plan is to be compiled to obtain the necessary information in order that consensus can be reached. If the land owner experienced water shortages during this time the mine must give assistance until the investigation is completed and consensus is reached on whether there is an impact or not on the water resources.

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10.8.4 Water level meters

Land owners must be made aware of the importance of water level monitoring and encourage to take part in the monitoring thereof. It's recommended that the mining company supply water level meters to the land owners who indicate willingness in monitoring the water levels of their boreholes. It will be of great value if water level meters are not only distributed to land owners in the hydrocensus area but also further away to those who show interest in participate in the monitoring.

On delivery of the water level meters the land owners must sign a form acknowledging receipt thereof. The signed form must be kept by the mining company and a copy of the form must be given to the land owners. The following must be noted on the forms:

- A short discussion explaining the reasons for water level monitoring and the importance thereof.
- Mentioning that all data will be incorporated into the mine's database and be used for discussion at the Environmental Forums.
- Request that the water levels of the boreholes be measured on a monthly base and the data submitted to the mining company either via email to the hydrogeologist or at the Environmental Forums or at any ad hoc water meeting that is being held. Should the data be submitted at meetings it is requested that it must be in writing, in this way the integrity of the data will be retain.
- The contact details (email and cell phone) of the mine's hydrogeologist (or relevant person if the mine don't have a hydrogeologist) should the land owners want to discuss data, have inquiries, or want to submit data.

10.8.5 Requests from land owners

At times requests will be received from land owners asking for some sort of assistance. The most common requests are the following:

- **Water level monitoring or chemical analysing of boreholes that is not included in the quarterly and yearly monitoring programmes respectively.**

  If the boreholes are relative close to the existing monitoring network some thought must be given to include them as data from outside the monitoring network area are always advantageous. If the boreholes are far from the monitoring network the land owner can be asked to participate in monitoring the boreholes on his farm by offering him a water level meter.

- **Pumping tests of boreholes of which the land owners indicate that they intend to expand the use off or start to use in an intensive capacity in the future for their farming activities and thus need to obtain the sustainable yields of the boreholes.**

  It is recommended that the mine assist in this regard as this information would be very valuable should a dispute arise in future to determine whether these boreholes are being impacted upon or not. These boreholes can be tested by a small pump with a yield of up to 10 L/s for a maximum of 24 hours. The testing can be done by the mine personnel assisted by the land owner.

- **Requests asking the mine to assist in identifying targets for drilling.**

  Normally the mining companies have geophysical and geological data for the adjacent farms that can assist and with time spent on interpretation and evaluation of the data drilling targets can be identified. If exploration boreholes are present on farms this can also be made available to land owners.

It is recommended that where possible the mining company extends a helping hand to the land owners in assisting with the requests as this will without a doubt improve the relationship between the two parties. However these requests must be judged on merit, not lead to exorbitant cost and the assistance provided must add some value in improving the understanding of the hydrogeological characteristics of the area.

10.9 VALIDATION OF MONITORING NETWORK

Any monitoring network needs to be validated on a continuous base to ensure that it still complies with the monitoring objectives as determined. Over time situations might arise that some of the monitoring objectives as originally set are only partially met or are not necessary to be met any more due to:

- Changes in the environmental legislation.
- Adjustments or additions made to the water licence of the mine by the Department.
- An increase or decrease in the activities of the mine or that of other mines in the area.
- An increase or decrease in the water usage of the surrounding water users.

The validation of the monitoring network can be seen as a GAP analyses identifying the shortcomings, and also provide the opportunity that corrective measurements can be identified and implemented.

10.10 REVIEW AND UPDATE OF MONITORING NETWORK

The evaluation and analysing of the monitoring data will highlight the problems as experienced during the surveys and also indicate the areas where additional data is needed or areas where excessiveness of data is present.

Depending on the outcome of the evaluation and analysing phase the monitoring network will have to be reviewed and updated. This usually involves one or more of the following aspects:

- Expanding of the monitoring area by including boreholes on adjacent properties.
- Drilling of boreholes in areas where data is scarce and/or additional data is needed.
- Removal of boreholes from the monitoring network where a number of boreholes are located in an area that reflect the same water level and chemistry results.
- Changes in the interval of the water level and or chemistry monitoring.
- Adding or omission of parameters for chemical analysis.

It is recommended that the monitoring network also be adjusted when the following situations manifest:

- When a decline or rise of more than 3 meters in the water levels comparing to the previous hydrocensus readings are observed, the specific boreholes must be moved from the (yearly) hydrocensus scheduling to quarterly monitoring. This is only applicable for open boreholes as a variance of 3 meters in water level for an equipped borehole is not that uncommon between readings.

  However should big differences between the hydrocensus measurements occur (for example ten meters or more) it will be advisable to monitor those equipped boreholes on a quarterly basis as well.

- New boreholes drilled by either the mine or the land owners must be added to the list of boreholes for the next hydrocensus and subject to the collecting of all information as discussed under the data acquisition phase.

- If the chemical analyses of a borehole differ greatly from the previous results (for instance a number of parameters don't comply with the drinking water standards as was the case with the previous analysis) the borehole must be moved from the hydrocensus scheduling to bi-annual sampling.

The setup and development of a monitoring network is not a once off occasion but an iterative process that must be evaluated on a continue basis (at least once a year) and the necessary changes be implemented to ensure that the monitoring network give a true reflection on the behaviour of the groundwater resources in an area. If this process is not followed it will not be possible to protect and manage the groundwater resources in an effective way.

After the establishment of the pre-mining monitoring programme the follow-up monitoring surveys will not always involve all the stages (as illustrated in Figure 45) but in most cases shall comprise of a bit more compact version as indicated in Figure 47 below.

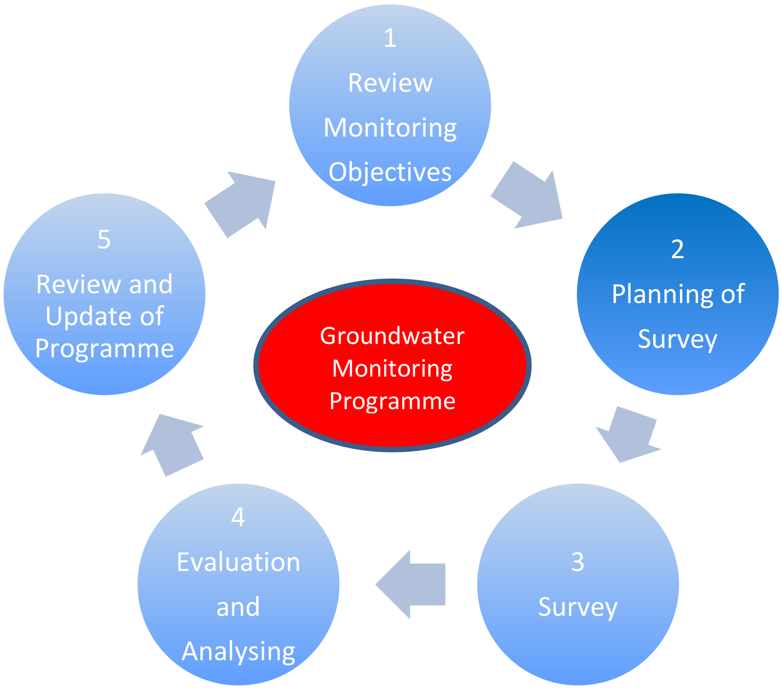

Figure 47: Stages of groundwater monitoring programme

Monitoring programmes will assist in obtaining the necessary information needed to develop the water management and monitoring programmes for mining operations to obtain the pre-mining hydrogeological condition of the aquifers in their operational areas. Monitoring forms the foundation on which the managing and protection of water resources are being built on.

The guideline for the set-up of a pre-mining groundwater monitoring network for open pit mines consist of the following phases namely; determining of monitoring objectives, desktop study, planning of hydrocensus, data acquisition during hydrocensus, set-up of monitoring network, evaluation and analysing of data, interested and affected parties, validation of monitoring network and finally the review and update of the monitoring network.

CHAPTER 11
CONCLUSIONS

On a global scale and in South Africa groundwater is an important freshwater resource for both socio-economic and environmental systems and in many areas forms the buffer during periods of drought. Two thirds of the country's rural population is depended on groundwater for their domestic needs while numerous towns are partially and others entirely dependent on groundwater as a source of water supply. Despite our dependence on groundwater the water resources in many parts of the country remained poorly understood and managed in the absence of appropriate monitoring data.

The mining industry consumes a relative small quantity of groundwater compared to some of the other sectors in the South African economy. This however does not alleviate the impact that mining has on the groundwater resources and still requires that the mining sector keeps on improving their efforts and try finding solutions to minimise the impacts that their operations have on the water quality and quantity aspects.

In the South African environment most open pit mining operations will require that mining be done below the regional water table which necessitate the implementing of a dewatering program. Besides the dewatering impact there is always a risk that the water resources be polluted as well. This risk will greatly depend on the type of ore mined, the chemicals used in the extraction processes and the effectiveness of the water management practices that are in place.

The mining sector annually spends millions on the remediation of polluted water resources. The classification and analysis of the pollutants are critical as this will identify the appropriate remediation measurements. Reliable monitoring data is thus vital in making informed decisions in the management and protection of the groundwater resources.

The main objectives of a monitoring programme, besides to be compliant to the environmental and water legislations as proclaimed in the various acts, are to obtain the necessary information. From this informed decisions can be made on a proactive basis to manage and protect the groundwater resources in an area.

Monitoring is without a doubt a management tool that if properly utilised can identify potential impacts on the surrounding environment that the necessary management plans can be developed in time. A good baseline characterisation is important to place potential future changes to the hydrogeological system into proper context.

Mining operators find it increasingly necessary to demonstrate to the public, regulators and NGO's that some changes to the hydrogeological systems resulted from natural variance or other external developments rather than from the mining activities.

The development of a monitoring network is not a once off occasion but an iterative process that must be evaluated on a continue basis and adjusted when necessary to ensure that the monitoring network is still effective in measuring the monitoring objectives as set out in the beginning of the programme.

The importance of monitoring cannot be emphasised enough as it is the foundation on which the managing and protection of water resources are being built on. The importance of monitoring is further propagated by the slogan:

If you don't measure and monitor you cannot manage.

As mentioned in the discussions the site conditions plays an integral part in the set-up of a monitoring network and must be recognised at all times. The aim of this dissertation is that the guidelines for the set-up of a pre-mining groundwater monitoring network for open pit mines will be of assistance in the planning, the execution of the fieldwork and data acquisition phases of the hydrocensus. Furthermore that it will provide the necessary guidance in establishing a monitoring programme that will be effective in identifying impacts on the environment timeously that action can be taken pro-actively.

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APPENDIX A

Hydrocensus Borehole Information Form

HYDROCENSUS LAND OWNER DETAILS			
Physical address			
Postal Address			
District/Town			
Owner			
Contact person			
Cell		*Tel*	
Contact person			
Cell		*Tel*	
Fax			
E-mail			

Hydrocensus borehole information										
Farm name		Borehole number								
Coordinates	X-coordinate		Y-coordinate		Z-coordinate					
Water level		Date	-							
Locality		Date drilled								
Borehole depth		Borehole diameter		Collar height						
Estimated yield per hour		Test certificate	Yes		No					
Reservoir & size										
Water strike/s depth										
Existing number / name of borehole										
Borehole equipment	Submersible		Mono pump		Windmill		Hand pump		Other	

Current* and Future Use Information								
In use	Yes		No		Other			
Current and future use	Irrigation		Livestock watering		Domestic		Other	

Sampling Information				
Sampler		Date sampled		Photo of borehole
Sample type		Static water level		
Short locality description				
Comments				

SUMMARY

After the discovery of minerals mining formed the backbone of the South African economy for more than a century. The contribution that mining had on the economy is probably best reflected when the country's currency was changed to the Rand (which refers to the gold deposits of the Witwatersrand) in 1961.

Although there have been a down scaling in production of some minerals over the last couple of decades the country is still a large producer of numerous commodities and dispose of mineral deposits matched by only a small number of countries. Without a doubt mining will still prevail as a pillar of the economy in the years to come.

Although the mineral industry in South Africa consumes a relatively small quantity of groundwater abstracted (13 percent) the use of water at mining operations has the potential to affect the quality of surface as well as groundwater. The abstraction of groundwater to ensure safe mine activities at especially open pit mines have a negative impact on the surrounding water sources.

Groundwater play an essential role in South Africa as two thirds of the country's rural population is depended on groundwater for their domestic needs while it is also an important source of water for numerous towns. The management and protection of the country's water resources cannot be stressed enough as South Africa is ranked as the 30th driest country in the world.

The protection of the country's water resources gain momentum in the late 1990's when a number of Acts, the important ones from a water resource point being the National Environmental Management Act (NEMA); Act 107 of 1998 and the National Water Act, Act 36 of 1998 were promulgated that placed strong emphasis on equitable access for all residents to the country's water resources.

In the mining sector groundwater monitoring are usually done for two reasons, the one to obtain the necessary data/information needed to develop the water management and monitoring programmes for the mining operation to effective protect and manage the groundwater resources in the area they operate within and the other to comply with the environmental and water licence regulatory requirements.

The literature review and in particular the first-hand experience as documented and described in the case study form the corner stone of the guideline developed for the set-up of a pre-mining groundwater monitoring network for open pit mines. The different phases for the set-up of the monitoring network is discussed in detail in the dissertation and can be summarized as follow:

- **Monitoring objectives -** For any monitoring programme to be successful clear objectives must be set on what exactly needs to be achieved with the focus on efficiency and practicality. A thorough understanding of the hydrogeological characteristics of the aquifers must be gained that informed decisions can be taken to effectively protect and manage the water resources.

- **Desktop study** – A desktop study must be performed in order that all available geological and hydrogeological reports, data and information of the area are sourced that a conceptual model of the area can be formalized. This is vital in the planning of the fieldwork to obtain the necessary hydrogeological information needed to fully characterize the water resources in the study area.

- **Planning of hydrocensus** – Evaluation of the data sourced during the desktop study will give guidance in demarcating the area that needed to be surveyed during the hydrocensus and also provide a good indication what to expect during the census. Effective and good communication with land owners regarding the hydrocensus is of cardinal importance as this will determine right from the start the success of the hydrocensus and the co-operation from the land owners.

- **Data acquisition during hydrocensus –** During a hydrocensus not only water level data must be obtained but all available information regarding the boreholes for example the water strikes and depths, yield and usage, geology and water quality. Other data such as rainfall and information on the water infrastructure network and the number of stock dependant on a watering point is also important and must also be noted during the hydrocensus survey.

- **Set-up of a monitoring network** - The exact number of monitoring points for a specific monitoring programme is always debateable. The monitoring objectives together with the hydrogeological conditions plays the major role in determining the number and position of the monitoring points while the site specific conditions (accessibility and topography) must also be taken into account when designing the monitoring programme.

- **Evaluation and analysing of data –** Evaluation and analysing of the monitoring data is indispensable in understanding the hydrogeological characteristics of the aquifers in an area and to update and adjust the conceptual model as outlined during the desktop study.

- **Interested and affected parties** – The efficiency and success of a monitoring programme will greatly depend on the relationship between the mining company and the land owners. It is necessary that an Environmental Forum be established that can be used as a platform for communication between the parties to ensure that the environmental aspects of which water is usually the main discussing point can be administered and managed in an effective manner that will be beneficial to both parties.

- **Validation of monitoring network** – The monitoring network needs to be validated on a continuous base to ensure that it still complies with the monitoring objectives as for example changes in the mine's water usages or modifications in the environmental legislation will necessitate that the monitoring objectives be adjusted accordingly.

- **Review and update of monitoring network** - The evaluation and analysing of the monitoring data will indicate areas where additional data is needed or where excessiveness of data is present. In data scarce areas it might be necessary for boreholes to be drilled or that the monitoring area be expanded to include boreholes from adjacent areas while in areas where there is excessive data the monitoring points can be decreased or the intervals between the monitoring periods can be lengthened.

The set-up and development of a monitoring network is not a once off occasion but an iterative process that must be evaluated at least once a year and the necessary changes implemented where necessary to ensure that the monitoring programme give a true reflection on the behaviour of the groundwater resources that are monitored otherwise it will not be possible to protect and manage the groundwater resources in a responsible and effective way.

Taking in account that every mining activity and its site conditions is unique it must be bear in mind that some of the guidelines described in the dissertation for the set-up of the monitoring network might not be practical or applicable and will need to be adjusted to fit the specific site conditions.

OPSOMMING

Na die ontdekking van minerale het mynbou die ruggraat gevorm van die Suid Afrikaanse ekonomie vir meer as ‘n eeu. Die bydrae wat mynbou tot die ekonomie gemaak het word waarskynlik die beste weerspieël toe die land se geldeenheid verander is na die Rand (wat verwys na die goud afsettings van die Witwatersrand) in 1961.

Alhoewel daar ‘n afname was in die produksie van sommige minerale oor die laaste paar dekades is die land nog steeds ‘n groot produsent van verskeie minerale en beskik oor minerale afsettings wat net ge-ewenaar word deur enkele lande. Die mynbousektor sal sonder twyfel nog vir jare ‘n steunpilaar wees vir die land se ekonomie.

Die minerale industrie in Suid Afrika verbruik ‘n klein volume (13 persent) van die grondwater wat ontrek word maar die gebruik van die water tydens die mynbouprosesse skep die geleentheid dat die kwaliteit van beide oppervlak sowel as grondwater benadeel kan word. Die ontrekking van grondwater om te verseker dat mynbou aktiwiteite veilig by veral oopgroefmyne gedoen kan word het ‘n negatiewe impak op die grondwaterwaterbronne in daardie areas.

Grondwater speel ‘n belangrike rol in Suid Afrika siende twee derdes van die land se landelike bevolking van grondwater afhanklik is vir huishoudelike gebruik terwyl dit ook ‘n waterbron vir verskeie dorpe is. Die bestuur en beskerming van die land se waterbronne kan nie genoeg beklemtoon word veral gesien in die lig dat Suid-Afrika gereken word as die 30ste droogste land in die wêreld.

Die beskerming van die land se waterbronne het eers in die laat 1990’s momentum gekry met die proklamasie van verskeie wette in besonder die Nastionale Omgewingsbestuurswet, Wet 107 van 1998 en die Nasionale Waterwet, Wet 36 van 1998 wat sterk fokus geplaas het op die gelyke toegang tot die land se waterbronne vir alle inwoners.

Grondwatermonitering in die mynbousektor word basies vir twee redes gedoen, naamlik om die nodige inligting/data te bekom vir die opstel van ‘n waterbestuurs- en moniteringsprogram vir die spesifieke mynbou aktiwiteit ter beskerming en bestuur van die groundwaterbronne in die area en tweedens om te voldoen aan die vereistes soos vervat in die waterlisensie.

Die literatuurstudie en in besonder die ondervinding soos opgedoen en beskryf in die gevalle studie vorm die basis van die handleiding wat opgestel is vir die ontwikkeling van ‘n grondwater moniteringsnetwerk voor die aanvang van mynbou aktiwiteite vir oopgroefmyne. Die verskillende stappe vir die opstel van die moniteringsnetwerk word breedvoerig beskryf in die tesis en kan as volg opgesom word:

- **Moniteringsdoelwitte –** Vir enige moniteringsprogram om suksesvol te wees moet daar duidelike doelwitte gestel word in wat bereik wil word met die monitering met inagneming van die praktiese uitvoerbaarheid van die program. Met die monitering moet die hidrogeologiese karakteristieke van die verskillende akwifere bepaal word dat ingeligte besluite geneem kan word ter beskerming en bestuur van die waterbronne.

- **Lessenaarstudie** – 'n Lessenaarstudie moet gedoen word waar alle beskikbare geologiese en hidrogeologiese verslae, data en inligting gebruik kan word om 'n konseptuele model van die area op te stel. Die konseptuele model is 'n belangrike aspek in die beplanning van die veldwerk om te verseker dat al die hidrogeologiese inligting ingesamel word dat die waterbronne ten volle gekarakteriseer kan word.

- **Beplanning van hidrosensus** – Evaluering van die data tydens die lessenaarstudie sal 'n goeie aanduiding gee van wat verwag kan word gedurende die hidrosensus en ook help met die afbakening van die area wat met die hidrosensus gedek moet word. Effektiewe kommunikasie met die grondeienaars aangaande die hidrosensus is van uiterste belang siende dit reg van die begin af die samewerking van die grondeienaars sal bepaal en derhalwe die sukses van die hidrosensus.

- **Data verkryging tydens hidrosensus –** Gedurende 'n hidrosensus moet nie net watervlakke ingesamel word nie maar alle beskikbare inligting rakende die boorgate as voorbeeld die waterbreuk- en boorgatdieptes, lewering en gebruik, geologie en waterkwaliteit. Addisionele data soos reënval en die water infrastruktuurnetwerk asook die getal vee afhanklik van 'n boorgat is ook belangrike inligting en moet gedurende die hidrosensus aangeteken word.

- **Opstel van moniteringsnetwerk** – Die presiese getal moniteringspunte wat benodig word vir 'n spesifieke moniteringsprogram is altyd 'n debatteerbare aspek. Die moniteringsdoelwitte en hidrogeologiese toestande van die spesifieke area sal die bepalende rol speel in die aantal en posisie van die moniteringspunte. Die terreintoestande (toeganglikheid en topografie) moet ook in ag geneem word met die opstel van die moniteringsnetwerk.

- **Evaluering en analisering van data –** Die evaluering en analisering van die moniteringsdata vorm 'n belangrike komponent in die verstaan van die hidrogeologiese karakteristieke van die akwifere in 'n gebied en die opdatering van die konseptuele model soos opgestel gedurende die lessenaarstudie.

- **Geïnteresseerde en geaffekteerde partye** – Die sukses van 'n moniteringsprogram hang grootliks af van die verhouding wat daar bestaan tussen die mynmaatskappy en die grondeienaars. Dit is belangrik dat 'n Omgewingsforum gestig word wat gebruik kan word as skakel vir kommunikasie tussen die partye. Van die omgewingaspekte is water gewoonlik die hoof besprekingspunt wat met behulp van die Omgewingsforum ten voordeel van beide partye bestuur kan word.

- **Evaluering van moniteringnetwerk** – Die moniteringsnetwerk moet op 'n gereelde basis ge-evalueer word ter bepaling of dit nog steeds voldoen aan die moniteringsdoelwitte. Sou daar veranderinge wees in die myn se watergebruike of veranderinge in die omgewingswetsgewing sal dit byvoorbeeld nodig wees dat die moniteringsdoelwitte aangepas sal moet word.

- **Opdatering van moniteringsnetwerk** - Die evaluering en analisering van die moniteringsdata sal die areas uitwys waar of bykomende data benodig word of te veel data beskikbaar is. In areas waar te min data beskikbaar is kan dit nodig wees dat boorgate geboor moet word of dat die moniteringsarea vergroot moet word om aangrensende areas se boorgate in te sluit. In gevalle waar te veel data beskikbaar is kan van die moniteringspunte verminder word of die moniterings interval kan verleng word.

Die opstel en ontwikkeling van 'n moniteringsnetwerk is nie eenmalig nie maar 'n aaneenlopende proses waartydens die moniteringsnetwerk ten minste jaarliks ge-evalueer en die nodige veranderinge aangebring moet word. Indien dit nie gedoen word nie sal die moniteringsprogram nie 'n ware refleksie gee van die waterbronne wat gemoniteer word nie en sal dit nie moontlik wees om die waterbronne effektief te beskerm en te bestuur nie.

Dit moet in ag geneem word dat elke mynaktiwiteit sy eie unieke terrein toestande het wat gaan meebring dat party van die stappe beskryf in die tesis vir die opstel van 'n moniteringsnetwerk dalk nie van toepassing of prakties uitvoerbaar is nie en gevolglik aangepas moet word om toepaslik te wees vir die spesifieke terrein toestande.

Sunset at Kolomela Mine