20
Years of Water & Environmental Science

GROUNDWATER IMPACT STUDY

FOR

THE PROPOSED TSHIVHASO POWERSTATION NEAR AT GROOTGELUK COAL-MINE IN LEPHALALE, LIMPOPO PROVINCE

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M2 ENVIRONMENTAL CONNECTIONS CC

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Disclaimer:

The results and conclusions of this report are limited to the Scope of Work agreed between GPT and the Client for whom this investigation has been conducted. All assumptions made and all information contained within this report and its attachments depend on the accessibility to and reliability of relevant information, including maps, previous reports and word-of-mouth, from the Client and Contractors. All work conducted by GPT is done in accordance with the GPT Standard Operating Procedures. GPT is an ISO 9001 accredited Company.

Declaration:

I hereby declare:

1. I have no vested interest (present or prospective) in the project that is the subject of this report as well as its attachments. I have no personal interest with respect to the parties involved in this project.
2. I have no bias with regard to this project or towards the various stakeholders involved in this project.
3. I have not received, nor have I been offered, any significant form of inappropriate reward for compiling this report.

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Customer Satisfaction:

Feedback regarding the technical quality of this report (i.e. methodology used, results discussed and recommendations made), as well as other aspects, such as timeous completion of project and value of services rendered, can be posted onto GPT's website at address: http://www.gptglobal.com/feedback.htm.

EXECUTIVE SUMMARY

GPT has been appointed by M^2 Environmental Connections cc (Menco) to investigate potential groundwater impacts that may result from the development of the proposed coal-fired power station. Within the scope of work the groundwater study aims to address the following:

- Provide baseline information on the groundwater environment and the site specific sensitivities in relation to the study area.
- Identify most likely impacts of power station activities on groundwater resources.

Completed Work

The following was performed to address the above:

- Hydrocensus and subsequent analysis of 4 samples
- Numerical Modelling
- Risk Assessment
- Impact Predictions
- Water Management Options

Conceptual Site Model

From the results of the field investigations and laboratory analyses, a conceptual hydrogeological model was compiled for the power station. This conceptual model is a simplified representation of the conditions at and in the vicinity of the power station, and will provide the framework during the development of the risk assessment and numerical flow and transport model

The CSM illustrates that contamination is likely to seep from the base of the ash disposal facility into the unsaturated zone. This contaminated leachate is likely to contain elevated concentrations of Ca, Na, Cl, SO_4 and metals such as Cu, Hg, Pb, Mn, Fe, Al, Cr etc. Perching of the discharged leachate may take place in the regolith underlying the ash disposal facility causing lateral flow which may reach neighbouring boreholes and is likely to contaminate the soil in the area. This will also cause a mounding of groundwater in the unsaturated zone. Therefore, monitoring of this shallow, perched aquifer will be required.

Seepage from the ash disposal facility may also reach the saturated fractured aquifer over time. Although this may occur over a long period of time, due to the 40 m thick unsaturated zone, groundwater contamination and mounding of the groundwater table is a possibility. Therefore, monitoring of the deeper fractured aquifer will also be necessary as neighbouring boreholes may be affected.

Due to large scale fracturing and faulting in the area, contamination has the potential to reach the neighbouring Grootgeluk opencast coal mine via preferential pathways. Flow is known to take place at higher velocities in the fault zones of this area and contamination could therefore travel much further in these structures as opposed to the weathered matrix blocks of the underlying aquifer.

Aquifer Sensitivity

The aquifer sensitivity in terms of the boundaries of the aquifer, its vulnerability, classification and finally protection classification, as this will help to provide a framework in the groundwater management process. The following information was obtained during the investigation:

- The underlying aquifer(s) can be regarded as a Minor Aquifer System
- The aquifer vulnerability can be regarded as Medium
- The aquifer protection classification is Medium

Numerical Flow and Transport Model

The following potential impacts were identified during the operational phase of the power station:

During the operational phase, no groundwater abstraction is expected. Therefore, no groundwater drawdown is expected from the power station and the current status in this regard, will be maintained. However, LEP 2 is likely to be destroyed during the establishment of the ash dump, which can be considered to be an impact on groundwater quantity. This depends on the selected site for ash dump development.

Also, should the power station extract groundwater for operational processes in future, it will be important to update the groundwater model with this information as receptors in the area may be impacted by this activity.

Appelvlakte Ash Dump Option

No boreholes are likely to be affected by the sulphate pollution plume from the ash dump within 100 years after operations have commenced with the exception of the destruction of LEP2. It should be noted that other privately owned boreholes, downstream of the site, may be affected if pumping takes place, as this may accelerate groundwater flow in the identified faults and subsequently, contaminant transport.

Graaffwater Ash Dump Option

No boreholes are likely to be affected by the sulphate pollution plume from the ash dump within 100 years after operations have commenced with the exception of LEP12. It should be noted that other privately owned boreholes, downstream of the site, may be affected if pumping takes place, as this may accelerate groundwater flow in the identified faults and subsequently, contaminant transport.

Risk Assessment

The groundwater risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor). The risk assessment approach is therefore aimed at describing and defining the relationship between cause and effect. In the absence of any one of the three components, it is possible to conclude that groundwater risk does not exist.

Potential sources	Farm Location	Transport mechanism	Exposure pathway	Available monitoring points	Potential receptors	Pathway complete	
						Yes/No	Current/Potential in future
Ash Disposal Facility	Appelvlakte 448	Leaching and Groundwater Transport	Baseflow, Abstraction	None	LEP2	Yes	Future
Ash Disposal Facility	Graaffwater 456	Leaching and Groundwater Transport	Baseflow, Abstraction	None	LEP12	Yes	Future

Water management options

The following measures should be implemented during operations:

- Waste residue deposits should be located as far away from surface water bodies as possible.
- Water management facilities should be designed to intercept and contain as much contaminated runoff and/or seepage as possible. The following facilities should be lined:
    - Ash dumps
- Apply effective storm water management principles to ensure that clean runoff is maximised and diverted to the receiving water resource, while contaminated runoff is minimised and contained for reuse within the operation.
- Monitoring boreholes as discussed in the following sections will be required in strategic locations near the pollution source, to obtain information on the groundwater regime as well as for future monitoring purposes.
- Construct detailed water and salt balances that take account of climatic and operational variability, as a planning tool to ensure that all pollution control dams are adequately sized and that they are integrated into a robust water reuse and reclamation strategy to ensure that captured contaminated water is effectively reused within the operations and that system spillages to the environment are avoided.
- Proper storage, handling and monitoring of fuel and chemicals used on site to minimize the risk of spillages to the environment.
- Institute detailed monitoring systems that are capable of detecting pollution at the earliest possible stage, at all facilities where significant pollution potential exists, in order that this can lead to rapid and effective management actions to address the pollution source and minimize it to the full extent possible.
- Safety measures such as freeboard allowances etc should be included in designs of storm water control facilities to allow for sufficient storage capacity and to ensure that risks of overflows or spillages are minimized and environmental impacts are therefore avoided.
- Design, construct, maintain and operate any clean water system at the site so that it is not likely to spill into any dirty water system more than once in 50 years;
- Design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years.
- Ensure that clean storm water is only contained if the volume of the runoff poses a risk, if the water cannot be discharged to watercourses by gravitation, for attenuation purposes, or when the clean area is small and located within a large dirty area. This contained clean water should then be released into natural watercourses under controlled conditions.
- Ensure the minimisation of contaminated areas, reuse of dirty water wherever possible and planning to ensure that clean areas are not lost to the catchment unnecessarily.
- Ensure that seepage losses from storage facilities (such as polluted dams) are minimised and overflows are prevented.
- Ensure that all possible sources of dirty water have been identified and that appropriate collection and containment systems have been implemented and that these do not result in further unnecessary water quality deterioration.

- Ensure that less polluted water or that moderately polluted water is not further polluted. Where possible less and more polluted water should be separated. This will assist in the reuse water strategy and improve possibilities for reuse based on different water quality requirements by different mine water uses.
- Where contaminants are transported along construction roads, emergency containment and mitigation measures must be developed to minimize impacts should accidental spillages occur along the transport routes.
- Store all potential sources of contamination in secure facilities with appropriate Storm Water management systems in place to ensure that contaminants are not released to the water resource through Storm Water runoff.
- Separate and collect all storm water that has a quality potentially poorer than the water quality specified and negotiated for the specific catchment into dirty water storage facilities for reuse within the mining operations.
- Ensure that all storm water structures that are designed to keep dirty and clean water separate can accommodate a defined precipitation event. (The magnitude of the precipitation event used in such an objective statement must, as a minimum, adhere to the relevant legal requirements.)
- Route all clean storm water directly to natural watercourses without increasing the risk of a negative impact on safety and infrastructure, e.g. loss of life or damage to property due to an increase in the peak runoff flow.
- Ensure that the maximum volume of clean water runoff is diverted directly to watercourses and the minimum amount of storm water reports to the pit floor of an open cast mine.
- Develop and implement proper environmental management and auditing systems to ensure that pollution prevention and impact minimisation plans and measures developed in the design and feasibility stages are fully implemented.
- Every effort should be made to maximise the clean area and minimise the dirty area when locating the diversion berms, channels and dams.
- Monitoring of water storage facilities, particularly pollution control dams, is imperative to manage the risk of spillage from the dams. Stage-storage (elevation-capacity) curves are useful tools to monitor the remaining capacity within a water storage facility.
- Prevent the erosion or leaching of materials from any ash deposit from any area and contain material or substances so eroded or leached in such area by providing suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources.
- Water quantity and quality data should be collected on a regular, ongoing basis during operations. These data will be used to recalibrate and update the water management model, to prepare monitoring and audit reports, to report to the regulatory authorities against the requirements of the IWMP and other authorisations and as feedback to stakeholders in the catchment, perhaps via the CMA.
- Water that has been in contact with ash, and must therefore be considered polluted, must be kept within the confines of the ash deposit until evaporated, treated to an acceptable quality for release, or re-used in some other way.
- A system of storm water drains must be designed and constructed to ensure that all water that falls outside the area of the ash deposit is diverted clear of the deposit. Provision must be made for the maximum precipitation to be expected over a period of 24 hours with a probability of

once in one hundred years. A freeboard of at least 0.5 m must be provided throughout the system above the predicted maximum water level.

- Ensure that the water use practices on and around the ash deposit do not result in unnecessary water quality deterioration, e.g. use of the return water dam for storage of poorer quality water.
- Lining of the ash disposal facility must be considered to avoid seepage of contaminated water into the subsurface. Capturing contaminated water in the subsurface will be especially challenging due to the thick unsaturated zone underlying the proposed sites. In the event of a leakage from these facilities, a pump and treat system will most likely be required to address contamination issues.

Recommendations

The following recommendations are put forward:

- Update the numerical model against monitored data during operations.
- Water quantity and quality data should be collected on a regular, ongoing basis during operations. These data will be used to recalibrate and update the water management model, to prepare monitoring and audit reports, to report to the regulatory authorities against the requirements of the IWMP and other authorisations and as feedback to stakeholders in the catchment, perhaps via the CMA.
- The monitoring as recommended in the report should be established prior to operation.
- Geochemical analyses and modelling must be conducted on the material during operations to update the transport model to refine geochemical predictions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF APPENDICES

LIST OF ABBREVIATIONS

Abbreviation	**Explanation**
ARD	Acid Rock Drainage
BPG	Best Practice Guidelines
CMS	Catchment Management Strategy
CSM	Conceptual Site Model
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
IWRMP	Integrated Water Resources Management Plan
IWRM	Integrated Water Resources Management
Km^2	Square Kilometre
L/s	Litres per second
mamsl	Metres above mean sea level
Ml/d	Megalitres per day
m	meter
mm	Millimetre
mm/a	Millimetres per annum
mS/m	Millisiemens per metre
m^3	Cubic metre
MAP	Mean Annual Precipitation
NEMA	National Environmental Management Act (Act No. 107 of 1998)
NWA	National Water Act (Act No. 36 of 1998)
ppm	Parts per million
RDM	Resource Directed Measures
RQO	Resource Quality Objective
RWQO	Resource Water Quality Objective
TDS	Total Dissolved Solids
WMA	Water Management Area
WMP	Water Management Plan

DEFINITIONS

Definition	Explanation
Aquiclude	A geologic formation, group of formations, or part of formation through which virtually no water moves
Aquifer	A geological formation which has structures or textures that hold water or permit appreciable water movement through them. Source: National Water Act (Act No. 36 of 1998).
Borehole	Includes a well, excavation, or any other artificially constructed or improved underground cavity which can be used for the purpose of intercepting, collecting or storing water in or removing water from an aquifer; observing and collecting data and information on water in an aquifer; or recharging an aquifer. Source: National Water Act (Act No. 36 of 1998).
Boundary	An aquifer-system boundary represented by a rock mass (e.g. an intruding dolerite dyke) that is not a source of water, and resulting in the formation of compartments in aquifers.
Cone of Depression	The depression of hydraulic head around a pumping borehole caused by the withdrawal of water.
Confining Layer	A body of material of low hydraulic conductivity that is stratigraphically adjacent to one or more aquifers; it may lie above or below the aquifer.
Dolomite Aquifer	See “Karst” Aquifer
Drawdown	The distance between the static water level and the surface of the cone of depression.
Fractured Aquifer	An aquifer that owes its water-bearing properties to fracturing.
Groundwater	Water found in the subsurface in the saturated zone below the water table.
Groundwater Divide or Groundwater Watershed	The boundary between two groundwater basins which is represented by a high point in the water table or piezometric surface.
Groundwater Flow	The movement of water through openings in sediment and rock; occurs in the zone of saturation in the direction of the hydraulic gradient.
Hydraulic Conductivity	Measure of the ease with which water will pass through the earth's material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (m/d).
Hydraulic Gradient	The rate of change in the total hydraulic head per unit distance of flow in a given direction.
Infiltration	The downward movement of water from the atmosphere into the ground.
Intergranular Aquifer	A term used in the South African map series referring to aquifers in which groundwater flows in openings and void spaces between grains and weathered rock.
Karst (Karstic)	The type of geomorphological terrain underlain by carbonate rocks where significant solution of the rock has occurred due to flowing groundwater.

Definition	**Explanation**
Karst (Karstic) Aquifer	A body of soluble rock that conducts water principally via enhanced (conduit or tertiary) porosity formed by the dissolution of the rock. The aquifers are commonly structured as a branching network of tributary conduits, which connect together to drain a groundwater basin and discharge to a perennial spring.
Monitoring	The regular or routine collection of groundwater data (e.g. water levels, water quality and water use) to provide a record of the aquifer response over time.
Observation Borehole	A borehole used to measure the response of the groundwater system to an aquifer test.
Phreatic Surface	The surface at which the water level is in contact with the atmosphere: the water table.
Piezometric Surface	An imaginary or hypothetical surface of the piezometric pressure or hydraulic head throughout all or part of a confined or semi-confined aquifer; analogous to the water table of an unconfined aquifer.
Porosity	Porosity is the ratio of the volume of void space to the total volume of the rock or earth material.
Production Borehole	A borehole specifically designed to be pumped as a source of water supply.
Recharge	The addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.
Recharge Borehole	A borehole specifically designed so that water can be pumped into an aquifer in order to recharge the ground-water reservoir.
Saturated Zone	The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere.
Specific Capacity	The rate of discharge from a borehole per unit of drawdown, usually expressed as m3/d•m.
Specific Yield	The ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.
Transmissivity	Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the average hydraulic conductivity and thickness of the saturated portion of an aquifer.
Unsaturated Zone (Also Termed Vadose Zone)	That part of the geological stratum above the water table where interstices and voids contain a combination of air and water.
Watershed (Also Termed Catchment)	Catchment in relation to watercourse or watercourses or part of a watercourse means the area from which any rainfall will drain into the watercourses or part of a watercourse through surface flow to a common point or points. Source: National Water Act (Act No. 36 of 1998).
Water Table	The upper surface of the saturated zone of an unconfined aquifer at which pore pressure is equal to that of the atmosphere.

GROUNDWATER IMPACT STUDY

THE PROPOSED TSHIVHASO POWER STATION NEAR GROOTGELUK COAL-MINE IN LEPHALALE, LIMPOPO PROVINCE

1. INTRODUCTION

GPT has been appointed by M^2 Environmental Connections cc (Menco) to investigate potential groundwater impacts that may result from the development of the proposed coal-fired power station.

As stated in the request for tender: *"The client, Cennergi (Pty) Ltd is proposing a 1200 MW coal-fired power station on the farm Graaffwater*. This report therefore aims to address the potential groundwater sensitivities and risk from the potential development as it is known from experience that groundwater contamination is a main environmental concern and will surely be requested by regulators such as DWS and DEA.

The rationale for the study was for the power station to be able to qualify the possible impacts on the surrounding water resources and receptors in the close proximity emanating from the power station and its related activities, before it commences. The latter will have a vital role in terms of developing a comprehensive water management plan for the power station, as well as complying with the legal requirement pertaining to water management.

1.1 Project Objectives

Within the scope of work the groundwater study aims to address the following:

- Providing baseline information on the groundwater environment and the site specific sensitivities in relation to the study area.
- Identify most likely impacts of power station activities on groundwater resources.

1.2 Scope of Work

1.2.1 Site Description

- Details of the current land owner and occupiers of the land;
- The farm, plot, and/or erf numbers;
- The current site plan, including local water drainage and other locally significant features on-site and immediately off-site.
- Location and size of the site and its boundaries within other areas of concern, such as catchments management area;
- Climate of the area including rainfall, temperature, wind and evaporation. Also account for potential different climate zones

1.2.2 Site Groundwater Description

- The local topography and geology, including soil types;
- The drainage patterns, surface cover, vegetation;
- Details of any relevant sensitive environments;

- A determination of groundwater quality and direction as well as sensitivity of aquifers and the depth to water table;
- The quality of and proximity to surface water;
- The proximity to drinking water supplies;
- Meteorological data, including annual rainfall
- General classification of the aquifers underlying the site using DWA's Aquifer Classification Map of South Africa
- General aquifer vulnerability of the aquifers underlying the site using DWA's Aquifer Vulnerability Map of South Africa
- Groundwater surface water interaction and hydrographical characteristics;
- Determination of contamination potential based on the planned site activities and waste facilities

1.2.3 Impact Prediction

- Characterise the groundwater regime in the site area in terms of quantity, quality and dynamics (groundwater flows, recharge and potential pollutant transport), highlighting specific sensitivities/vulnerabilities;
- Description of the operational hydrogeological environment against which impacts will be measured.
- Develop a conceptual site model of the regional and local hydrogeology.
- Develop a numerical model to simulate and predict impact of dewatering; and pollution migration behaviour during the entire life span of the power station ; i.e. commissioning, operation, decommission and closure;
- Prediction of the environmental impact of the proposed power station activities on the hydrogeological regime of the area. This includes the description of possible negative impacts during construction, decommissioning and after closure;
- Delineation of potential pollution plumes;
- Assess and simulate different mitigation options related to water impacts;
- Risk assessment of the potential impacts on potential receptors
- Compilation of all the relevant data and recommendations in a hydrogeological report, structured in such a way that it can be incorporated into the EIA documents.

1.2.4 Groundwater management options and mitigation measures

- Pollution prevention strategies that can be effectively planned developed and implemented in the pre-operational, operational and closure of the operation. Effective pollution prevention reduces the management and financial burden associated with remediation during the operational and especially closure phases.
- What additional water management (e.g. covers, infiltration reduction measures, etc.) or treatment measures need to be instituted to reduce the contaminant loads from the various source terms or to intercept the pathways in order to ensure that the critical receptor is not adversely impacted.
- How would proposed alternative layouts affect the potential impact on the identified receptor or water resource?

2. PROJECT METHODOLOGY

The impact of the proposed ash dump areas was investigated through field investigations, data analyses and the use of numerical models (flow and transport models). The work completed for the purposes of compiling the groundwater report will be discussed in the following paragraphs.

2.1 Desk Study

This entailed the gathering of information through the collation, scrutiny and evaluation of available and relevant meteorological, geographical, geological, hydrogeological and water quality data.

2.2 Hydrocensus

The hydrocensus was done as a site familiarisation exercise and the collection of data from the study area and surrounding environments. It comprised a census of key boreholes, wells, springs and any other groundwater related information.

2.3 Sampling and Chemical Analyses

The sampling and analyses conducted for the study is discussed in the following paragraphs.

2.3.1 Groundwater sampling

Groundwater was sampled in accordance with the GPT's Standard Operating Procedure for groundwater sampling[1] by bailing. Before the bailed sample is collected a electrical conductivity (EC) profile down the hole is considered to detect changes in EC. EC profiles, compared with the construction logs of monitoring wells are then used to determine the optimum sampling depth of each hole. The sample was taken at a depth where the EC reaches a maximum. The bailer is then lowered to the prescribed depth and the sample taken.

2.3.2 Groundwater analysis

The following groundwater cation/anion parameters as listed in Table 1 were analysed by an accredited laboratory for interpretation.

Table 1: Groundwater Parameters Analysed

Methodology	Parameter
LPM 2	Total Dissolved Solids
LPM 32/76	Nitrate & Nitrite as N, Ammonia - NH_3
LPM 30/76	Chloride - Cl
LPM 11/81	Total Alkalinity as $CaCO_3$
LPM 28/76	Sulphate - SO_4
LPM 15	Calcium - Ca

[1] Available on request from morne@gptglobal.com

Methodology	Parameter
LPM 15	Magnesium - Mg
LPM 15	Sodium - Na
LPM 15	Potassium - K
LPM 15	Iron - Fe
LPM 15	Manganese - Mn
LPM 15	Zinc – Zn
LPM 51/82	Conductivity at 25° C in mS/m
LPM 51/82	pH-Value at 25 ° C
Calculation	pH by 21° Celsius

2.4 Quality Assurance and Quality Controls (QA/QC)

Geo Pollution Technologies (Pty) Ltd, comply with the Quality Management System and the requirements of ISO 9001:2000. The methodology followed by GPT for groundwater sampling is in accordance with the American Environmental Protection Agency (EPA). On request of the Client, GPT can supply Chain of Custody forms, field notes as well as standard operating procedures outlining the methodology followed for groundwater sampling,

Furthermore GPT uses SANAS accredited laboratories that are competent to carry out specific tasks in terms of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act (Act 19 of 2006). SANAS's purpose is to instil confidence and peace of mind to companies and individuals through accreditation which is required for economic and social well-being for all.

2.5 Aquifer Classification

The aquifer(s) underlying the subject area were classified in accordance with "A South African Aquifer System Management Classification, December 1995."

The main aquifers underlying the area were classified in accordance with the Aquifer System Management Classification document[2]. The aquifers were classified by using the following definitions:

- Sole Aquifer System: An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
- Major Aquifer System: Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (Electrical Conductivity of less than 150 mS/m).

[2] Department of Water Affairs and Forestry & Water Research Commission (1995). A South African Aquifer System Management Classification. WRC Report No. KV77/95.

- Minor Aquifer System: These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.
- Non-Aquifer System: These are formations with negligible permeability that are regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

2.6 Aquifer Vulnerability

Aquifer vulnerability is the intrinsic characteristics that determine the aquifer's sensitivity to the adverse effects resulting from the imposed pollutant[3]. It is determined to indicate the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction of a contaminant at some location above the uppermost aquifer

The following factors have an effect on groundwater vulnerability:

- Depth to groundwater: Indicates the distance and time required for pollutants to move through the unsaturated zone to the aquifer.
- Recharge: The primary source of groundwater is precipitation, which aids the movement of a pollutant to the aquifer.
- Aquifer media: The rock matrices and fractures which serve as water bearing units.
- Soil media: The soil media (consisting of the upper portion of the vadose zone) affects the rate at which the pollutants migrate to groundwater.
- Topography: Indicates whether pollutants will run off or remain on the surface allowing for infiltration to groundwater to occur.
- Impact of the vadose zone: The part of the geological profile beneath the earth's surface and above the first principal water-bearing aquifer. The vadose zone can retard the progress of the contaminants [3].

The Groundwater Decision Tool (GDT) was used to quantify the vulnerability of the aquifer underlying the site. Please note that vulnerability of groundwater is a relative, non-measurable and dimensionless property which is based on the concept that some areas are more vulnerable to groundwater contamination than others.

2.7 Conceptual Site Model

A Groundwater Conceptual Site Model (CSM) was constructed as a descriptive representation of the groundwater system that incorporates an interpretation of the geological and hydrological conditions. Preliminary model simulations were conducted to test elements of the conceptualization and highlight additional data that may be required.

[3] The South African Groundwater Decision Tool (SAGDT), Manual Ver. 1 (Department of Water Affairs and Forestry)

2.8 Modelling

Modelling was done as representation of a groundwater flow system or geochemical processes that attempts to mimic the natural processes. It is therefore a simplified version of the natural system, compiled with geological, hydrogeological, hydrological and meteorological data, which utilises governing equations to incorporate all this data and simulates the hydraulic properties or geochemical properties of the system.

These models were utilised to provide a quantitative understanding of a groundwater system in terms of existing conditions as well as induced stresses, which inherently aids in the identification of cost-effective and efficient solutions to groundwater contamination and management challenges.

2.8.1 Numerical modelling

Numerical groundwater modelling is considered to be the most reliable method of anticipating and quantifying the likely impacts on the groundwater regime.

The finite difference numerical model was created using Aquaveo's Groundwater Modelling System (GMS 10.0) as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes.

MODFLOW is a 3D, cell-centred, finite difference, saturated flow model developed by the United States Geological Survey. MODFLOW can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options. It was developed by McDonald and Harbaugh of the US Geological Survey in 1984 and underwent eight overall updates since. The latest update (Modflow NWT) incorporates several improvements extending its capabilities considerably, the most important being the introduction of the new Newton formulation and solver, vastly improving the handling of dry cells that has been a problem in Modflow previously.

2.8.2 Transport modelling

Transport modelling was done using MT3DMS. MT3DMS is a 3-D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure similar to the structure utilized by MODFLOW, and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation.

2.9 Risk Assessment

The groundwater risk assessment was assessed by defining the three components, which are the source, the pathway and the receptor. The risk assessment approach is therefore aimed at describing and defining the relationship between cause (source) through the groundwater pathway and the effect to the receptor. In the absence of any one of the three components, it is possible to conclude that groundwater risk does not exist.

2.10 Mitigation and Management Measures

The groundwater management measures were developed by taking in consideration the National Water Act, Act 36 of 1998 (NWA) and, to a lesser extent, the Mineral and Petroleum Resources Development Act, Act No. 28 of 2002 (MPRDA) and the National Environmental Management Act, Act 107 of 1998 (NEMA). Chapter 4 of the NWA addresses the use of water.

The Department of Water Affairs (DWA), has recognised the challenges facing both the water user and the authorities in managing groundwater in an integrated manner. This recognition has resulted in a number of guideline documents that provides the mining industry with an opportunity to marry together legislation and best practice into useable tools of implementation. The management measures discussed in this report was based on these Best Practice Guidelines (BPG) series (DWAF, 2008). The relevant guidelines for this report are listed below:

- Activity Series Guidelines
  - BPG A2. Water Management for Mine Residue Deposits
  - BPG A4. Pollution Control Dams
- Hierarchy Series Guidelines
  - H1. Pollution prevention
  - H2. Minimisation of impacts
  - H3. Water reuse and reclamation
  - H4. Water treatment
- General Series Guidelines
  - G1. Storm water management
  - G2. Water and salt balances
  - G3. Water monitoring systems
  - G4. Impact prediction

3. DESK STUDY

A desk study was done on all available information pertaining to groundwater situation at the proposed Tshivhaso power station site.

3.1 Information Reviewed

A desk study was conducted, entailing the gathering of information from the relevant topographical map (1:50 000-scale 2327 CB Topographic Sheet), geological map (1:250 000 sheet 2326 Ellisras) and geohydrological map (Groundwater Resources of South Africa Sheets 1 and 2). The National Groundwater Archive was consulted to obtain borehole positions in the area as well as logs of these boreholes. Previous reports done for sites in the area were consulted. A conceptual layout of the power station site was made available at the time of this study, while some borehole logs were obtained from the National Groundwater Archive. Meteorological information was obtained from the Department of Water Affairs (DWS) Hydrological Services.

3.2 Activity Description

Based on available information received the surface infrastructure of the power station will be located on one of two farms *viz*. Graaffwater 456 or Appelvlakte 448 (Figure 1). Note that Figure 1 only shows major infrastructure that has the potential to contaminate groundwater resources. The surface infrastructure will consist out of the following:

- Ash Storage Facilities

A description of the size, location and composition of the expected activities is listed in Table 3 below

3.3 Summary of Previous Findings

A summary of the findings out of the above mentioned reports are discussed under the headings below.

3.3.1 Conceptual site model

Based on the collected information such as operation layouts and geological logs as well as available data regarding aquifer sensitivity and sensitive receptors in the previous reports, a source-pathway-receptor conceptual site model (CSM) was constructed.

To understand the environmental risk as a result of the power station and its associated infrastructure, it is important to understand the source-pathway-receptor principle. For a groundwater risk to be established a continuous linkage between sources of the pollution, the pathway along which the pollution has migrated towards the receptor, and the actual arrival at the receptor must be demonstrated or proven.

For the CSM we assume that all receptors depend on groundwater usage, the pathways depend on hydrogeology and the source(s) depend(s) on the activities on site that can release contaminants to impact on the groundwater/or that can lower the groundwater table through dewatering of the aquifers. Together these risk factors form the CSM. Thus the CSM is a simplified version of the real situation. A CSM is dynamic and may change with more data becoming available as the activities on site progress.

(Note that a risk can only exist if a source, pathway and receptor are all present).

Sources/Impact Origin

A conceptual layout of the planned infrastructure at the power station was available during the study. Based on the scope of work for the project, only the ash dump and coal stockpile were used as potential sources, in terms of contamination. As the site changes sources may change and therefore the conceptual model will change and thus needs to be updated on a regular basis. The currently identifiable potential sources and their associated impacts are tabulated below (Table 2).

Table 2: Identified Potential Impact Origins, Types and Descriptions

Impact origin	Impact Type	Impact Description
Ash Dump	Groundwater Contamination	Elevated Ca, SO_4, Cl, Na, Hg.
Coal Stockpile	Groundwater Contamination	Elevated SO_4, Ca and possible Cl
Fuel and Oil Handling Facilities	Groundwater Contamination	Hydrocarbon Contaminants
Laboratory Waste	Groundwater Contamination	Various hydrocarbon and inorganic contaminants
Bulk Storage Areas	Groundwater Contamination	Various hydrocarbon and inorganic contaminants
Sewage Treatment Plants	Groundwater Contamination	Elevated total coliform, faecal coliform and nitrogen species
Solid Waste Disposal Areas	Groundwater Contamination	Various bacteriological, organic and inorganic contaminants

Pathways

The following groundwater pathways are inferred to be on site:

The unsaturated pathway in the proposed project area is in the order of ≈40 metres thick (based on static groundwater levels measured in the existing boreholes). The unsaturated pathway along with the shallow aquifer is also the most likely to be impacted by surface point pollution sources. However, due to the thickness of the unsaturated zone, as well as slower flow velocities in unsaturated porous media, pollution may take extensive periods to reach the phreatic surface.

An intermediate groundwater pathway formed by fracturing of the Karoo sediments. Groundwater is stored within the pores and fractures of these sediments (matrix) with low flow velocities.

Groundwater movement is predominantly along the fractures/faults with much higher flow velocities.

Groundwater pathways formed within the more permeable fault zones and in coal seams. The coal seam forms a layered sequence within the hard rock sedimentary units. The margins of coal seams or plastic partings within coal seams are often associated with groundwater. The coal itself tends to act as an aquitard allowing the flow of groundwater at the margins. Fault zones may act as preferential pathways for groundwater movement due to high levels of fracturing and subsequent porosity. These zones normally cross cut the horizontally deposited sediments at 30 to 60 degree angles. These zones are often associated with groundwater and targeted for abstraction boreholes. In the case of the Power Station area, major fault zones are abundant and these zones will most likely act as the major contaminant transport pathways.

Based on limited slug test information the hydraulic conductivities associated with these pathways are in the order of 0.1 m/day. However this value is most probably associated with flow within the matrix and conductivities along fractures are expected to be orders of magnitude higher.

Receptors

Any user of a groundwater or surface water resource that is affected by impact from any of the above mentioned sources is defined as a receptor. Furthermore, a borehole or surface water resource may also be a receptor of deterioration in groundwater quantity and quality. The following receptors may be found:

Groundwater users by means of borehole abstraction

The main water use in the vicinity of the proposed power station is for livestock. Water is primarily sourced from boreholes in the vicinity of the proposed power station and its associated infrastructure.

Based on the available information no other groundwater users/receptors apart from those mentioned above are likely to be negatively affected by the proposed power station. Also, due to the complexity of the fault network in the area, not all identified boreholes may be affected.

The Grootgeluk Opencast could also be a potential receptor as the mine could be directly connected to the powerstation by the Daarby Fault, crosscutting both sites. Due to dewatering at Grootgeluk, a hydraulic gradient could potentially be formed towards the mine and any contamination produced at the power station could potentially travel along the Daarby Fault towards the mine. However, a detailed regional study will be required to determine the connectivity of the two sites by this fault as well as the fault's hydraulic characteristics.

3.3.2 Recommended management measures

- Groundwater quality must be monitored on a quarterly basis.
- The monitoring results must be interpreted annually by a qualified hydrogeologist and the monitoring network should be audited annually to ensure compliance with regulations.
- Numerical groundwater model must be updated by calibrating the model with monitoring data.
- Ash dumps and stockpiles should be lined to prevent ingress of contamination
- Ash and coal material should be submitted for kinetic geochemical testing and associated analyses to develop a geochemical model for contaminant release prediction

- Ensure that the appropriate design facilities (berms, storm water channels etc.) are constructed before constructing the ash dump and stockpile.
- Groundwater monitoring boreholes should be sited with the aid of geophysics at designated positions based on final infrastructure layout, to comply with the design requirements of a groundwater monitoring system, as recommended. This will also provide data to verify the conceptual model.
- Groundwater monitoring boreholes should be installed to comply with the minimum requirements as set by governmental guidelines.
- Clean and dirty water systems should be separated.
- Cessation of pumping in boreholes drilled into faults downstream from the site and re-establishment upstream from the site.

Table 3: Activity Summary

Surface Infrastructure	Amount	Size (m^2)	Farm Location	Expected Hydro chemical or Geochemical Description
Ash Disposal Facility	1	11493909	Graaffwater 456	Ca, SO_4, Cl, Na
Ash Disposal Facility	1	11460501	Appelvlakte 448	Ca, SO_4, Cl, Na

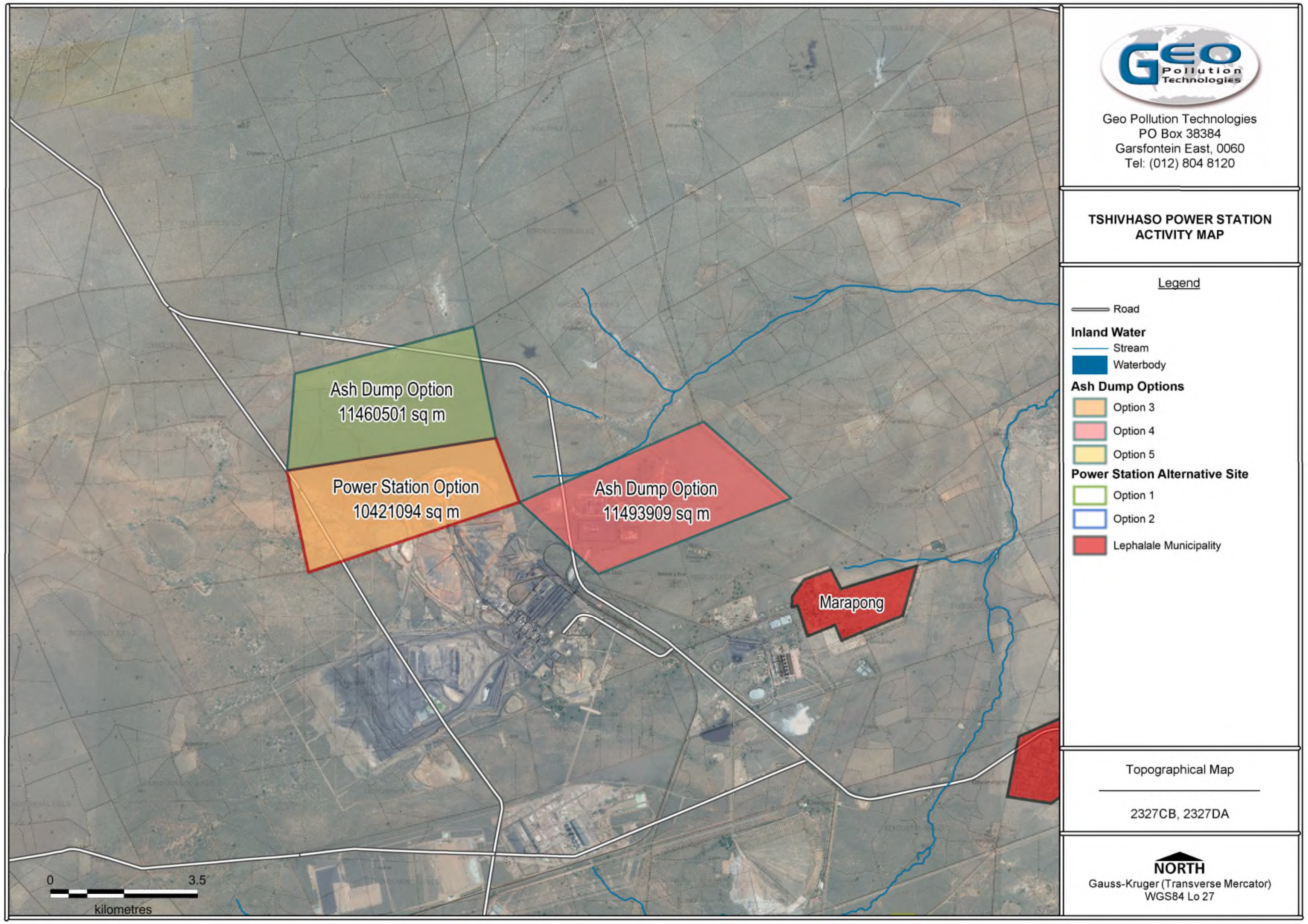

Figure 1: Planned Activity Map

4. REGIONAL INFORMATION

A description of the regional area information is described under the headings below.

4.1 Site Location

The proposed power station will likely be developed on the farm Graaffwater. Accompanying the powerstation site are ash disposal facility sites which will be located either on the farm Graaffwater 456 or Appelvlakte 448. These farms are located approximately 20 km north-west of Lephalale, Limpopo Province (Figure 3). Mining activity in the area is well developed with the Grootgeluk Mine extracting coal on a large scale near the proposed sites.

4.2 Regional water Management Setting and Sensitivity

The sites are situated in the Limpopo Water Management Area (WMA), in quaternary catchment A41E and A42J (Figure 3).

4.2.1 Present ecological status

The present ecological status category (PESC) is the practicality of restoring a system following an assessment of the changes that have occurred, to arrive at an attainable ecological management. The PESC status is defined as follows:

- Category A: Unmodified natural
- Category B: Largely natural
- Category C: Moderately modified
- Category D: Largely modified

Based on the Provincial Water Resources Assessments for the National Water Balance of 1999, the sensitivity, and present ecological status for the A41E and A42J quaternary catchments is given as B.

4.3 Climatic Conditions

Climatic data was obtained from the DWA weather station Mokolo Nature Reserve at the Mokolo Dam for the Lephalale area (Table 4)[4]. The proposed power station site is located in the summer rainfall region of Southern Africa with precipitation usually occurring in the form of convectional thunderstorms. The average annual rainfall (measured over a period of 34 years) is approximately 578.00 mm, with the high rainfall months between October and March. If the evaporation is compared with the average monthly rainfall it is found that evaporation exceeds rainfall in every month of the year. The highest evaporation measurements for the Lephalale area are seen from October to January.

[4] Department of Water Affairs (DWA): www.dwa.gov.za

Table 4: Climatic Data

Month	Average monthly rainfall (mm)	Mean monthly evaporation
January	111.5	221.6
February	83	191.7
March	77.3	182.7
April	54.3	142.7
May	12.6	129.3
June	5.9	92.9
July	1.4	102.9
August	4.2	139.1
September	10.5	185.3
October	50.2	222.4
November	109.3	215.8
December	180.3	222.5
Annual	578.0	2014.0

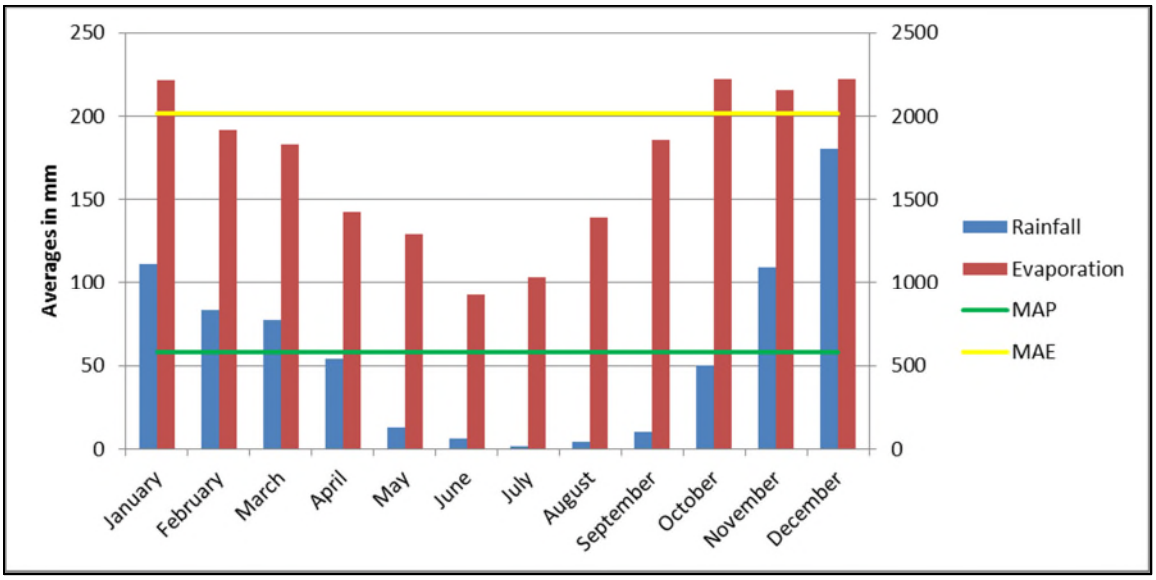

Figure 2: Climatic data representation

4.4 Regional Geology

The investigated area falls within the 2326 Ellisras 1:250 000 geology series map and is situated approximately 20 km north-west of Lephalale, Limpopo. An extract of this map is shown in Figure 4.

The proposed power station is situated in the Ellisras basin of the Karoo Super Group, which extends from the Limpopoo River in the west to Ga- Monkeki in the east covering a surface area of approximately 1 200 km^2. Regionally the rocks of the Clarens Formation, Eendragtpan Formation, Lisbon Formation and the Lethaba Formation can be found.

The Clarens Formation forms a layer of well sorted fine grained sandstone that is approximately 130m thick in the Ellisras Basin. The sandstone in this formation is mostly cream-coloured but can have light pink colours locally and is thought to be of aeolian origin. Variegated mudstones make up the Eendragtpan Formation. These mudstones are generally purplish-red in colour and attain a maximum thickness of 110m. The Lisbon Formation is comprised of dominantly red, massive mudstones and siltstones as well as minor sandstones. These rocks were probably deposited on an extensive flood plain and have a fairly constant thickness of 100-110m.[5] The rocks of the Lethaba Formation are also present regionally. This formation is composed of basaltic rocks.

The generally horizontally disposed sediments of the Karoo Supergroup are typically undulating with a gentle regional dip to the south. The extent of the coal is largely controlled by the pre-Karoo topography. Steep dips can be experienced where the coal buts against pre-Karoo hills. Displacements, resulting from intrusions of dolerite sills, are common.

There is also a number of approximately east-west and north-south trending faults in the area.

From the sheet of 2326 Ellisras geology series map it is evident that the cream coloured aeolian sandstone and the red mudstones of the Eendragtpan outcrop in the area. The coal bearing rocks of the Grootgeluk Formation also outcrop to the north of the site. This group is approximately 110m thick and consists of coal, carbonaceous shale and mudstone.

The local geology is best concluded from information obtained from exploration borehole logs from the National Groundwater Archive. Three hundred and nine boreholes logs were used to derive a statistical analysis of the borehole logs (Table 5) for the proposed power station area.

A number of faults traverse the proposed power station site. Two of the approximately east-west trending faults and 1 approximately north-south trending fault lies beneath the area of the proposed ash dump. The north-south trending fault is called the Daarby Fault and it runs though the east- west faults displacing them slightly.

Table 5: Statistical analysis of the borehole logs (derived from 309 logs)

Hydrogeological Description	Statistics in m	
Soil overburden thickness	Minimum	0.03
	Maximum	12.8
	Mean	4
Weathering thickness(Highly weathered zone, followed by a slightly weathered/fractured zone)	Minimum	0.4
	Maximum	36.88
	Mean	16.11
Unweathered thickness (fractured zone)	Minimum	0.16
	Maximum	117.9
	Mean	32.5

[5] Johnson M.R., van Vuuren C. J., Visser J. N. J., Cole D. I., Wickens H. De. V., Christie A. D. M., Roberts D. L. and Bandl G. (2006). Sedimentary Rocks of the Karoo Supergroup. In The Geology of South Africa. Council for Geoscience. Pretoria.

4.5 Regional Hydrogeology

The area of concern is situated in the Limpopo Water Management area. On regional and local scale the hydrogeology consist of intergranular and fractured aquifers of the Karoo Supergroup, with both arenaceous (sandstone) argillaceous (mudstone) rocks present. Blow yields of 0.3 – 3.0 l/s can be expected regionally.

The hydrogeology of the area can be described in terms of the saturated and unsaturated zones.

4.5.1 Saturated Zone

In the saturated zone, at least two aquifer types may be inferred from knowledge of the geology of the area:

- An intermediate aquifer formed by fracturing and faulting of the Karoo sediments.
- Aquifers formed within the more permeable coal seams and sandstone layers.

Although these aquifers vary considerably regarding geohydrological characteristics, they are seldom observed as isolated units. Usually they would be highly interconnected by means of fractures and intrusions. Groundwater will thus flow through the system by means of the path of least resistance in a complicated manner that might include any of these components.

4.5.2 Fractured Karoo rock aquifers

The area consists of consolidated sediments of the Karoo Supergroup and consists mainly of sandstone and shale and coal beds of the Clarens and Eendracht Formation. The geology map indicates a number of faults and fractures in the area and from experience it can be assumed that numerous major and minor fractures do exist in the host rock. These conductive zones effectively interconnect the strata of the Karoo sediments, both vertically and horizontally into a single, but highly heterogeneous and anisotropic unit.

4.5.3 Aquifers associated with coal seams

The coal seam forms a layered sequence within the hard rock sedimentary units. The margins of coal seams or plastic partings within coal seams are often associated with groundwater. The coal itself tends to act as an aquitard allowing the flow of groundwater at the margins.

4.5.4 Unsaturated Zone

Although a detailed characterization of the unsaturated zone is beyond the scope of this study, a brief description thereof is supplied.

The unsaturated zone is likely to consist of colluvial sediments at the top, underlain by residual sandstone of the Clarens Formation that becomes less weathered with depth. The thickness of the unsaturated zone can be determined from water levels measured during the hydrocensus. Experience of Karoo geohydrology in this area, indicates that recharge to the shallow groundwater aquifer is relatively low, less than 3% of the Mean Annual Precipitation (MAP).

4.6 Local Hydrogeology

Based on borehole logs obtained from the NGA, slug testing and literature, the following local hydrogeological description (within the aquifer boundary) from top (surface) to bottom (Dwyka Tilites) can be deduced as follows:

4.6.1 Shallow weathered aquifer (unconfined)

This aquifer comprises of weathered arenaceous sandstones and shales. The Ecca and Clarens sediments are weathered below surface throughout the area. The upper aquifer is associated with this weathered zone and water is found deep below the surface, often deeper than this hydrogeological unit. The hydraulic conductivity value for the aquifer is estimated at $1x10^{-6}$ m/d to 0.10 m/d

The estimated thickness of the aquifer ranges from a minimum of 1 m to a maximum of 45.41 m at a mean of 8.05 m. Water levels measured in this aquifer ranged from 14.41 to 22.39 meters below ground level.

4.6.2 Deeper fractured aquifer (confined)

The pores within the Karoo and more specifically the Ecca and Clarens sediments are too well-cemented to allow any significant flow of water. All groundwater movement therefore occurs along secondary structures, such as fractures and joints in the sediments. These structures are better developed in competent rocks, such as sandstone, hence the better water-yielding properties of the latter rock type.

It should be emphasised, however, that not all secondary structures are water-bearing. Many of these structures are constricted because of compression forces that act within the earth's crust The chances of intersecting a water-bearing fracture by drilling decrease rapidly with depth. At depths of more than 30 m, water-bearing fractures with significant yield were observed to be spaced at 100 m or greater.

The estimated thickness of the aquifer ranges from a minimum of 2 m to a maximum of 89 m at an mean of 30.2 m. Water levels measured in this aquifer ranged from 35.02 to 53.56 m below ground level.

Dwyka Tillite occurs at the base of the aquifer. Packer testing of the Dwyka Tillite done by Hodgson (1998) had a permeability distribution as indicated in Table 6. This permeability is very low and therefore can be regarded as a confining layer.

Table 6: Statistics for results on packer hydraulic conductivity testing of the Dwyka Tillite (Hodgson et al., 1998).

Statistics	Dwyka Permeability (m/d)
Mean	0.0034
Median	0.0024
Standard Deviation	0.0034
Minimum	0.0002
Maximum	0.0148

4.6.3 Lateral extent of aquifers

The lateral extent of the groundwater zone is a severely complex issue. The weathered and fractured Karoo aquifers, barring the occurrence of dolerite intrusions and hydraulic boundaries on the scale of the area of investigation can be taken as infinite. It is obvious however that their lateral extent in the study area is highly dependent on the distribution of dolerite dykes and sills.

Ignoring the effects of geological features, the maximum lateral extent of the aquifers is also limited by hydraulic boundaries as formed by major rivers/streams which act as groundwater discharge boundaries, topographical watersheds which act as no-flow boundaries and surface infiltration sources which usually represent constant head influxes.

4.6.4 Recharge

The main source of recharge into the upper aquifer is rainfall that infiltrates the aquifer through the overlying unsaturated zone. Rainfall that manifests as surface run-off and drains to streams may also subsequently enter the shallow aquifer by infiltrating the stream bed (Grobbelaar, 2001). Water impoundments and features such as tailings dams may constitute additional recharge sources in certain areas.

The rainfall ultimately recharging the upper aquifer is estimated at less than 3%. A higher proportion of infiltration may occur in areas where the natural permeability is increased, such as the increased fracturing associated with high extraction mining. Generally accepted values for recharge in high extraction areas are between 5 % and 7 %.

Recharge of the deep Karoo aquifer occurs from the shallow Karoo aquifer through permeable fracture systems that link the two aquifers. The natural distribution of such fracture systems is highly variable, and the recharge of the deep aquifer is expected to be some orders of magnitude lower than for the shallow aquifer. However, induced fracturing associated with mining can extend from the deep aquifer up to the surface and provides a relatively direct and highly permeable recharge route. The magnitude of recharge by this route depends on the extent of mining and the nature of the induced fracture pattern.

The recharge calculation for the unconfined (water table) aquifer for the study area is calculated below in Table 7.

Table 7: Recharge calculation for the shallow unconfined aquifer

Recharge Estimation			
Method	**mm/a**	**% of rainfall**	**Certainty (Very High=5 ; Low=1)**
Chloride	11.6	2	
Schematic maps			
Soil	11.6	2	4
Geology	19.1	3.3	3
Vegter	8	1.4	3
Acru	9	1.6	3
Harvest Potential	2.5	0.4	3

4.6.5 Summary

Based on the data detailed in the preceding sections the following can be concluded.

- Two aquifers are inferred to be present across the power station site at varying depths.
- The extent and depth of the aquifers is controlled by the sub-surface Karoo formation layering, weathering, geometry and post-Karoo intrusions and faults.
- Flow within the weathered aquifer is thought to be multi-porous and is controlled by weathering, flow within the fractured aquifer is controlled by the fracturing network while the competent host rocks serve as storage.

- Recharge into the weathered aquifer is thought to be directly linked to rainfall while recharge into the fractured aquifer is linked to shallower aquifers.

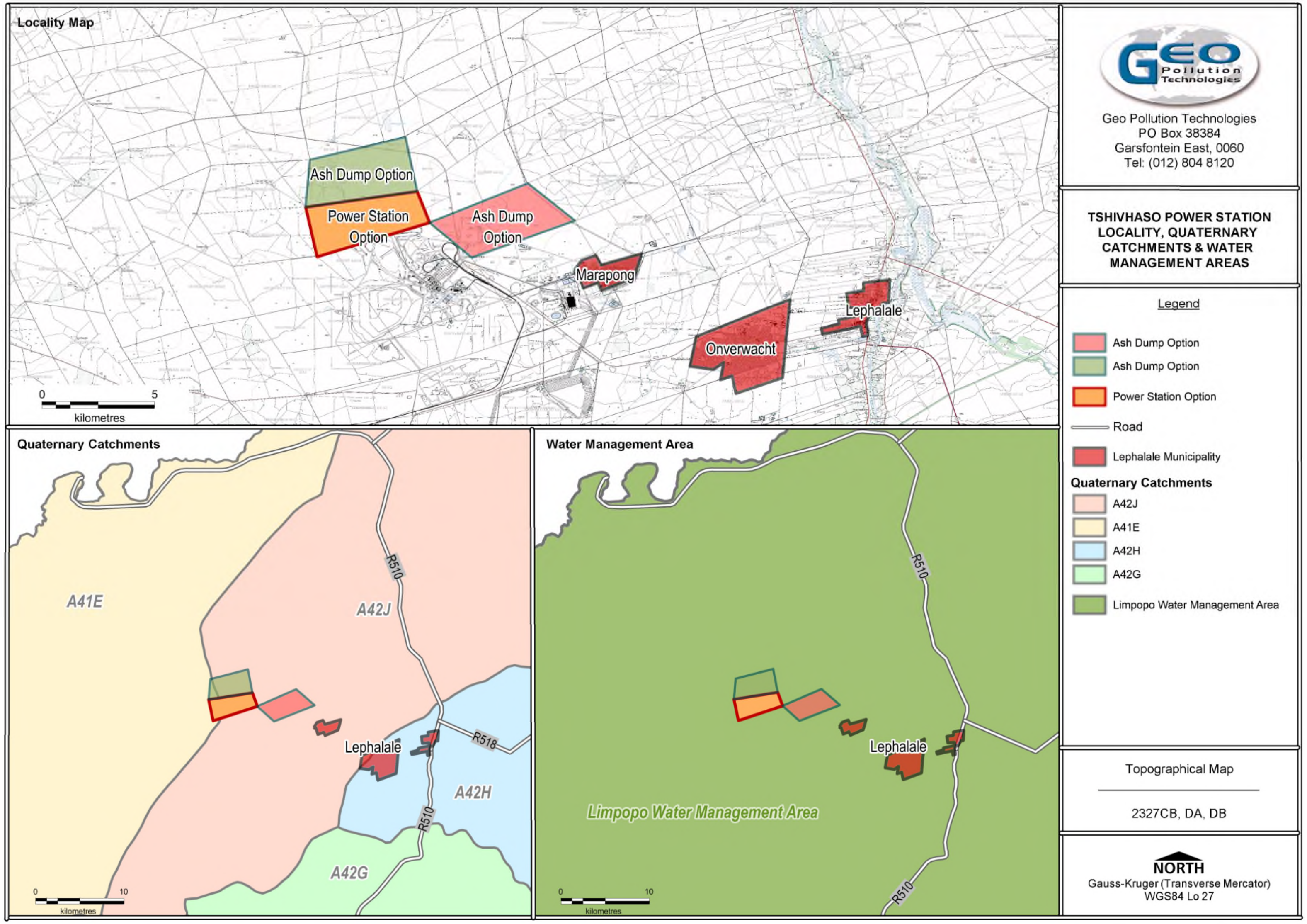

Figure 3: Site Location and Quaternary Catchment Boundaries

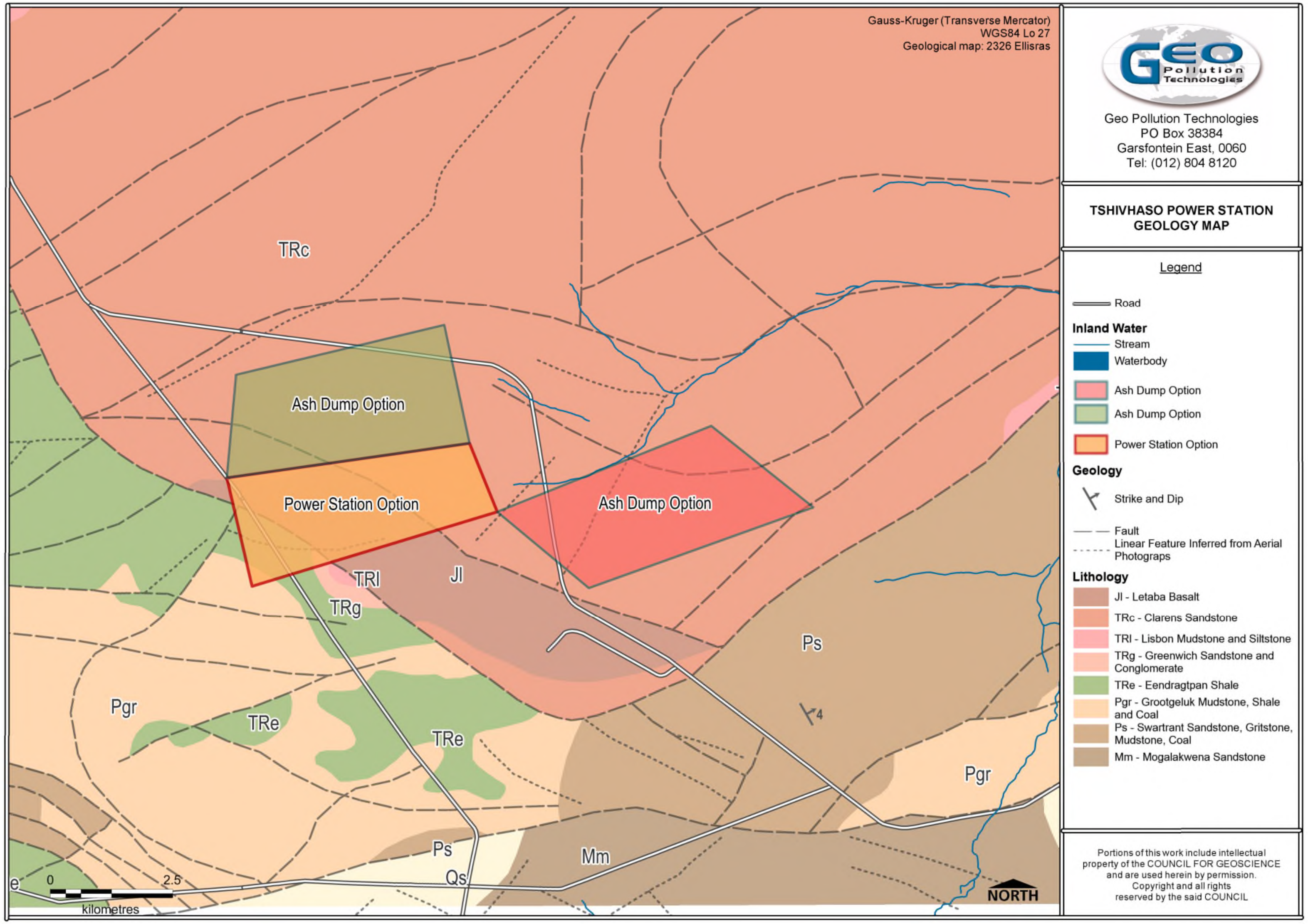

Figure 4: Regional Geology Map (1:250 000 geology series map)

5. HYDROGEOLOGICAL SETTING

The backbone of any groundwater impact prediction or management system is to understand the hydrogeological setting and how the potential stresses will influence the natural groundwater conditions. The hydrogeological setting is described under the headings below.

5.1 Site Topography and Drainage

The topography (shown in Figure 7) can normally be used as a good first approximation of the hydraulic gradient in the unconfined aquifer. This discussion will focus on the slope and direction of fall of the area under investigation, features that are important from a groundwater point of view.

The area is characterised by a gentle undulating topography and in the area of the proposed power station site the slope is more or less in the order of 1:200 (0.005).

There are no surface water points in and around the proposed power station site. On larger scale, drainage occurs towards the generalised flow of the Sandloop which confluences with the Mokolo River approximately 24 km from the site.

5.2 Hydrocensus

A hydrocensus was conducted for the proposed power station site and in the surrounding area, during August 2016. The position of all the boreholes relative to the power station area can be seen in Figure 5. A total of 17 boreholes were identified during this hydrocensus study. The main characteristics of this data are summarized in Table 5 and Figure 6. The boreholes identified were the property of Exxaro. Some of the boreholes were used for livestock watering but the majority were not in use.

5.2.1 Boreholes

Seventeen boreholes were found during the hydrocensus of which (see Figure 8):

- Twelve boreholes are either not in use or used for monitoring purposes. This is denoted as "other" uses. The distribution of use is presented as percentage of use in Figure 5 below
- Four boreholes are used for livestock watering.

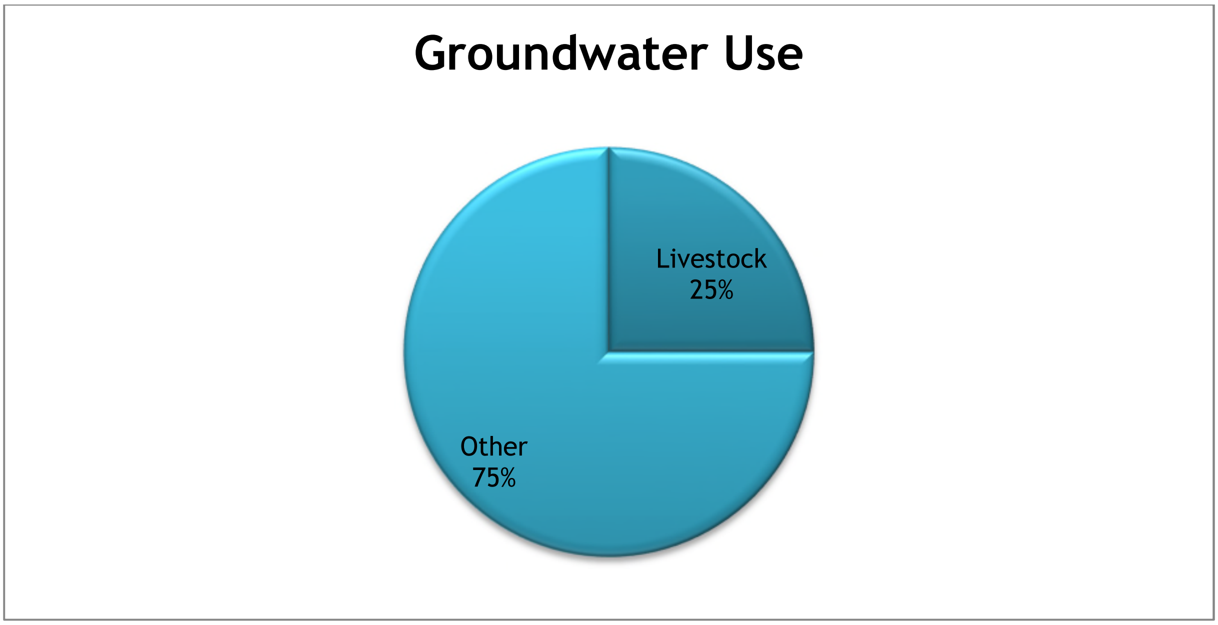

Figure 5: Groundwater distribution % use of the boreholes found during the hydrocensus

5.3 Water Levels

During the hydrocensus, 16 boreholes were available for groundwater level measurement. The groundwater levels varied between a minimum of 11 m and a maximum of 59 m below ground level. The relationship, using the boreholes from the hydrocensus, is shown in Figure 6 below.

This general relationship is useful to make a quick calculation of expected groundwater levels at selected elevations, or to calculate the depth of to the groundwater level:

Groundwater level = (Elevation x 0.2) + 663

Depth to the groundwater level = Elevation – ((Elevation x 0.2) + 663)

However, based on measured water levels the relationship between topography and static groundwater level is highly erratic, most likely due to large scale groundwater abstraction in the area as well as complex faulting.

The calibrated static water levels as modelled have been contoured and are displayed in Figure 9. Groundwater flow direction should be perpendicular to these contours and inversely proportional to the distance between contours. Using this relationship, the inferred groundwater flow directions are depicted as Figure 6 below. The groundwater flow is mainly from topographical high to low areas, eventually draining to the local streams.

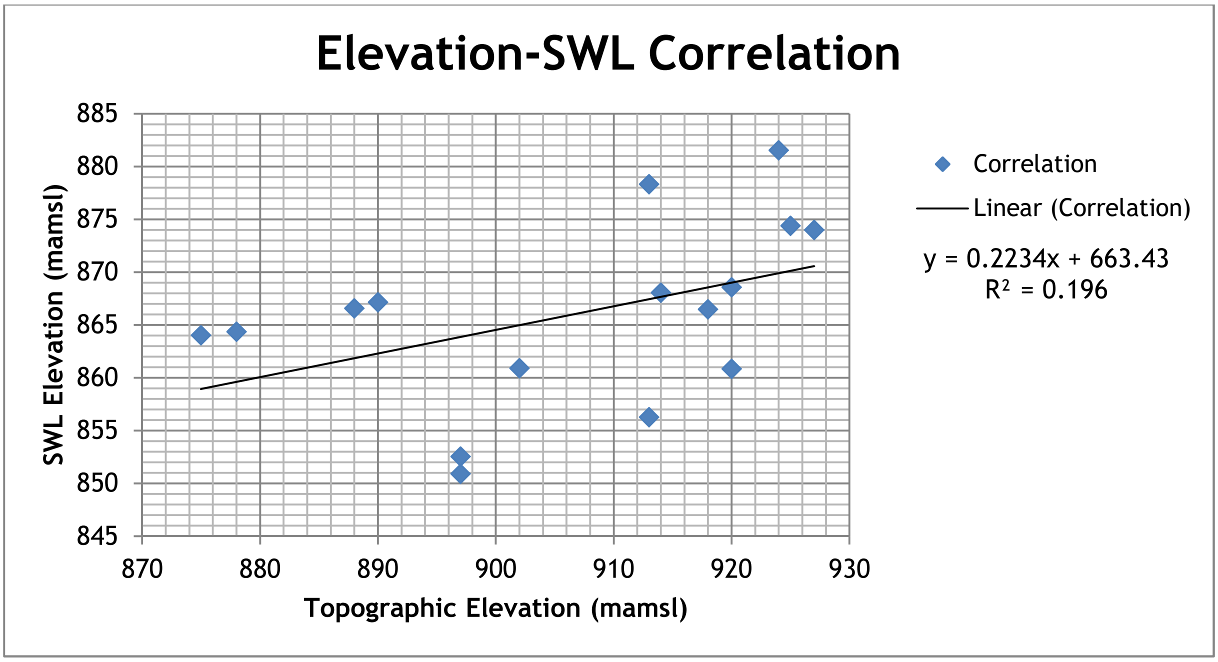

Figure 6: Correlation Graph of topography vs available groundwater levels

5.3.1 Unsaturated zone

Although a detailed characterisation of the unsaturated zone is beyond the scope of this study, a brief description thereof is supplied. The unsaturated or vadose zone serves as a buffer for protection of the underlying aquifer against contamination originating from surface. This unsaturated zone buffer through which surface water and precipitation move downwards is often referred to as aquifer vulnerability which will be discussed in detail further in in the report.

As shown in Figure 10, the unsaturated zone in the proposed power station area is in the order of between 11 m and 59 m metres thick (based on static groundwater levels measured in the existing boreholes during the 2016 hydrocensus) and consists of overlying clayey materials and underlying in-situ weathered sands derived from the decomposing parent rock.

These static water levels were also subtracted from the elevations to determine the interpolated unsaturated aquifer thicknesses of different points over the study area. These values are intrinsically the same as the interpolated depth to the natural groundwater level measured from the surface. The mean depth to the groundwater levels in the fractured aquifer in the proposed power station area is 40 metres.

5.4 Water Quality

Water samples were collected from 5 boreholes around the site during the investigation. The samples were submitted for major cation and anion analyses to determine water quality in the area. The groundwater results are compared with the recommended concentrations of the SANS 241 standard (Table 9).

The results from these analyses were plotted as Pie diagrams (Figure 11), Stiff diagrams (Figure 12) and a Piper diagram (Figure 13).

The pie diagrams show both the individual ions present in a water sample and the total ion concentrations in meq/L or mg/L. The scale for the radius of the circle represents the total ion concentrations, while the subdivisions represent the individual ions. It is very useful in making quick comparisons between waters from different sources and presents the data in a convenient manner for visual inspection.

A Stiff pattern is basically a polygon created from four horizontal axes using the equivalent charge concentrations (meq/L) of cations and anions. The cations are plotted on the left of the vertical zero axis and the anions are plotted on the right. Stiff diagrams are very useful in making quick comparisons between waters from different sources.[6]

On the piper diagram the cation and anion compositions of many samples can be represented on a single graph. Certain trends in the data can be discerned more visually, because the nature of a given sample is not only shown graphically, but also show the relationship to other samples. The relative concentrations of the major ions in mg/L are plotted on cation and anion triangles, and then the locations are projected to a point on a quadrilateral representing both cation and anions.

5.4.1 General groundwater quality

From the tables and figures the following can be deduced:

- The major cations in the groundwater samples are sodium, calcium and magnesium
- The major anions in the groundwater samples are chloride, sulphate and bicarbonate
- The groundwater quality can be described as Ca-SO_4 water which is due to evaporative effects and could possibly be traced to mining activity in the area. Additionally, Na and Cl constitute a large portion of the groundwater chemistry and can be attributed to evaporative effects.

5.4.2 Groundwater quality vs SANS Standard

From the tables and figures the following can be deduced:

- The constituents above the DWS guidelines are NO_3, NH_3, Cl, Fe and Mn

The elevation of the constituents described above can be interpreted as follows:

- Nitrogen based constituents are potentially elevated by agriculture in the area.
- Cl is elevated due to the geology of the area and evaporative effects due to limited recharge.
- Fe and Mn are elevated due to the geology of the area.

[6] EAS 44600 Groundwater Hydrology, Lecture 14: Water chemistry 1, Dr Pengfei Zhang

Table 8: Hydrocensus Information

No.	ID	Latitude	Longitude	Elevation	Owner	Property	Casing height	Static water level (mbgl)	Static water level (mamsl)	Sampled (Y/N)	Use				Comments
											Irrigation	Livestock	Domestic	Other	
Groundwater															
1	BH / LEP1	-23.60818	27.5708	888	EXXARO	Gelykebult	0.040	21.82	866.18	Yes		X			
2	BH / LEP2	-23.62564	27.58165	890	EXXARO	Appelulante	0.050	23.35	866.65	Yes		X			
3	BH / LEP3	-23.654531	27.60182	878	EXXARO	Nelsonskop	0.018	13.83	864.17	Yes				X	Not used. Closed
4	BH / LEP4	-23.5658	27.57263	920	EXXARO	Eindracht 1	0.023	59.39	860.61	Yes				X	Not in use
5	BH / LEP5	-23.56833	27.56807	927	EXXARO	Eindracht 1	0.046	53.47	873.53	Yes		X			Not in use
6	BH / LEP6	-23.57861	27.54471	918	EXXARO	Eindracht 2	0.034	51.87	866.13	Yes				X	Not in use
7	BH / LEP7	-23.59141	27.53042	914	EXXARO	Eindracht Pan 2	0.034	46.28	867.72	Yes		X			Pump powered by sun panel
8	BH / LEP8	-23.59638	27.50916	919	EXXARO	Gelykebult	0.045			No				X	Hole blocked between 34 and 35 m
9	BH / LEP9	-23.60222	27.4843	920	EXXARO	Onbeluk	0.045	51.89	868.11	Yes				X	
10	BH / LEP10	-23.60319	27.46093	924	EXXARO	McCabes Vley	0.022	42.67	881.33	Yes				X	
11	BH / LEP11	-23.64911	27.46862	897	EXXARO	McCabes Vley	0.016	46.24	850.76	No				X	Monitoring
12	BH / LEP12	-23.62596	27.50607	925	EXXARO	Goedehoop	0.026	50.88	874.12	Yes				X	Not in use. Cap.
13	BH / LEP13	-23.62361	27.47679	913	EXXARO	Van der Walts Pan	0.000	56.71	856.29	Yes				X	Not in use. Open well, no cap
14	BH / LEP14	-23.6202	27.47365	913	EXXARO	Van der Walts Pan	0.016	34.83	878.17	Yes				X	Not in use
15	BH / LEP15	-23.62776	27.46144	902	EXXARO	Van der Walts Pan	0.051	41.6	860.4	Yes				X	Not in use
16	BH / LEP16	-23.6278	27.45153	897	EXXARO	Van der Walts Pan	0.047	44.91	852.09	Yes				X	New point installed with name VN310LQ3
17	BH / LEP17	-23.62718	27.56747	875	EXXARO	Van der Walts Pan	0.022	11.18	863.82	Yes				X	Newly drilled BH

Table 9: Water qualities compared to SANS water quality guidelines

Parameter		Unit	SANS 241: 2015 Recommended Limits	Risk	Results				
					LEP1	LEP2	LEP11	LEP16	LEP12
Physical & Aesthetic determinands									
Electrical conductivity at 25^{0}C	EC	mS/m	≤ 170	Aesthetic	8.05	459	158	108	46.1
Total Dissolved Solids	TDS	mg/liter	≤ 1200	Aesthetic	56.4	3210	1110	759	323
pH at 25^{0}C		pH units	≥ 5 to ≤9.7	Aesthetic	8.36	7.85	6.95	7.48	7.45
Chemical Determinands - Macro determinands									
Free chlorine	Cl_2^-	mg/liter	≤ 5	Chronic Health	6.4	957	195	64.8	105
Nitrate as N	NO_3	mg/liter	≤ 11	Acute Health	5.27	975	245	219	12.4
Sulphate	SO_4	mg/liter	Acute Health ≤500; Aesthetic ≤250	Acute Health/Aesthetic	1.2	55.4	17.5	12.1	5.3
Ammonia as N	NH_3	mg/liter	≤ 1.5	Aesthetic	7.14	343	171	123	67.1
Chloride	Cl	mg/liter	≤ 300	Aesthetic	6.4	957	195	64.8	105
Sodium	Na	mg/liter	≤ 200	Aesthetic	0	0	0	0	0
Zinc	Zn	µg/liter	≤5000	Aesthetic	0	0	0	0	0
Chemical Determinands - Micro determinands									
Total Iron	Fe	mg/liter	Acute Health ≤ 2.0; Aesthetic ≤0.3	Acute/Aesthetic	0.97	26.4	34.3	15.1	4.81
Total manganese	Mn	mg/liter	Acute Health ≤0.4; Aesthetic ≤0.1	Acute/Aesthetic	7.54	513	101	72.1	20.2
Aluminium	Al	µg/liter	≤ 300	Operational	0	110	60	0	0
Concentration deemed to present an acceptable health risk for lifetime consumption.									

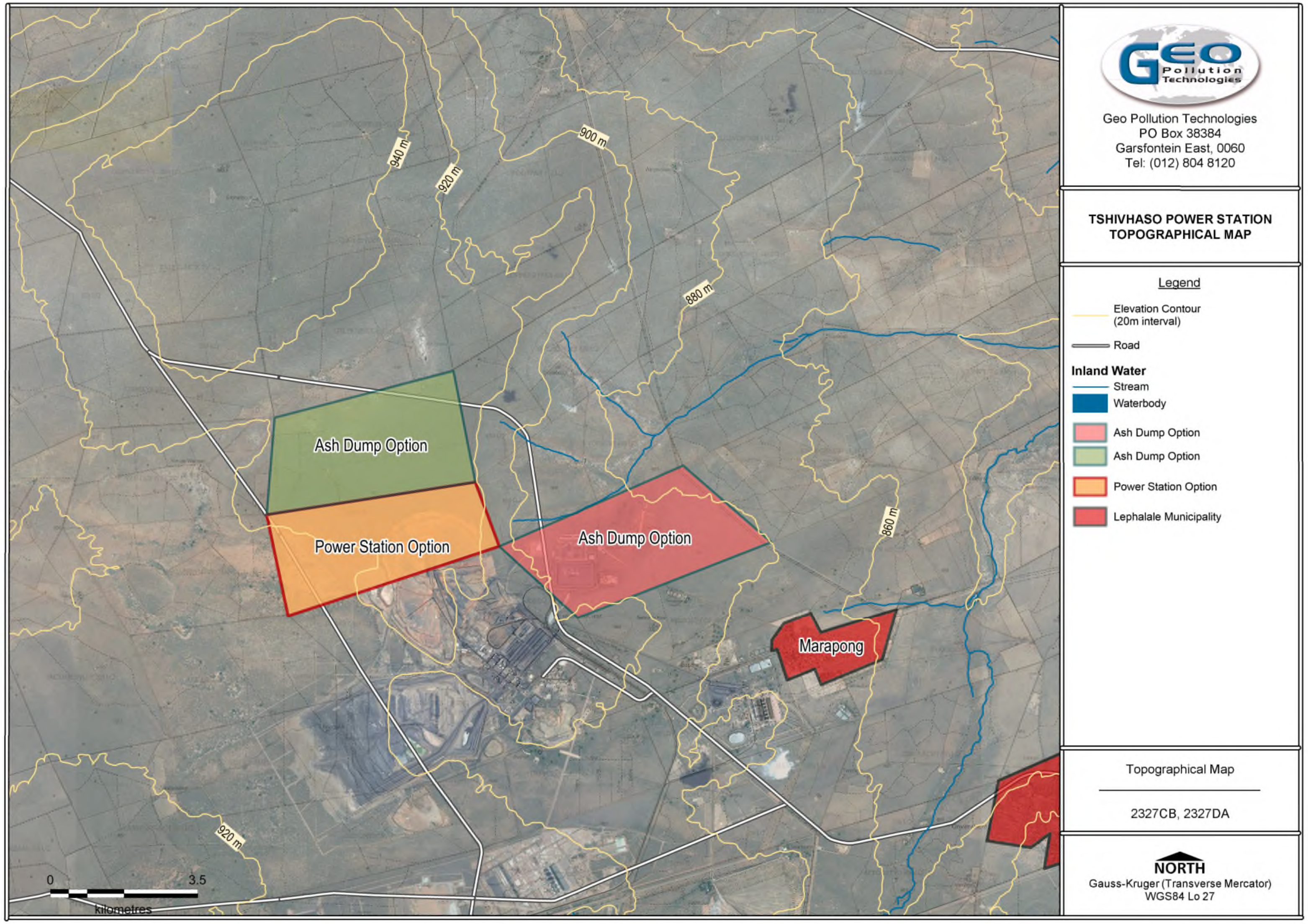

Figure 7: Site Topography

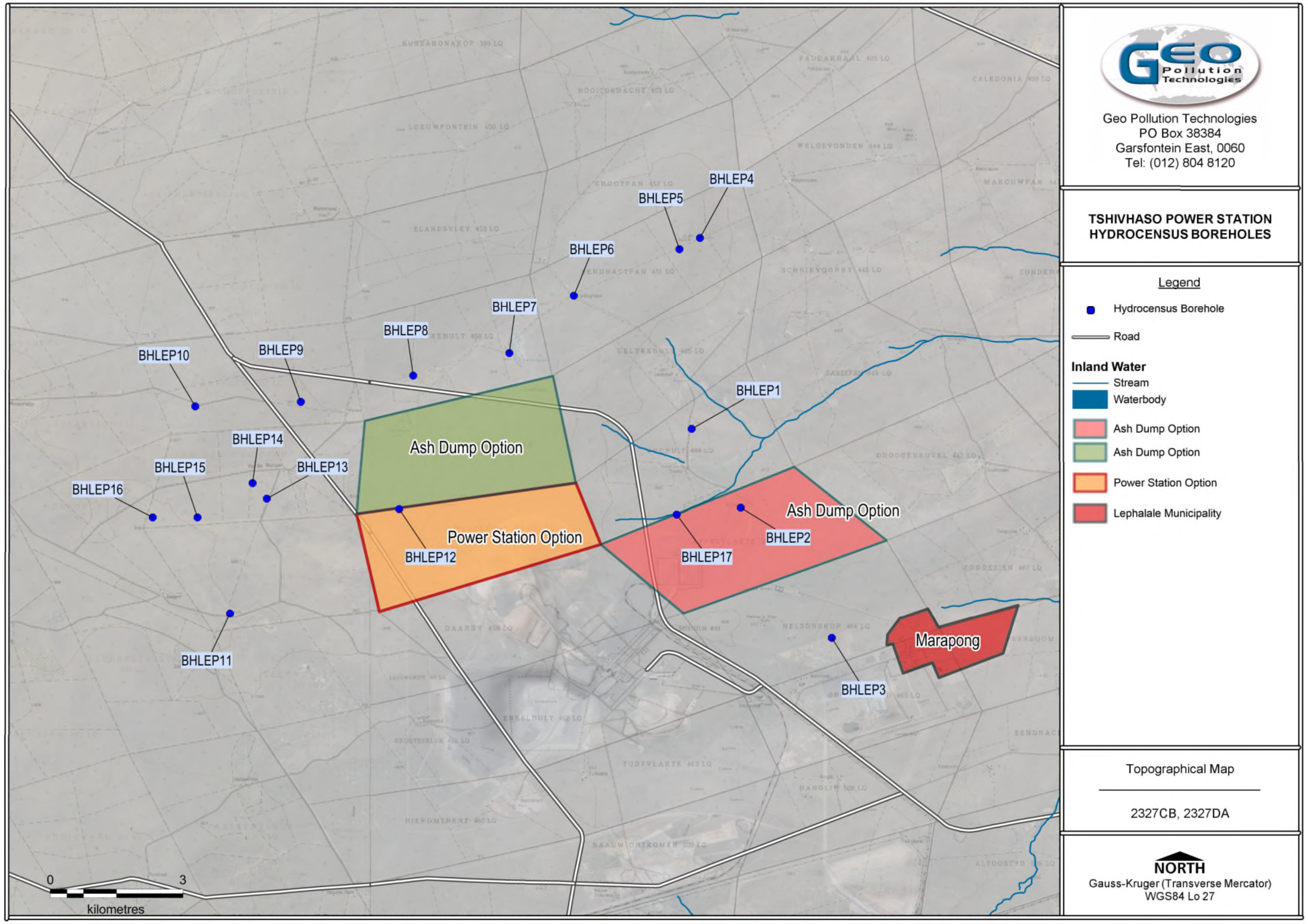

Figure 8: Hydrocensus points

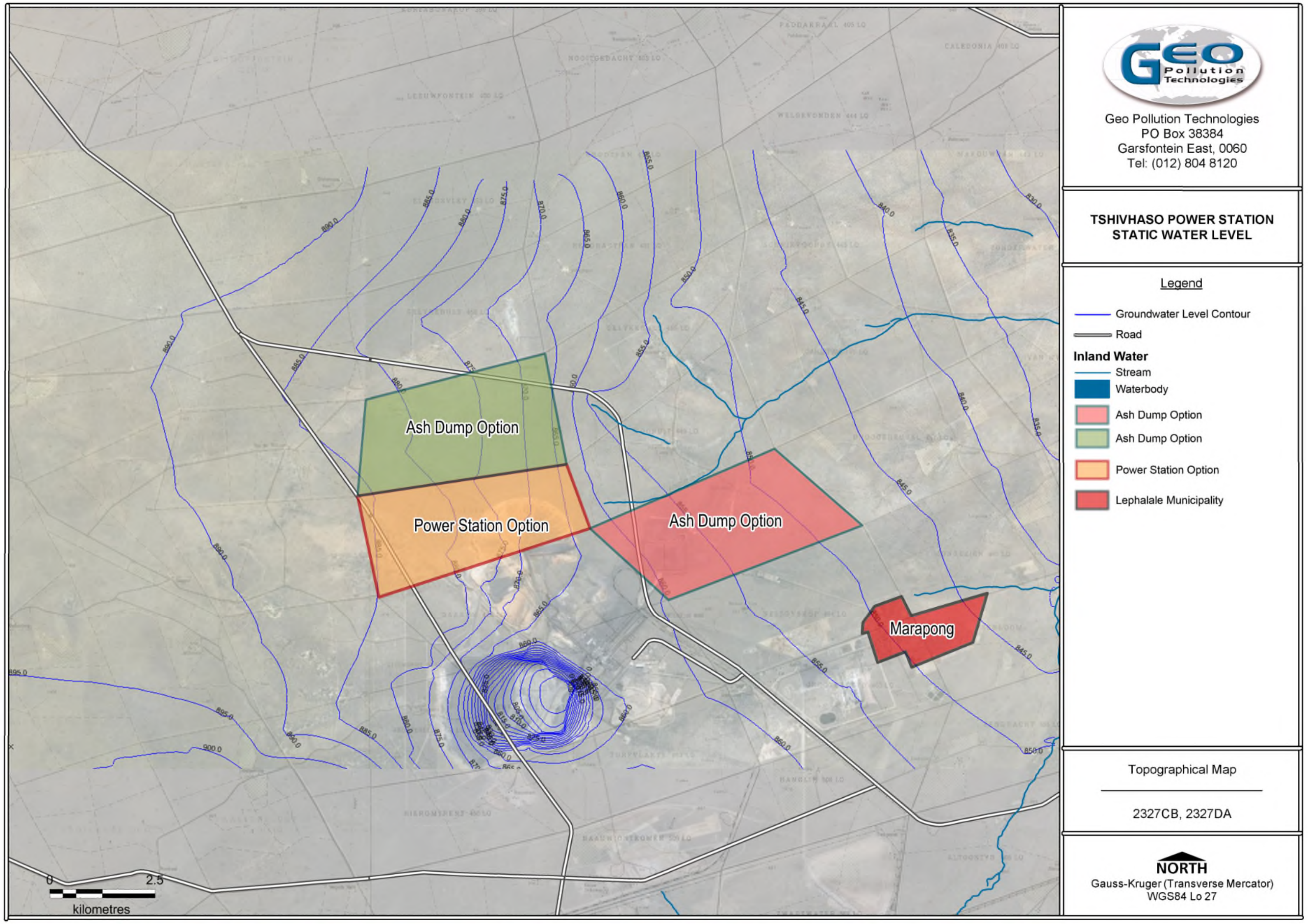

Figure 9: Contoured water levels of the water table aquifer (unconfined aquifer)

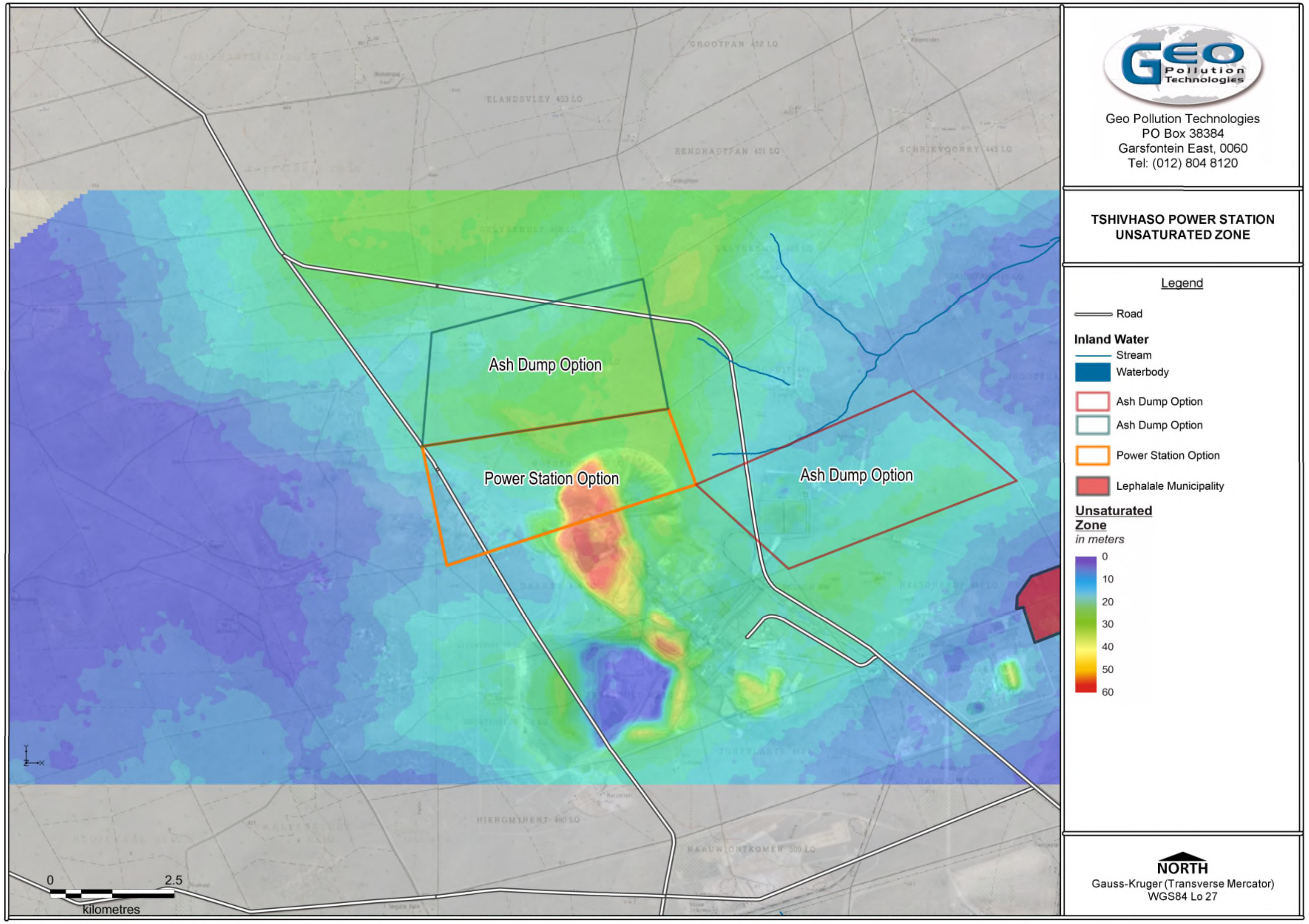

Figure 10: Contoured unsaturated zone (function of water level depth)

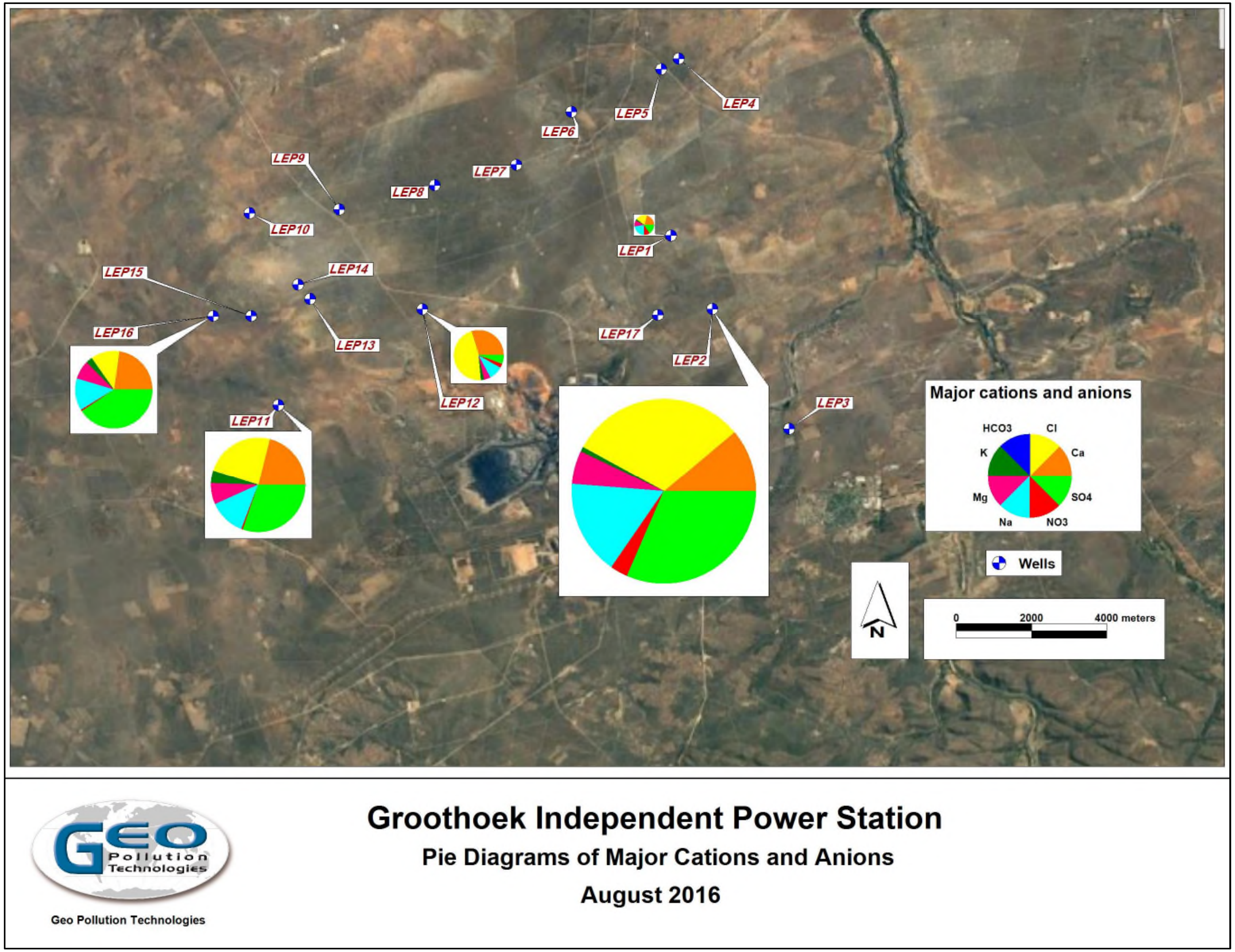

Figure 11: Pie diagrams for the Hydrocensus points

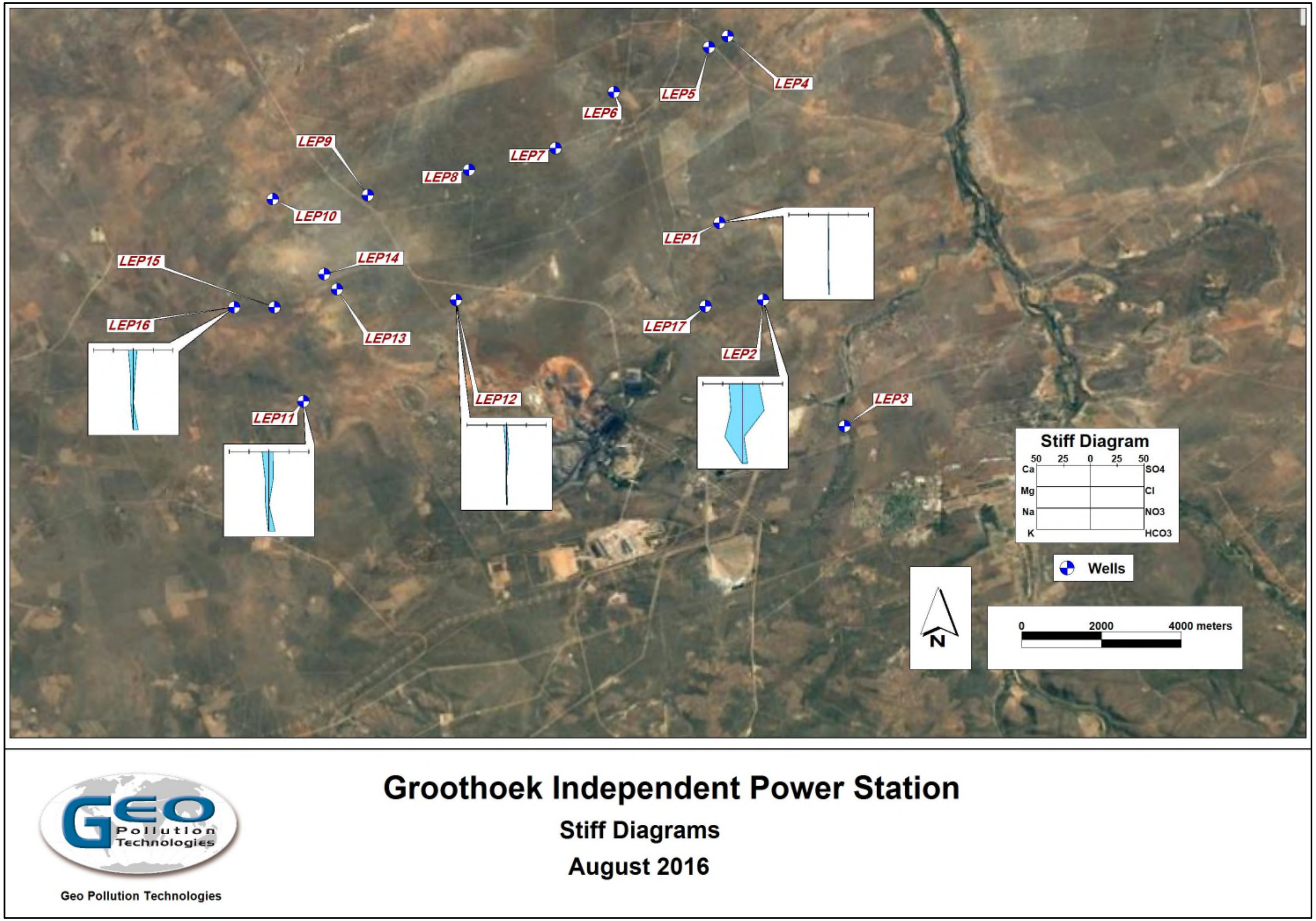

Figure 12: Stiff diagrams for the Hydrocensus points

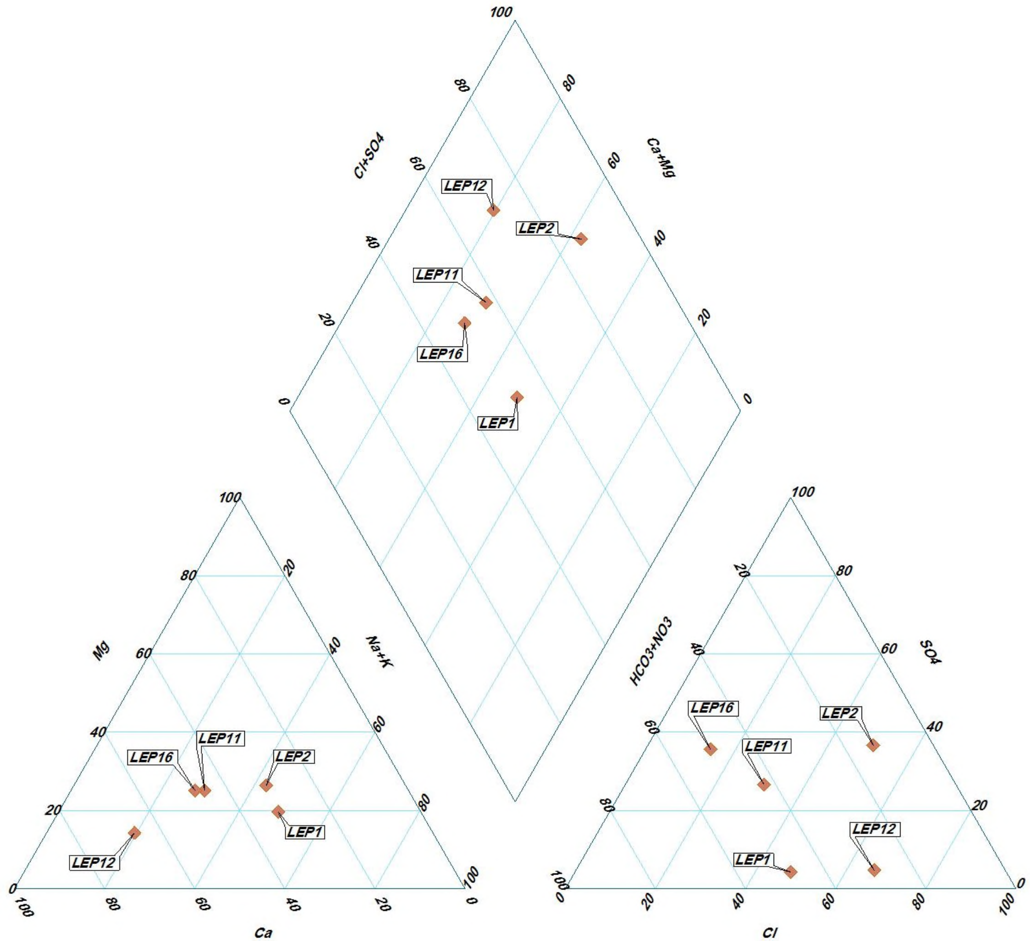

Figure 13: Piper Diagram

6. CONCEPTUAL SITE MODEL

From the results of the field investigations and laboratory analyses, a conceptual hydrogeological model was compiled for the power station. This conceptual model is a simplified representation of the conditions at and in the vicinity of the power station, and will provide the framework during the development of the risk assessment and numerical flow and transport model

The conceptual hydrogeological model for the proposed power station is illustrated schematically in Figure 14 by considering a cross-section through the various ash disposal facility sites and the adjacent and underlying geological units.

The CSM illustrates that contamination is likely to seep from the base of the ash disposal facility into the unsaturated zone. This contaminated leachate is likely to contain elevated concentrations of Ca, Na, Cl, SO_4 and metals such as Cu, Hg, Pb, Mn, Fe, Al, Cr etc. Perching of the discharged leachate may take place in the regolith underlying the ash disposal facility causing lateral flow which may reach neighbouring boreholes and is likely to contaminate the soil in the area. This will also cause a mounding of groundwater in the unsaturated zone. Therefore, monitoring of this shallow, perched aquifer will be required.

Seepage from the ash disposal facility may also reach the saturated fractured aquifer over time. Although this may occur over a long period of time, due to the 40 m thick unsaturated zone, groundwater contamination and mounding of the groundwater table is a possibility. Therefore, monitoring of the deeper fractured aquifer will also be necessary as neighbouring boreholes may be affected.

Due to large scale fracturing and faulting in the area, contamination potential to reach the neighbouring Grootgeluk opencast coal mine via preferential pathways. Flow is known to take place at higher velocities in the fault zones of this area and contamination could therefore travel much further in these structures as opposed to the weathered matrix blocks of the underlying aquifer.

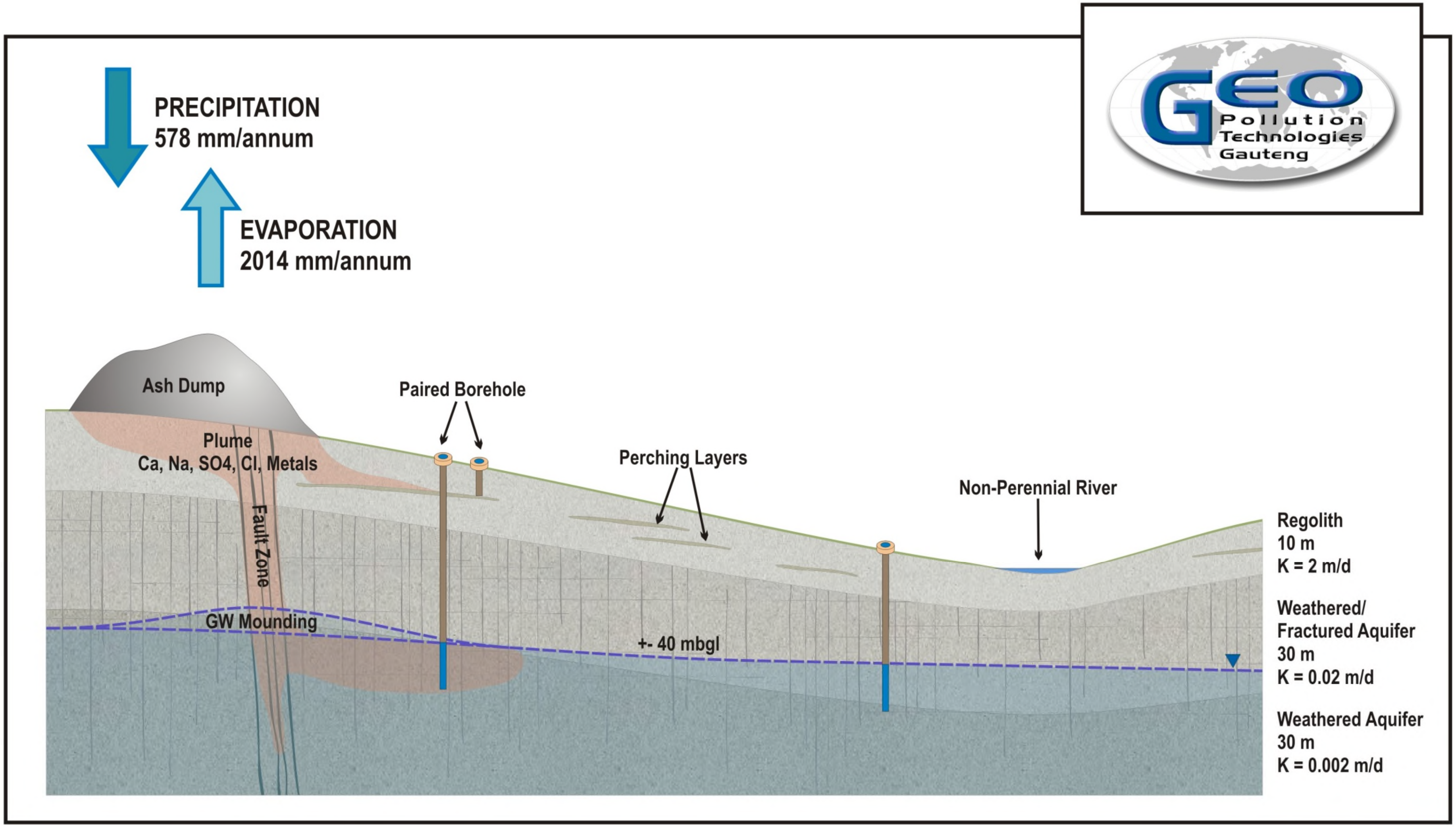

Figure 14: Conceptual Site Model

7. AQUIFER SENSITIVITY

The term aquifer refers to a strata or group of interconnected strata comprising of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to boreholes and /or springs (Vegter, 1994). In the light of South Africa's limited water resources it is important to discuss the aquifer sensitivity in terms of the boundaries of the aquifer, its vulnerability, classification and finally protection classification, as this will help to provide a framework in the groundwater management process.

7.1 Aquifer Classification

The aquifer(s) underlying the subject area were classified in accordance with "A South African Aquifer System Management Classification, December 1995."

The main aquifers underlying the area were classified in accordance with the Aquifer System Management Classification document[7]. The aquifers were classified by using the following definitions:

- Sole Aquifer System: An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
- Major Aquifer System: Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (Electrical Conductivity of less than 150 mS/m).
- Minor Aquifer System: These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.
- Non-Aquifer System: These are formations with negligible permeability that are regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Based on information collected during the hydrocensus it can be concluded that the aquifer system in the study area can be classified as a "Minor Aquifer System", based on the fact that the local population is not solely dependent on groundwater and very little groundwater is expected to be extractable from the local aquifers.

In order to achieve the Aquifer System Management and Second Variable Classifications, as well as the Groundwater Quality Management Index, a points scoring system as presented in Table 10 and Table 11 was used.

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[7] Department of Water Affairs and Forestry & Water Research Commission (1995). A South African Aquifer System Management Classification. WRC Report No. KV77/95.

Table 10: Ratings - Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	
Major Aquifer System:	4	
Minor Aquifer System:	2	2
Non-Aquifer System:	0	
Special Aquifer System:	0 - 6	
Second Variable Classification (Weathering/Fracturing)		
Class	Points	Study area
High:	3	
Medium:	2	2
Low:	1	

Table 11: Ratings - Groundwater Quality Management (GQM) Classification System

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	
Major Aquifer System:	4	
Minor Aquifer System:	2	2
Non-Aquifer System:	0	
Special Aquifer System:	0 – 6	
Aquifer Vulnerability Classification		
Class	Points	Study area
High:	3	
Medium:	2	2
Low:	1	

As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability. The GQM index for the study area is presented in Table 12.

The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer, in terms of the above, is classified as **medium.**

The level of groundwater protection based on the Groundwater Quality Management Classification:

GQM Index = Aquifer System Management x Aquifer Vulnerability

= 2 x 2 = 4

Table 12: GQM Index for the Study Area

GQM Index	Level of Protection	Study Area
<1	Limited	
1 - 3	Low Level	
3 - 6	Medium Level	4
6 - 10	High Level	
>10	Strictly Non-Degradation	

7.2 Aquifer Vulnerability

Aquifer vulnerability assessment indicates the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Stated in another way, it is a measure of the degree of insulation that the natural and manmade factors provide to keep contamination away from groundwater.

- Vulnerability is high if natural factors provide little protection to shield groundwater from contaminating activities at the land surface.
- Vulnerability is low if natural factors provide relatively good protection and if there is little likelihood that contaminating activities will result in groundwater degradation.

The following factors have an effect on groundwater vulnerability:

- Depth to groundwater: Indicates the distance and time required for pollutants to move through the unsaturated zone to the aquifer.
- Recharge: The primary source of groundwater is precipitation, which aids the movement of a pollutant to the aquifer.
- Aquifer media: The rock matrices and fractures which serve as water bearing units.
- Soil media: The soil media (consisting of the upper portion of the vadose zone) affects the rate at which the pollutants migrate to groundwater.
- Topography: Indicates whether pollutants will run off or remain on the surface allowing for infiltration to groundwater to occur.
- Impact of the vadose zone: The part of the geological profile beneath the earth's surface and above the first principal water-bearing aquifer. The vadose zone can retard the progress of the contaminants [3].

The Groundwater Decision Tool (GDT) was used to quantify the vulnerability of the aquifer underlying the site using the below assumptions.

- Depth to groundwater below the site was estimated from water levels measured during the hydrocensus inferred to be at a mean of ~40 mbgl.
- Groundwater recharge of ~8 mm/a,
- Sandy loam soil vadose zone
- Gradient of 0.4% was assumed and used in the estimation.

The aquifer vulnerability for a contaminant released from surface to a specified position in the groundwater system after introduction at some location above the uppermost aquifer was determined using the criteria described below and assuming a worst case scenario:

- Highly vulnerable (> 60), the natural factors provide little protection to shield groundwater from contaminating activities at the land surface.
- Medium Vulnerable = 30 to 60%, the natural factors provide some protection to shield groundwater from contaminating activities at the land surface, however based on the contaminant toxicity mitigation measures will be required to prevent any surface contamination from reaching the groundwater table.
- Low Vulnerability (< 30 %), natural factors provide relatively good protection and if there is little likelihood that contaminating activities will result in groundwater degradation
- The GDT calculated a vulnerability value of 30%, which is medium.

7.3 Aquifer Protection Classification

A Groundwater Quality Management Index of 4 was estimated for the study area from the ratings for the Aquifer System Management Classification. According to this estimate a **medium level groundwater protection** is required for the aquifer. Reasonable and sound groundwater protection measures based on the modelling will therefore be recommended to ensure that no cumulative pollution affects the aquifer, even in the long term.

DWS' water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that measures must be taken to limit the risk to the following environments.

- The protection of the underlying aquifer.

8. GROUNDWATER FLOW AND TRANSPORT MODELLING

The numerical groundwater flow model is constructed and simulated to aid in decision making processes and environmental management.

The groundwater regime of the study area is highly heterogeneous due to complex faulting and intrusions, which ultimately influence the groundwater flow patterns. Constructing a groundwater flow model with all the detail is close to impossible; however, assumptions are made based on data gathered in the field and used to simulate different scenarios to conclude with management protocol.

Therefore the purpose of the numerical model is to develop a tool than can be used to assess the impact of the activities associated with the power station during the operational phase.

8.1 Objectives

The aim of the groundwater flow model is to simulate the groundwater system to determine the groundwater flow balance, groundwater flow directions and impact of cumulative pollution on the local environment, if any. The aim of the model is to gain an understanding of the groundwater flow dynamics and will be used to:

- The spread and migration rate of the pollution plume during and post power station operations

8.2 Flow Model setup and Construction

The detailed model setup and construction is discussed in Appendix G, with only the conceptual model input and fixed aquifer parameters discussed below.

8.2.1 Conceptual model input

For the purpose of this study, the subsurface was envisaged to consist of the following hydrogeological units.

- The upper few meters below surface consist of completely weathered material. This layer is anticipated to have a reasonably high hydraulic conductivity, but in general unsaturated.
- The next few tens of meters are weathered, highly fractured shale/sandstone bedrock with a low hydraulic conductivity. The permanent groundwater level commonly resides in this unit. The groundwater flow direction in this unit is influenced by regional topography and for the site flow would be in general from high to lower lying areas.
- Below a few tens of meters the fracturing of the aquifer is less frequent with depth and fractures less significant due to increased pressure. This results in an aquifer of lower hydraulic conductivity and very slow groundwater flow velocities.
- Fracturing of the bedrock could consist of both major fault structures and/or minor pressure-relieve joints. On a large enough scale (bigger than the Representative Elemental Volume) the effects of lesser structures become less important in a rock matrix. Therefore, parts of the aquifer that did not show major fault zones have been considered as homogeneous in this study. However, in this specific area, large fault structures such as the Daarby Fault are also present according to the data analysed in the desk study. The magnitude of these structures leads to the assumption that they extend to depth as master faults with lesser faults extending from these structures in fault zones and intersections.

Groundwater, originating from the vertical infiltration of rainwater through the upper layer(s) up to the groundwater level, will flow mostly horizontally in the directions as discussed above. Water flow volumes and velocities will, on average, decrease gradually with depth.

The following assumptions and simplifications were made in constructing the numerical model:

- The upper completely weathered aquifer mostly unsaturated, but could be an important part of the hydrogeological system in low lying areas. Although it is very thin in comparison to the fractured bedrock aquifer, it has been modelled as a separate layer to improve model predictions where the groundwater levels are shallow. This is especially relevant as the thickness of this layer could reach up to 30m in this area based on data obtained for Bayes interpolation from the National Groundwater Archive[8]. The permanent groundwater level could be present in this layer in some places.
- The bedrock has been modelled as three layers of decreasing hydraulic conductivity and specific yield. Fractures in bedrock close up at depth, which result in a lowering of the hydraulic conductivity[9].
- It is generally known that only the upper 30 - 50 meters of the Clarens Formation and Ecca Group contains significant groundwater. Thus, a layer representing the weathered and fractured zone where the permanent groundwater level commonly resides was modelled. However, the thickness of this layer was varied based on the interpolated thickness of the uppermost layer of the model representing the upper completely weathered aquifer. This layer was followed by two more layers of 40 metres thickness each. The hydraulic parameters were decreased by an order of magnitude in each successive layer.
- No provision has been made for the lower Dwyka Group and Glenover Complex as a separate unit, as neither its vertical position nor properties are known with any certainty. However, at depth secondary porosity due to bedrock fracturing is more important than the original bedrock properties. It can thus reasonably be assumed that the hydraulic properties are reasonable similar to that of the fractured Ecca and Clarens rock.
- The local effect of identified discontinuities, such as major faults, has been incorporated into the model. These structures were found to influence groundwater abstraction significantly as most boreholes found during the hydrocensus study were drilled in fault zones. Therefore, these structures were considered to be major water transmitting units for the area and were incorporated into the model as preferred flowpaths with differing hydraulic characteristics from that of rock matrix blocks.
- Large fault structures identified were considered to be fault zones due to the scale of fracturing and displacement.
- These structures were considered to be of raised hydraulic conductivity even to depth due to large displacements and subsequently, high levels of fracturing. This may also be supported by the number of boreholes in the area, specifically targeting these structures for water abstraction.

[8] http://www3.dwa.gov.za/NGANet/Security/WebLoginForm.aspx

[9] Barnes, S. L. et al. Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania. Pennsylvania Department of Environmental Protection

8.2.2 Fixed aquifer parameters

Although the most relevant aquifer parameters are optimised by the calibration of the model, many parameters are calculated and/or judged by conventional means. The following fixed assumptions and input parameters were used for the numerical model of this area:

- Recharge = 12 mm/a ≈ 0.00003 m/d. This value was calculated using the RECHARGE program[10]. This value relates to a recharge percentage of less than 3%. Please note that this is not effective recharge, as evapotranspiration was also modelled as discussed below. The result will thus be higher recharge in high topographical areas and lower recharge where the water table is shallow, similar to the conditions in nature.
- Maximum Evapotranspiration = 2014 mm/a ≈ 0.005 m/d. This value is based on the S-pan evaporation data for this area[4]. Note that this rate of evapotranspiration is used by the modelling software only if the groundwater should rise to the surface. For the groundwater level between the surface and the extinction depth, the evapotranspiration is calculated proportionally.
- Evapotranspiration Extinction Depth = 1 m. This depth relates to the expected average root depth of plants in this area.
- The specific storage over the area was taken as 0.000001. This is a typical value for fractured bedrock.
- Evapotranspiration Extinction Depth = 1 m. This depth relates to the expected average root depth of plants in this area.
- The specific storage over the area was taken as 0.000001. This is a typical value for fractured bedrock.
- Horizontal Hydraulic Permeability of Rock Matrix= 0.02 m/d as an initial value, declining with depth by an order of magnitude at the fourth layer due to decreasing weathering of the bedrock and increased pressure that tend to close fractures.
- Horizontal Hydraulic Permeability of Fault Zones= 5 m/d as a maximum value
- Vertical Hydraulic Anisotropy (KH/KV) of the bedrock = 10. By nature of the pronounced horizontal layering, this value is commonly used in the Karoo sedimentary layers.
- The effective porosity value of the bedrock was taken as 0.05, declining gradually to 0.01 at a depth of 100 - 150 metres. This value could not be determined directly and was taken as typical of the fractured bedrock.
- Longitudinal dispersion was taken as 50 metres, which is about 10% of expected plume dimensions, as recommended in various modelling guidelines.
- Transverse and vertical dispersion was taken as 5 metres and 0.5 metre respectively as recommended in various textbooks, being about 10% of the expected plume dimensions.
- The existing Grootegeluk mining area was modelled as a drain. A value of $7m^2/day/m^2$ was used for the drain conductance. This value was found to be just enough to lower the groundwater level to the coal floor during mining.

8.3 Model Boundaries and Discretisation

Boundaries for the numerical model have to be chosen where the groundwater level and/or

[10] Gerrit van Tonder, Yongxin Xu: RECHARGE program to Estimate Groundwater Recharge, June 2000. Institute for Groundwater Studies, Bloemfontein RSA.

groundwater flow is known. The most obvious locations are zero flow conditions at groundwater divides, while groundwater levels are known at prominent perennial dams and rivers connected to the groundwater.

To simulate the groundwater conditions in and around the proposed power station area, the aquifer as described below, has been modelled. Boundaries were chosen to include the area where the groundwater pollution plume could reasonably be expected to spread and simultaneously be far enough removed from the power station boundaries not to be affected contaminant movement.

Wherever practical, natural topographical water divides have been used as no-flow boundaries, assuming that the groundwater elevation follows the topography. In this particular area, water divides (topographical highs) served as no-flow boundaries to the north and west whereas the Sandloop served as a boundary to the south and to the east the Mokolo River.

These boundaries resulted in an area of about 5 to 20 km around the proposed power station, which is considered far enough for the expected groundwater effects not to be influenced by boundaries.

The modelling area was discretised by a 324 by 558 grid, refined at the power station area resulting in finite difference elements of about 25 by 25 meters at the power station area and up to 200 meters at the edges of the model. All modelled features, like ash dumps, are sizably larger than these dimensions, and the grid is thus adequate for the purpose. Nevertheless, the total amount of active cells over all layers added up to about 606 000 cells, resulting in a relatively large model.

8.4 Calibration

Water level data obtained the hydrocensus was used to calibrate the steady state numerical groundwater flow model. The results obtained during the steady state scenarios will be used as initial conditions to simulate contaminant transport impacts. A good fit was obtained for the measured groundwater levels as shown in, as can be seen in Figure 15 to Figure 16.

All other parameters were unchanged, with values as listed in the paragraphs above. The calibration error statistics can be seen in Table 14. The head error was below 5, which can be regarded as acceptable.

Table 13: Optimal Calibrated Aquifer Parameters

Aquifer	Model layer	Layer thickness (m)	Porosity (%)	Hydraulic conductivity (m/d)
Unsaturated Zone	Layer 1	Variable	30	2
Shallow Weathered Aquifer	Layer 2	30	5	0.2
Fractured Aquifer	Layer 3	30	4	0.01
Deep Fractured Aquifer	Layer 4	30	3	0.001
Fault Zones	Layer 2-4	Variable	5	5

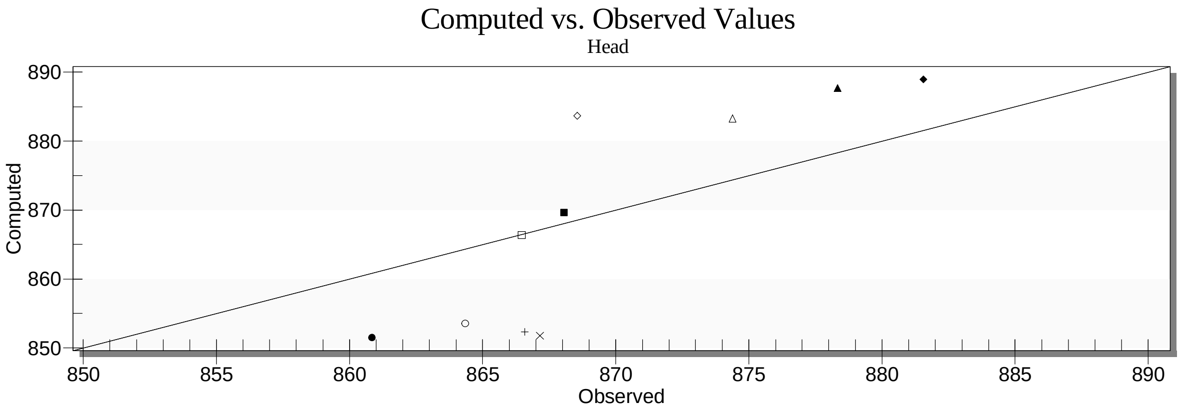


Figure 15: Water level Calibration Graph

Table 14: Calibration Statistics

Description	Value
Mean Residual (Head)	-4.25
Mean Absolute Residual (Head)	8.7
Root Mean Squared Residual (Head)	10.53

8.5 Modelling Scenarios

The calibrated model as described above was used to estimate the impact of the proposed power station on the groundwater quality. Models ran and assumptions made, were the following:

8.5.1 Construction Phase

This scenario represents the construction of the power station. It is assumed that additional no groundwater abstraction will take place except for what is currently being used in the area. Therefore, the hydrogeological scenario is assumed to remain in its current status with the exception of lesser hydrocarbon contamination. Therefore, this situation was modelled to represent the current situation.

8.5.2 Operational Phase

This model represents the groundwater situation during the operation of the proposed power station. For the purposes of this model a worst-case scenario was assumed, namely that the ash dump will be present in the magnitude planned, based on data from the client, from the start of operations, and will release the assumed sulphate concentration constantly.

8.6 LIMITATIONS OF THE MODELLING EXERCISE

The modelling was done within the limitations of the scope of work of this study and the amount of monitoring data available. Although all efforts have been made to base the model on sound assumptions and has been calibrated to observed data, the results obtained from this exercise should be considered in accordance with the assumptions made. Especially the assumption that a fractured aquifer will behave as a homogeneous porous medium locally, can lead to error. However, on a large enough scale (bigger than the REV, Representative Elemental Volume) this assumption should hold reasonable well. Also, the faults were given an assumed hydraulic conductivity which lead to an improved calibration. The assumed hydraulic conductivity may also lead to error and the values should be confirmed by pump testing of boreholes drilled into the fault structures present on site.

8.7 Predicted Groundwater impacts

It is the aim of this chapter to assess the likely hydrogeological impact that the proposed power station might have on the receiving environment. The typical stages that will be considered in this section are:

- Construction Phase: Construction of the power station at the specific site before actual operation commences.
- Operational Phase: The conditions expected to prevail during the operation of the new power station.

8.7.1 Construction phase impacts

It is accepted for the purposes of this document that the construction phase will consist of preparations for the power station, which is assumed to consist mainly of establishment of infrastructure on site and the physical construction of the power station.

This phase is not expected to influence the groundwater levels. With the exception of lesser oil and diesel spills, there are also no activities expected that could impact on regional groundwater quality. This phase should thus cause very little additional impacts in the groundwater quality. It is expected that the current status quo will be maintained.

8.7.2 Operational Phase Impacts

The operational phase is interpreted as the active operation of the power station as well as the associated ash dump. It is inevitable that these operations will impact on the groundwater regime. The potential impacts that will be considered are the groundwater quantity and quality.

Conceptual layouts were made available at the time of this study, and conservative assumptions were thus made regarding layout planning. It is recognised that the layout might be simplistic, and it is essential that this model is updated once final information is available.

8.7.2.1 Impacts on groundwater quantity

During the operational phase, no groundwater abstraction is expected. Therefore, no groundwater drawdown is expected from the power station and the current status in this regard, will be maintained. However, LEP 2 is likely to be destroyed during the establishment of the ash dump on Appelvlakte, which can be considered to be an impact on groundwater quantity. This depends on the selected site for ash dump development.

Also, should the power station extract groundwater for operational processes in future, it will be important to update the groundwater model with this information as receptors in the area may be impacted by this activity.

8.7.2.2 Impacts on groundwater quality

During the operation of the power station, the main impact on groundwater is considered to be contamination from the ash dump. As sulphate is normally a significant solute in drainage from these facilities, it has been modelled as a conservative (non-reacting) indicator of pollution. A starting concentration of 2 000 mg/litre has been assumed as a worst case scenario, based on past experience.

The migration of contaminated water from the ash dump areas has been modelled as described, and the results are presented in Figure 18 in terms of the extent of the pollution plume 10, 25, 50 and 100 years during operation of the power station.

As stated previously, the results must be viewed with caution as homogeneous aquifer matrix conditions and extended fault zones have been assumed. Furthermore, no chemical interaction of the sulphate with the minerals in the surrounding bedrock has been assumed. As there must be some interaction and retardation of the plume, this prediction will represent a worst-case scenario.

Within the limitations of the abovementioned assumptions, it can be estimated from these figures that:

Appelvlakte Ash Dump Option (Figure 17).

No boreholes are likely to be affected by the sulphate pollution plume from the ash dump within 100 years after operations have commenced with the exception of the destruction of LEP2. It should be noted that other privately owned boreholes, downstream of the site, may be affected if pumping takes place, as this may accelerate groundwater flow in the identified faults and subsequently, contaminant transport.

*Graaffwater Ash Dump Option (*Figure 18*).*

No boreholes are likely to be affected by the sulphate pollution plume from the ash dump within 100 years after operations have commenced with the exception of LEP12. It should be noted that other privately owned boreholes, downstream of the site, may be affected if pumping takes place, as this may accelerate groundwater flow in the identified faults and subsequently, contaminant transport.

8.7.3 Cumulative effects

The cumulative pollution impacts of all current and historic mining and power station activities in addition to the proposed new power station could not be calculated as any data on surrounding activities is not available. However it is highly recommended that a regional study be undertaken to quantify impacts on at least a quaternary scale or a data sharing agreement should be reached with neighbouring mines and power stations.

8.8 Assumptions and Limitations

The modelling was done within the limitations of the scope of work of this study and the amount of data available. Although all efforts have been made to base the model on sound assumptions and has been calibrated to observed data, the results obtained from this exercise should be considered in accordance with the assumptions made. Especially the assumption that a fractured aquifer will behave as a homogeneous porous medium can lead to error. However, on a large enough scale (bigger than the REV, Representative Elemental Volume) this assumption should hold reasonable well. Additionally, the simplistic layout is insufficient to make accurate calculations for the contaminant transport situation. A list of the main assumptions and simplifications is detailed below:

- The topographic elevations were interpolated from a DEM obtained from the ASTER global digital elevation model.
- The bedrock has been modelled as three layers of decreasing hydraulic conductivity and specific yield. Fractures in bedrock close up at depth, which result in a lowering of the hydraulic conductivity[11].

[11] Barnes, S. L. et al. Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania. Pennsylvania Department of Environmental Protection

Table 15: Summary of potential impacts during operation of the power station - spread of pollution

Surface Infrastructure	Area (m^2)	Farm Location	Potential impacted receptor	Estimated increase in concentrations during operation (mg/ℓ)
Ash Disposal Facility	11493909	Graaffwater 456	LEP12	2000
Ash Disposal Facility	11460501	Appelvlakte 448	LEP2	2000

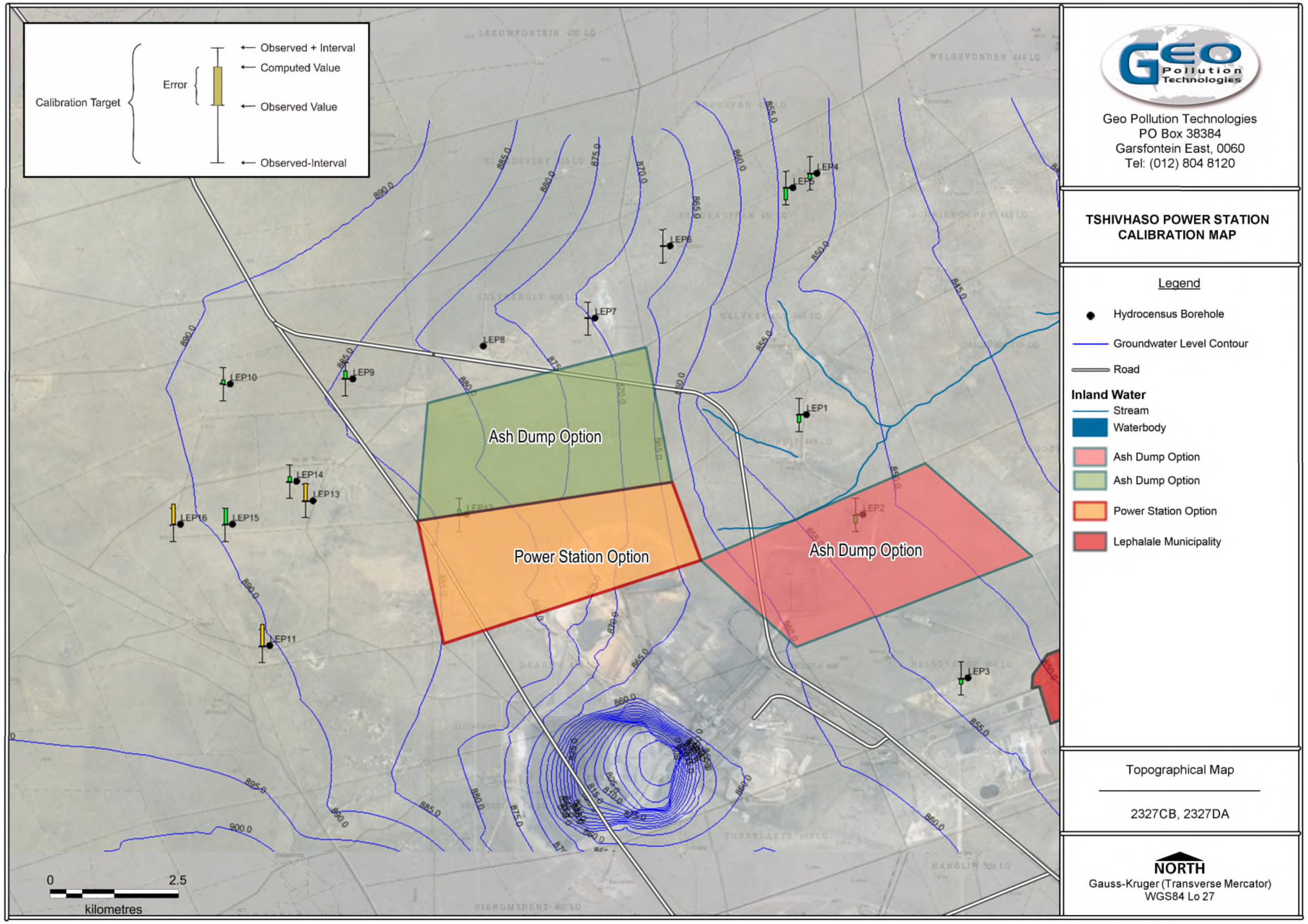


Figure 16: Calibration of the numerical model (5 m head interval)

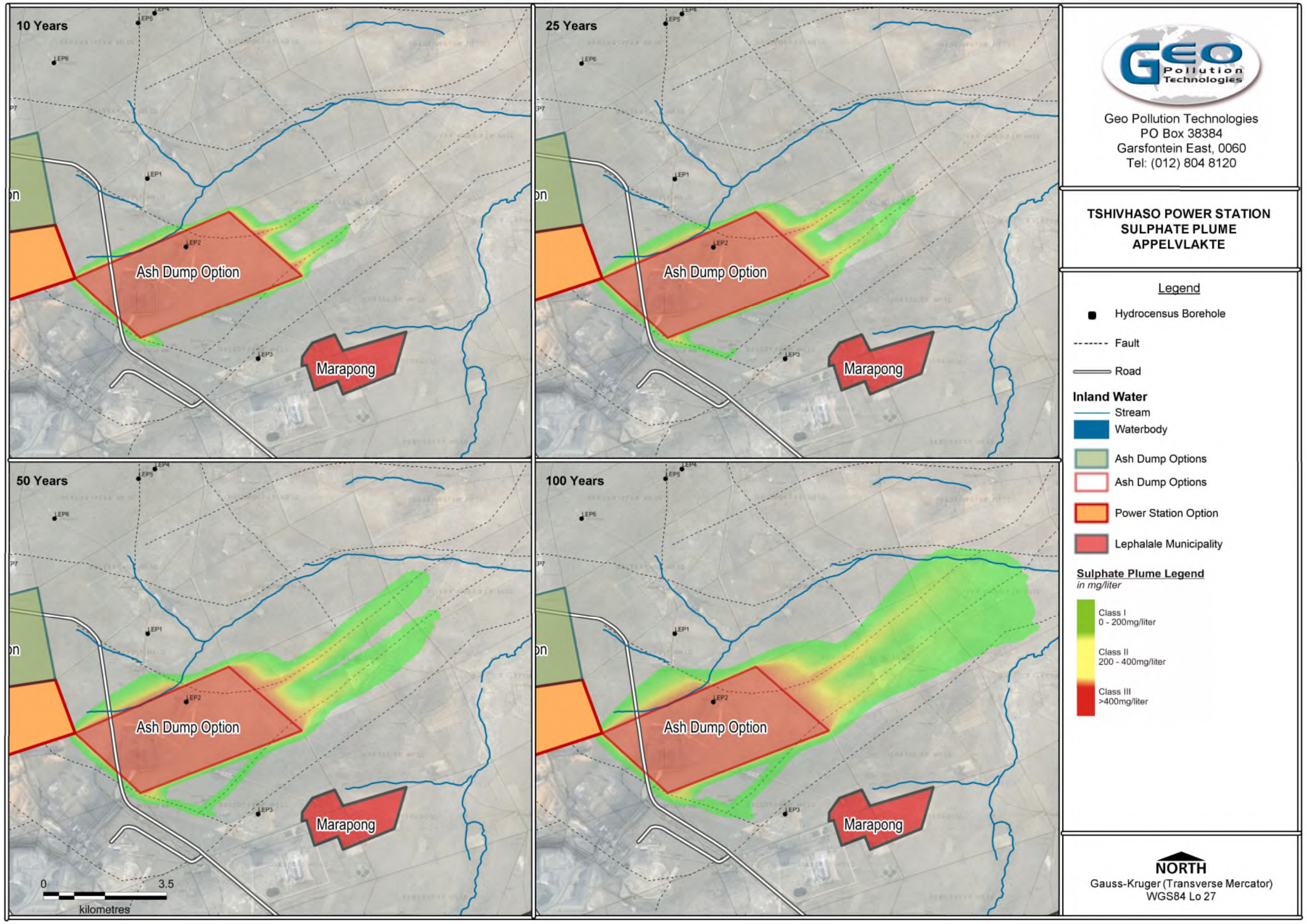


Figure 17: Predicted spread of pollution during operations (Appelvlakte)

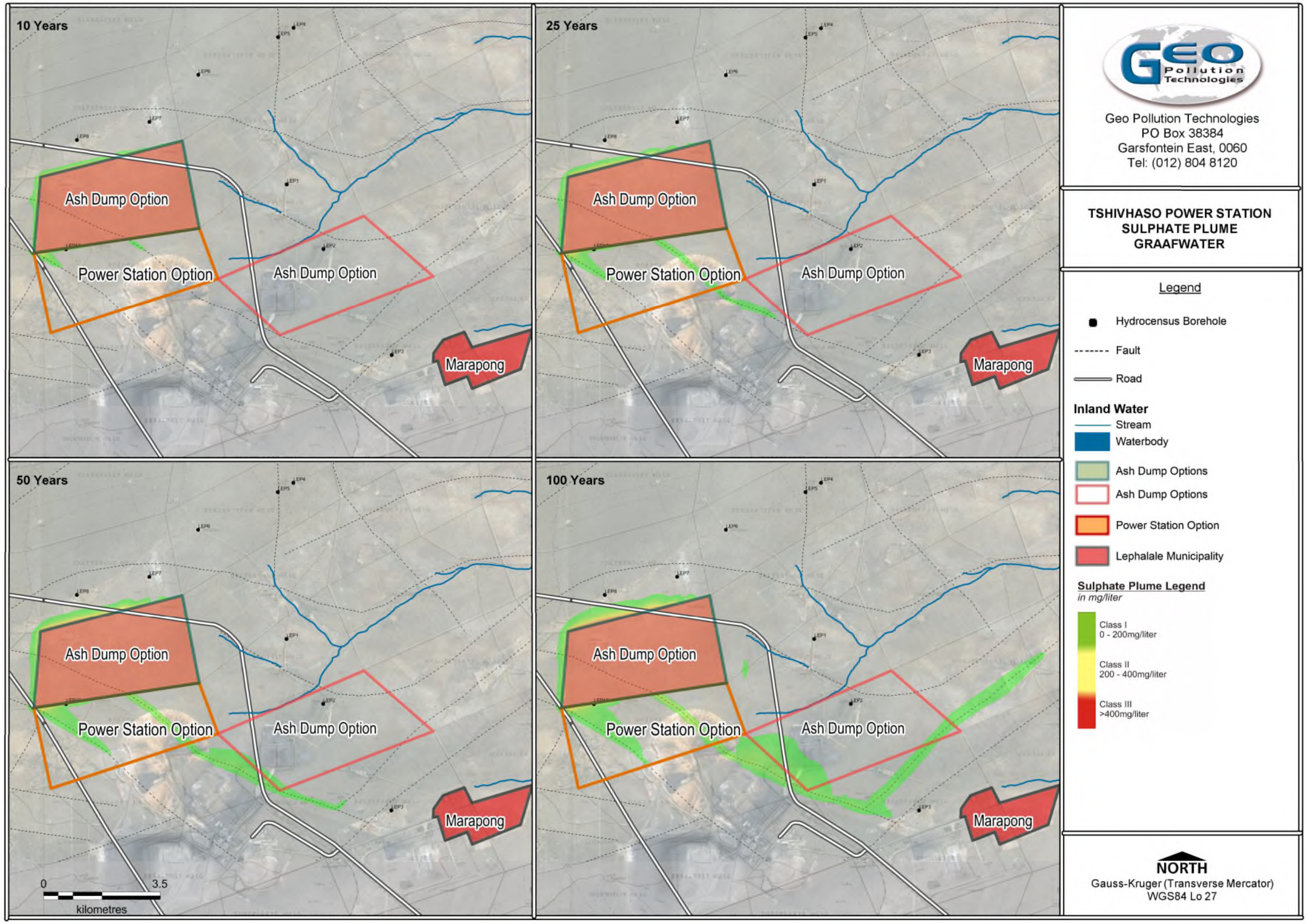


Figure 18: Predicted spread of pollution during operations (Graaffwater)

9. GROUNDWATER RISK ASSESSMENT

The groundwater risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor). The risk assessment approach is therefore aimed at describing and defining the relationship between cause and effect. In the absence of any one of the three components, it is possible to conclude that groundwater risk does not exist.

9.1 Source Term(s)

The approach to define the behaviour of the source term will always start with the definition of the key questions that need to be answered for the source term:

- Will any waste material be generated that has a potential to contaminate?
- Toxicity of the waste? The potential for different wastes to pollute water resources differs greatly, depending on the composition of the waste and its potential for degradation over time. South African legislation broadly classifies waste under two categories, namely general and hazardous waste. Between these two categories lies a continuum, with a transition from what could be described as nontoxic to toxic. When referring to a level of toxicity, then the constituent itself must be considered and also the potential user of the water, e.g. human, animal, aquatic life, or irrigation
- Quantity of waste? Toxicity and quantity of waste go hand in hand. Experience has shown that it is easier to dispose of, manage and contain small quantities of waste than large quantities. The risk for groundwater pollution is usually greater at large waste disposal facilities, where it is often impossible to prevent groundwater pollution because of the nature and scale of operations.
- Potential for leachate generation? It is theoretically possible, by using synthetic liners, to completely contain leachate from a waste site. This is, however, mostly impractical and very costly. It is also now generally accepted that all liners leak to a greater or lesser (or to some) extent. In reality, therefore, leachate that is generated in a disposal site may eventually reach the groundwater regime.

It needs to be recognised that source terms are dynamic in nature and could exhibit a variable quality over time, due to changes in hydrology and to changes in the chemistry. An impact assessment that defines the source term as a static constant feature over time is unlikely to be realistic and would be inappropriate for anything other than the most basic screening level assessment.

A definition of the identified source terms of the mine is shown in Table 16.

9.2 Pathways

With respect to potential impacts on the water resource, the groundwater pathway through which contaminants could move are the following:

- Movement through the vadose (unsaturated) zone;
- Movement through an aquifer;

Within the context of defining the pathways it is important to note that the pathways may have the following features:

- Hydraulic conduit (pathway) for the mobilization and movement of the contaminants of concern from the source term to the receptor.
- Attenuation of contaminants, release of new contaminants and alteration of the chemistry of the discharge from the source term through a variety of chemical reactions.
- Habitat for receptors.

A definition of the groundwater pathway terms of the mine is shown in …

9.3 Receptors

As the final component of the risk assessment, the receptors in the context of the water resource would be users of the water resource itself. The following receptors were found:

- Groundwater user abstracting contaminated groundwater through a borehole for domestic use, livestock watering or irrigation.
- Aquatic fauna and flora in a receiving watercourse.
- Any water user abstracting water from an impacted watercourse.

A definition of the identified receptors of the mine is shown in Table 17.

Table 16: Source Terms

Potential sources	Primary or Secondary	Area extent (m^2)	Farm Location	Waste material	Potential leachate	Available monitoring points	Groundwater vulnerability
Ash Disposal Facility	Primary	11493909	Graaffwater 456	Ash	Ca, SO4, Cl, Na, Metals	LEP12	Low
Ash Disposal Facility	Primary	11460501	Appelvlakte 448	Ash	Ca, SO4, Cl, Na, Metals	None	Low

Table 17: Pathways and Receptors

Potential sources	Farm Location	Transport mechanism	Exposure pathway	Available monitoring points	Potential receptors	Pathway complete	
						Yes/No	Current/Potential in future
Ash Disposal Facility	Graaffwater 456	Leaching and Groundwater Transport	Baseflow, Abstraction	None	LEP12	Yes	Future
Ash Disposal Facility	Appelvlakte 448	Leaching and Groundwater Transport	Baseflow, Abstraction	None	LEP2	Yes	Future

10. IMPACT ASSESSMENT AND GROUNDWATER MANAGEMENT PROGRAMME

Direct, indirect and cumulative impacts of the issues identified through the hydrogeological study are assessed in terms of the following criteria:

- The **nature**, which shall include a description of what causes the effect, what will be affected and how it will be affected.
- The **extent**, wherein it will be indicated whether the impact will be local (limited to the immediate area or site of development) or regional, and a value between 1 and 5 will be assigned as appropriate (with 1 being low and 5 being high):
- The **duration**, wherein it will be indicated whether:
    - o the lifetime of the impact will be of a very short duration (0–1 years) – assigned a score of 1;
    - o the lifetime of the impact will be of a short duration (2-5 years) - assigned a score of 2;
    - o medium-term (5–15 years) – assigned a score of 3;
    - o long term (> 15 years) - assigned a score of 4; or
    - o permanent - assigned a score of 5;
- The **consequences (magnitude)**, quantified on a scale from 0-10, where 0 is small and will have no effect on the environment, 2 is minor and will not result in an impact on processes, 4 is low and will cause a slight impact on processes, 6 is moderate and will result in processes continuing but in a modified way, 8 is high (processes are altered to the extent that they temporarily cease), and 10 is very high and results in complete destruction of patterns and permanent cessation of processes.
- The **probability** of occurrence, which shall describe the likelihood of the impact actually occurring. Probability will be estimated on a scale of 1–5, where 1 is very improbable (probably will not happen), 2 is improbable (some possibility, but low likelihood), 3 is probable (distinct possibility), 4 is highly probable (most likely) and 5 is definite (impact will occur regardless of any prevention measures).
- the **significance**, which shall be determined through a synthesis of the characteristics described above and can be assessed as low, medium or high; and
- the **status**, which will be described as either positive, negative or neutral.
- the degree to which the impact can be reversed.
- the degree to which the impact may cause irreplaceable loss of resources.
- the degree to which the impact can be mitigated.

The **significance** is calculated by combining the criteria in the following formula:

S = (E+D+M)P

S = Significance weighting

E = Extent

D = Duration

M = Magnitude

P = Probability

The **significance weightings** for each potential impact are as follows:

- < 30 points: Low (i.e. where this impact would not have a direct influence on the decision to develop in the area),
- 30-60 points: Medium (i.e. where the impact could influence the decision to develop in the area unless it is effectively mitigated),
- > 60 points: High (i.e. where the impact must have an influence on the decision process to develop in the area).

<u>Assessment of Impacts</u>

<table>
<tr><td colspan="3">Nature:

Leachate from the ash disposal facility which may potentially reach groundwater which could be detrimental to the aquifer system.</td></tr>
<tr><td></td><td>Without mitigation</td><td>With mitigation</td></tr>
<tr><td>Extent</td><td>3</td><td>2</td></tr>
<tr><td>Duration</td><td>5</td><td>3</td></tr>
<tr><td>Magnitude</td><td>6</td><td>2</td></tr>
<tr><td>Probability</td><td>4</td><td>2</td></tr>
<tr><td>Significance</td><td>56 - Medium</td><td>14 - Low</td></tr>
<tr><td>Status (positive or negative)</td><td>Negative</td><td>Negative</td></tr>
<tr><td>Reversibility</td><td>Low</td><td>Medium</td></tr>
<tr><td>Irreplaceable loss of resources?</td><td>No</td><td>No</td></tr>
<tr><td>Can impacts be mitigated?</td><td>Yes</td><td>Yes</td></tr>
<tr><td colspan="3">Mitigation:
Surface hydrology design should include surface drainage and storm water diversion drains, to meet the requirements of the Water Act. This includes the separation of unpolluted from polluted surface water and the containment of polluted water on site in impoundments. Also, where leachate is generated, it must be contained separately from water which is only slightly polluted through contact with the waste.
In the case of hazardous waste disposal sites, the design must make provision for containment of hazardous waste. This implies the complete</td></tr>
</table>

separation of the waste body and any associated leachate from the surrounding soil or rock strata, by means of a liner and a leachate collection system.

- Leachate management is necessary at hazardous waste disposal sites, where significant leachate is generated. The design includes a liner underlying the site, as well as leachate collection and treatment measures. It must make provision for the control of significant seasonal or continuous leachate generation, predicted by means of the Climatic Water Balance, or the Site Water Balance.
- Monitoring systems for surface and ground water pollution should be indicated. This will include the positions of both surface water sampling points and monitoring boreholes.
- Drains must divert or contain the peak design storm of 50 year return period for the particular catchment area. The system must effectively separate unpolluted water that has not come into contact with waste, from polluted water. The upslope cut-off drains must divert clean storm water around the site and into the natural drainage system
- "Polluted water, on the other hand, must be collected in toe drains, retained on the site and managed in accordance with the Department's directives. This may include controlled release, recycling and evaporation or treating with any leachate that has been collected."
- "It is a Minimum Requirement that there is always an acceptable physical separation between the proposed waste body and the wet season high elevation of the ground water. This applies whether cover excavations take place on site or not. The minimum permissible separation is 2m."
- Leachate collection is usually achieved using a graded underliner and drains which lead to a collection point or sump. Depending on soil quality, the underliner may be an engineered low permeability natural soil or clay liner, a geomembrane liner, or both.
- "All landfills have the potential to generate sporadic leachate. In all landfills, therefore, the base must be so sloped that any leachate formed, even sporadic leachate, is directed to a control point."
- The leachate treatment system will depend on the leachate composition and on the most appropriate method of treatment. This could be on-site chemical, physical or biological treatment, and/or off-site treatment where leachate is passed into a sewer or pipeline for treatment elsewhere.
- Clean, uncontaminated water, which has not been in contact with the waste, must be allowed to flow off the site into the natural drainage system, under controlled conditions. All drains must be maintained. This involves ensuring that they are not blocked by silt or vegetation.
- The Department requires a Water Quality Monitoring Plan as part of the permitting requirements. This involves background analyses, detection monitoring, investigative monitoring and post-closure monitoring. The Water Quality Monitoring Plan ensures that the water quality in the vicinity of a waste disposal site is regularly monitored and reported upon throughout its life, so that, where necessary, remedial action can be taken.

Residual:

A risk of leachate entering the groundwater is inherently always associated with waste disposal facilities. However, if the facility is managed correctly, this risk can be minimised to an acceptable level in which case receptors being exposed to the risk will be affected negligibly. This means that the impact upon the receptor will be minimal to none. Therefore, the residual risk, after lining of the facilities and correct routing of surface water around the facility, impacts upon receptors will be of an acceptable level.

11. WATER MANAGEMENT OPTIONS

In this section various water management options available to the proposed power station ash dump facilities during operations are discussed. The water management options are subdivided into actions that:

- Address surface- and groundwater quality issues,

Pollution prevention is the foundation of the hierarchy of decision taking used by DWS with the purpose of protecting the water resource from waste impacts. This hierarchy is based on a precautionary approach using the following order of priority for waste water:

- Pollution Prevention;
- Minimisation of Impacts though water reuse, reclamation and treatment;
- Discharge or disposal of waste water through a site specific risk based approach whereby the polluter pays.

The core of integrated water management in the first instance is to seek to optimally implement pollution prevention measures. If these measures do not address all the water management issues, then the operation should secondly develop and implement appropriate water reuse and reclamation strategies. These strategies may include a greater or lesser degree of water treatment in order to render the water suitable for reuse. If there is still a residual water management problem, then the operation could evaluate and negotiate options with DWA for the discharge of such water to the water resource. The above-mentioned fundamental principle of pollution prevention can be elaborated upon by way of defining a number of secondary principles:

- Prevention is better than cure and good planning reduces the environmental and financial liabilities.
- Sustainability is a key principle, as it would ensure a positive legacy for future generations, not a liability.
- Use and impact on as little water as is practically possible.
- The closer a pollution prevention system is to the source, the more effective it is likely to be.
- Pollution prevention is a planning and design process that is considered and applied for each life-cycle phase of the operation through to post-closure.
- Pollution prevention measures must be considered and applied throughout the entire operation process chain to waste disposal.
- Passive pollution prevention systems are preferred to active systems due to their generally more robust nature, often with a lower risk of failure.

- If measures are properly applied during the full life cycle, risks and liabilities are reduced.
- Pollution prevention is not the end point and minimisation of residual impacts through recycling, treatment and/or safe and secure disposal will most likely be required.
- Apply closure pollution prevention measures during the operational phase and monitor the performance in order to validate pollution prevention performance.
- Continuous improvement, pollution prevention systems should be monitored, assessed and improved on an ongoing basis.

Pollution source management should be based on passive management principles, i.e. the need for ongoing intervention and active management is minimal, but not zero. Examples of passive measures include storm water diversion berms and drains, lining of pollution control dams, finger drains under ash disposal facilities and toe paddocks around such facilities, etc. Passive pollution prevention measures are essentially based on good planning and design to prevent a pollution problem from arising, rather than relying on active intervention to intercept and treat contaminated water. However, situations are often encountered where active impact minimisation management measures are required to supplement the passive pollution prevention measures.

11.1 Pre-establishment of the Operation

Pollution prevention starts in the planning phase of an operation through evaluation of plans and, aimed at understanding the potential impacts of alternative working methodologies and a conscious effort to select, design and implement the alternatives that maximise the ability to prevent pollution. Pre-establishment of an operation, typical pollution prevention considerations include those shown below:

- Waste residue deposits should be located as far away from surface water bodies as possible.
- Water management facilities should be designed to intercept and contain as much contaminated runoff and/or seepage as possible. The following facilities should be lined:
    - Ash dumps
- Apply effective storm water management principles to ensure that clean runoff is maximised and diverted to the receiving water resource, while contaminated runoff is minimised and contained for reuse within the operation.
- Monitoring boreholes as discussed in the following sections will be required in strategic locations near the pollution source, to obtain information on the groundwater regime as well as for future monitoring purposes.
- Construct detailed water and salt balances that take account of climatic and operational variability, as a planning tool to ensure that all pollution control dams are adequately sized and that they are integrated into a robust water reuse and reclamation strategy to ensure that captured contaminated water is effectively reused within the operations and that system spillages to the environment are avoided.
- Proper storage, handling and monitoring of fuel and chemicals used on site to minimize the risk of spillages to the environment.
- Institute detailed monitoring systems that are capable of detecting pollution at the earliest possible stage, at all facilities where significant pollution potential exists, in order that this can lead to rapid and effective management actions to address the pollution source and minimize it to the full extent possible.

- Safety measures such as freeboard allowances etc should be included in designs of storm water control facilities to allow for sufficient storage capacity and to ensure that risks of overflows or spillages are minimized and environmental impacts are therefore avoided.
- Design, construct, maintain and operate any clean water system at the site so that it is not likely to spill into any dirty water system more than once in 50 years;
- Design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years.

11.1.1 Key considerations

There are three key considerations that prior to development:

- Pollution prevention consideration. Deterioration of water quality must be prevented wherever possible and minimised where complete prevention is not possible.
- Conservation consideration. Losses of water and consumptive use of water must be minimised.
- The plan must be sustainable over the life cycle of the operation and over different hydrological cycles.

11.2 During Operations

11.2.1 Surface Water Management

The following surface water management options are recommended during operations:

11.2.1.1 General

- Ensure that clean storm water is only contained if the volume of the runoff poses a risk, if the water cannot be discharged to watercourses by gravitation, for attenuation purposes, or when the clean area is small and located within a large dirty area. This contained clean water should then be released into natural watercourses under controlled conditions.
- Ensure the minimisation of contaminated areas, reuse of dirty water wherever possible and planning to ensure that clean areas are not lost to the catchment unnecessarily.
- Ensure that seepage losses from storage facilities (such as polluted dams) are minimised and overflows are prevented.
- Ensure that all possible sources of dirty water have been identified and that appropriate collection and containment systems have been implemented and that these do not result in further unnecessary water quality deterioration.
- Ensure that less polluted water or that moderately polluted water is not further polluted. Where possible less and more polluted water should be separated. This will assist in the reuse water strategy and improve possibilities for reuse based on different water quality requirements by different mine water uses.
- Where contaminants are transported along construction roads, emergency containment and mitigation measures must be developed to minimize impacts should accidental spillages occur along the transport routes.
- Store all potential sources of contamination in secure facilities with appropriate Storm Water management systems in place to ensure that contaminants are not released to the water resource through Storm Water runoff.

- Separate and collect all storm water that has a quality potentially poorer than the water quality specified and negotiated for the specific catchment into dirty water storage facilities for reuse within the mining operations.
- Ensure that all storm water structures that are designed to keep dirty and clean water separate can accommodate a defined precipitation event. (The magnitude of the precipitation event used in such an objective statement must, as a minimum, adhere to the relevant legal requirements.)
- Route all clean storm water directly to natural watercourses without increasing the risk of a negative impact on safety and infrastructure, e.g. loss of life or damage to property due to an increase in the peak runoff flow.
- Ensure that the maximum volume of clean water runoff is diverted directly to watercourses and the minimum amount of storm water reports to the pit floor of an open cast mine.
- Develop and implement proper environmental management and auditing systems to ensure that pollution prevention and impact minimisation plans and measures developed in the design and feasibility stages are fully implemented.
- Every effort should be made to maximise the clean area and minimise the dirty area when locating the diversion berms, channels and dams.

11.2.1.2 Ash deposits and pollution control dams

- Monitoring of water storage facilities, particularly pollution control dams, is imperative to manage the risk of spillage from the dams. Stage-storage (elevation-capacity) curves are useful tools to monitor the remaining capacity within a water storage facility.
- Prevent the erosion or leaching of materials from any ash deposit from any area and contain material or substances so eroded or leached in such area by providing suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources.
- Water quantity and quality data should be collected on a regular, ongoing basis during operations. These data will be used to recalibrate and update the water management model, to prepare monitoring and audit reports, to report to the regulatory authorities against the requirements of the IWMP and other authorisations and as feedback to stakeholders in the catchment, perhaps via the CMA.
- Water that has been in contact with ash, and must therefore be considered polluted, must be kept within the confines of the ash deposit until evaporated, treated to an acceptable quality for release, or re-used in some other way.
- A system of storm water drains must be designed and constructed to ensure that all water that falls outside the area of the ash deposit is diverted clear of the deposit. Provision must be made for the maximum precipitation to be expected over a period of 24 hours with a probability of once in one hundred years. A freeboard of at least 0.5 m must be provided throughout the system above the predicted maximum water level.
- Ensure that the water use practices on and around the ash deposit do not result in unnecessary water quality deterioration, e.g. use of the return water dam for storage of poorer quality water.
- Lining of the ash disposal facility must be considered to avoid seepage of contaminated water into the subsurface. Capturing contaminated water in the subsurface will be especially challenging due to the thick unsaturated zone underlying the proposed sites. In the event of a leakage from these facilities, a pump and treat system will most likely be required to address contamination issues.

12. MONITORING PROGRAMME

12.1 Groundwater Monitoring Network

A groundwater monitoring system has to adhere to the criteria mentioned below. As a result the system should be developed accordingly.

12.1.1 Source, plume, impact and background monitoring

A groundwater monitoring network should contain monitoring positions which can assess the groundwater status at certain areas. The boreholes can be grouped classification according to the following purposes:

- **Source monitoring:** Monitoring boreholes are placed close to or in the source of contamination to evaluate the impact thereof on the groundwater chemistry.
- **Plume monitoring:** Monitoring boreholes are placed in the primary groundwater plume's migration path to evaluate the migration rates and chemical changes along the pathway.
- **Impact monitoring:** Monitoring of possible impacts of contaminated groundwater on sensitive ecosystems or other receptors. These monitoring points are also installed as early warning systems for contamination break-through at areas of concern.
- **Background monitoring:** Background groundwater quality is essential to evaluate the impact of a specific action/pollution source on the groundwater chemistry.

12.2 System Response Monitoring Network

Groundwater levels: Static water levels are used to determine the flow direction and hydraulic gradient within an aquifer. Where possible all of the above mentioned borehole water levels need to be recorded during each monitoring event.

12.3 Monitoring Frequency

In the operational phase, quarterly monitoring of groundwater quality and groundwater levels is recommended. Quality monitoring should take place before after and during the wet season, i.e. during September and March. It is important to note that a groundwater-monitoring network should also be dynamic. This means that the network should be extended over time to accommodate the migration of potential contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources.

12.4 Monitoring Parameters

The identification of the monitoring parameters is crucial and depends on the chemistry of possible pollution sources. They comprise a set of physical and/or chemical parameters (e.g. groundwater levels and predetermined organic and inorganic chemical constituents). Once a pollution indicator has been identified it can be used as a substitute to full analysis and therefore save costs. The use of pollution indicators should be validated on a regular basis in the different sample position. The parameters should be revised after each sampling event; some metals may be added to the analyses during the operational phase, especially if the pH drops.

12.4.1 Abbreviated analysis (pollution indicators)

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
    - o pH, EC
- Laboratory analyses:
    - o Major anions and cations (Ca, Na, Cl, SO4)
    - o Other parameters (EC)

12.4.2 Full analysis

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
    - o pH, EC
- Laboratory analyses:
    - o Anions and cations (Ca, Mg, Na, K, NO3, Cl, SO4, F, Fe, Mn, Al, & Alkalinity)
    - o Other parameters (pH, EC, TDS)
    - o Petroleum hydrocarbon contaminants (where applicable, near workshops and petroleum handling facilities)
    - o Sewage related contaminants (E.Coli, faecal coliforms) in borehole in proximity to septic tanks or sewage plants.

12.4.3 Ash Disposal Facility Monitoring

DWAF (1998) states that "A monitoring hole must be such that the section of the groundwater most likely to be polluted first, is suitably penetrated to ensure the most realistic monitoring result."[12]

Currently a monitoring network does not exist for the proposed sites. The recommended boreholes are listed in Table 18 and the areas to site these monitoring boreholes are shown in Figure 19 to Figure 20. These boreholes can be utilised for water level monitoring during the operation as well as groundwater quality monitoring.

However, a monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually.

[12] Department of Water Affairs and Forestry (DWAF). (1998). Minimum Requirements for the Water Monitoring at Waste Management Facilities. CTP Book Printers. Cape Town.

Table 18: Proposed Monitoring Positions (New boreholes to be site by geophysics)

ID	Latitude (South)	Longitude (East)	Owner	Property	Borehole Depth - Paired Shallow/Deep (mbgl)	Reasoning	Frequency	Existing/New
Groundwater Monitoring Points - Appelvlakte								
MonAV9	-23.61809469	27.59766	Tshivhaso	Appelvlakte	10/50	Source monitoring	Quarterly	New
MonAV8	-23.62198704	27.60209	Tshivhaso	Appelvlakte	10/50	Source monitoring	Quarterly	New
MonAV7	-23.62573523	27.60871	Tshivhaso	Appelvlakte	10/50	Source monitoring	Quarterly	New
MonAV6	-23.62949306	27.61282	Tshivhaso	Appelvlakte	10/50	Source monitoring	Quarterly	New
MonAV5	-23.6383703	27.6031	Tshivhaso	Appelvlakte	10/50	Source monitoring	Quarterly	New
MonAV4	-23.64965678	27.57199	Tshivhaso	Appelvlakte	10/50	Source monitoring	Quarterly	New
MonAV3	-23.64014142	27.55684	Tshivhaso	Appelvlakte	10/50	Source monitoring	Quarterly	New
MonAV2	-23.62575167	27.56621	Tshivhaso	Appelvlakte	10/50	Source monitoring	Quarterly	New
MonAV1	-23.62077261	27.57958	Tshivhaso	Appelvlakte	10/50	Source monitoring	Quarterly	New
Groundwater Monitoring Points - Graaffwater								
MONGF1	-23.6125842	27.49596818	Tshivhaso	Graaffwater	10/50	Source monitoring	Quarterly	New
MONGF2	-23.6267422	27.49574709	Tshivhaso	Graaffwater	10/50	Source monitoring	Quarterly	New
MONGF3	-23.63025674	27.50344336	Tshivhaso	Graaffwater	10/50	Source monitoring	Quarterly	New
MONGF4	-23.62398882	27.52579121	Tshivhaso	Graaffwater	10/50	Source monitoring	Quarterly	New
MONGF5	-23.60076069	27.51678277	Tshivhaso	Graaffwater	10/50	Source monitoring	Quarterly	New
MONGF6	-23.60888456	27.54383795	Tshivhaso	Graaffwater	10/50	Source monitoring	Quarterly	New

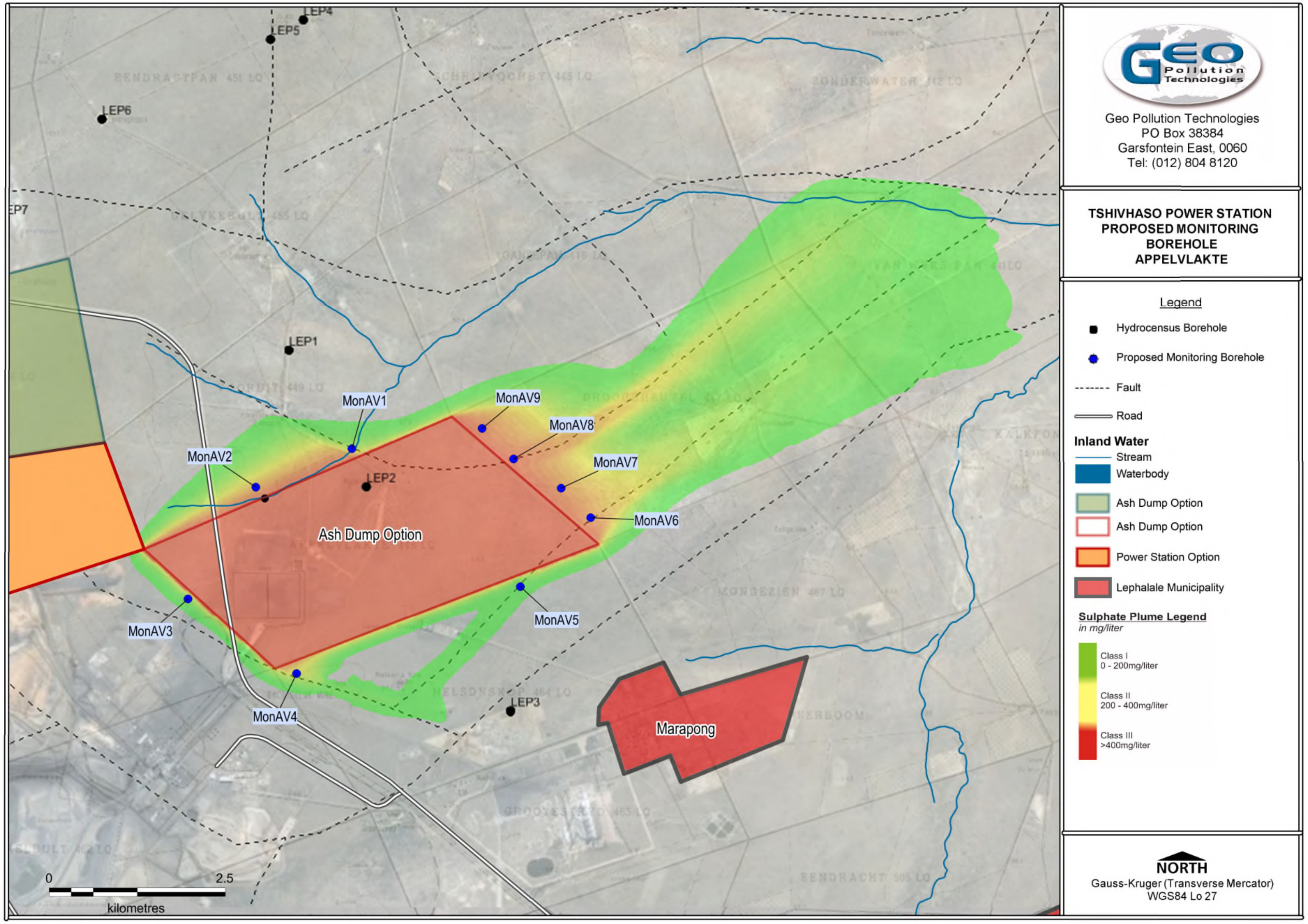


Figure 19: Proposed monitoring positions (new boreholes to be sited by geophysics)

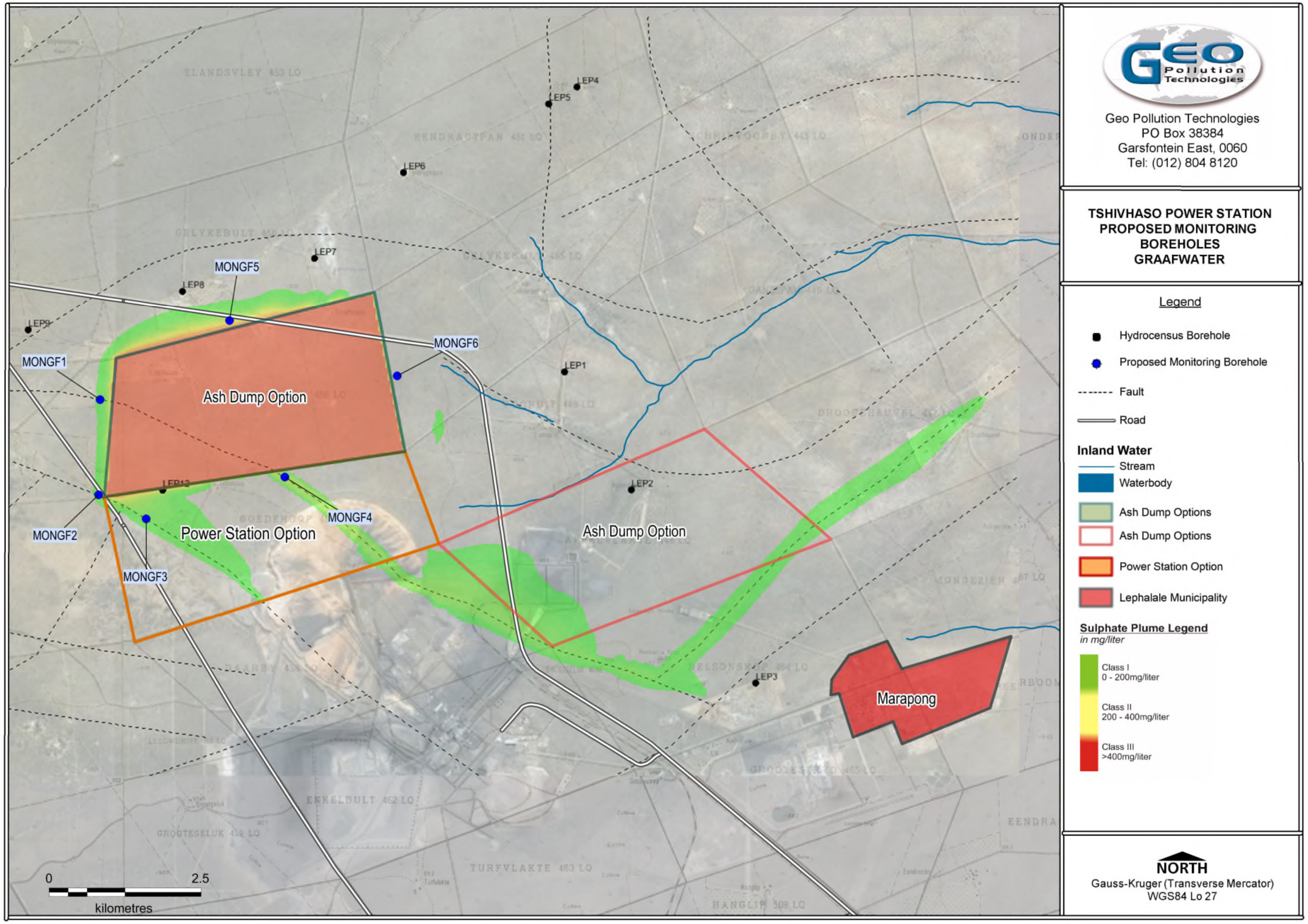


Figure 20: Proposed monitoring positions (new boreholes to be sited by geophysics)

13. CONCLUSIONS AND RECOMMENDATIONS

This section will briefly summarise the current groundwater conditions in the area of the proposed power station, the expected impacts of the proposed power station facilities on the groundwater and the recommendations to minimise the effect of this on the groundwater.

This report was not intended to be an exhaustive description of the project, but rather as a specialist interim hydrogeological study to evaluate the hydrogeological impact the proposed power station facilities might have on the receiving groundwater environment.

13.1 Project Objectives

Within the scope of work the groundwater study aims to address the following:

- Providing baseline information on the groundwater environment and the site specific sensitivities in relation to the study area.
- Identify most likely impacts of power station activities on groundwater resources.

13.2 Desk Study

A desk study was done on all available information pertaining to groundwater situation at the proposed Tshivhaso power station site. The key findings are listed below

Based on available information received the surface infrastructure of the power station will be located on one of two farms *viz*. Graaffwater 456 or Appelvlakte 448. The surface infrastructure will consist out of the following:

- Power station and Ash Storage Facilities

13.3 Regional Information

A description of the regional area information is given below:

- The sites are situated in the Limpopo Water Management Area (WMA), in quaternary catchment A41E and A42J
- The present ecological status for the A41E and A42J quaternary catchments is given as B.
- The average annual rainfall (measured over a period of 70 years) is approximately 578.00 mm, with the high rainfall months between October and March.
- The proposed power station is situated in the Ellisras basin of the Karoo Super Group, which extends from the Limpopo River in the west to Ga- Monkeki in the east covering a surface area of approximately 1200 km^2. Regionally the rocks of the Clarens Formation, Eendragtpan Formation, Lisbon Formation and the Lethaba Formation can be found.

13.4 Hydrogeological Setting

13.4.1 Topography and drainage

- The area is characterised by a gentle undulating topography and in the area of the proposed power station site the slope is more or less in the order of 1:200 (0.005).
- There are no surface water points in and around the proposed power station site. On larger scale, drainage occurs towards the generalised flow of the Sandloop which confluences with the Mokolo River approximately 24 km from the site.

13.4.2 Hydrocensus

A hydrocensus was conducted for the proposed power station site and in the surrounding area, during August 2016. The following features were found in the vicinity of the site:

- Twelve boreholes are either not in use or used for monitoring purposes.
- Four boreholes are used for livestock watering.

13.4.3 Water levels

During the hydrocensus, 16 boreholes were available for groundwater level measurement. The groundwater levels varied between a minimum of 11 m and a maximum of 59 m below ground level. The unsaturated zone in the proposed power station area is in the order of between 11 m and 59 m metres thick (based on static groundwater levels measured in the existing boreholes during the 2016 hydrocensus) and consists of overlying clayey materials and underlying in-situ weathered sands derived from the decomposing parent rock.

13.4.4 Water quality

Water samples were collected from 5 boreholes around the site during the investigation. The samples were submitted for major cation and anion analyses to determine water quality in the area. The groundwater results are compared with the recommended concentrations of the SANS 241 standard.

- The major cations in the groundwater samples are sodium, calcium and magnesium.
- The major anions in the groundwater samples are chloride, sulphate and bicarbonate.
- The groundwater quality can be described as $Ca\text{-}SO_4$ water which is due to evaporative effects and could possibly be traced to mining activity in the area. Additionally, Na and Cl constitute a large portion of the groundwater chemistry and can be attributed to evaporative effects.
- The constituents above the DWS guidelines are NO_3, NH_3, Cl, Fe and Mn

The elevation of the constituents described above can be interpreted as follows:

- Nitrogen based constituents are potentially elevated by agriculture in the area.
- Cl is elevated due to the geology of the area and evaporative effects due to limited recharge.
- Fe and Mn are elevated due to the geology of the area.

13.5 Conceptual Site model

From the results of the field investigations and laboratory analyses, a conceptual hydrogeological model was compiled for the power station. This conceptual model is a simplified representation of the conditions at and in the vicinity of the power station, and will provide the framework during the development of the risk assessment and numerical flow and transport model.

The CSM illustrates that contamination is likely to seep from the base of the ash disposal facility into the unsaturated zone. This contaminated leachate is likely to contain elevated concentrations of Ca, Na, Cl, SO4 and metals such as Cu, Hg, Pb, Mn, Fe, Al, Cr etc. Perching of the discharged leachate may take place in the regolith underlying the ash disposal facility causing lateral flow which may reach neighbouring boreholes and is likely to contaminate the soil in the area. This will also cause a mounding of groundwater in the unsaturated zone. Therefore, monitoring of this shallow, perched aquifer will be required.

Seepage from the ash disposal facility may also reach the saturated fractured aquifer over time. Although this may occur over a long period of time, due to the 40 m thick unsaturated zone, groundwater contamination and mounding of the groundwater table is a possibility. Therefore, monitoring of the deeper fractured aquifer will also be necessary as neighbouring boreholes may be affected.

Due to large scale fracturing and faulting in the area, contamination has the potential to reach the neighbouring Grootgeluk opencast coal mine via preferential pathways. Flow is known to take place at higher velocities in the fault zones of this area and contamination could therefore travel much further in these structures as opposed to the weathered matrix blocks of the underlying aquifer.

13.6 Aquifer Sensitivity

The aquifer sensitivity in terms of the boundaries of the aquifer, its vulnerability, classification and finally protection classification, as this will help to provide a framework in the groundwater management process. The following information was obtained during the investigation:

- The underlying aquifer(s) can be regarded as a Minor Aquifer System
- The aquifer vulnerability can be regarded as Medium
- The aquifer protection classification is Medium

13.6.1 Groundwater impacts during operation

During the operational phase, no groundwater abstraction is expected. Therefore, no groundwater drawdown is expected from the power station and the current status in this regard, will be maintained. However, LEP 2 is likely to be destroyed during the establishment of the ash dump, which can be considered to be an impact on groundwater quantity. This depends on the selected site for ash dump development.

Also, should the power station extract groundwater for operational processes in future, it will be important to update the groundwater model with this information as receptors in the area may be impacted by this activity.

During the operation of the power station, the main impact on groundwater is considered to be contamination from the ash dump. As sulphate is normally a significant solute in drainage from these facilities, it has been modelled as a conservative (non-reacting) indicator of pollution. A starting concentration of 2 000 mg/litre has been assumed as a worst case scenario, based on past experience.

As stated previously, the results must be viewed with caution as homogeneous aquifer matrix conditions and extended fault zones have been assumed. Furthermore, no chemical interaction of the sulphate with the minerals in the surrounding bedrock has been assumed. As there must be some interaction and retardation of the plume, this prediction will represent a worst-case scenario.

Within the limitations of the abovementioned assumptions, it can be estimated from these figures that:

Appelvlakte Ash Dump Option

No boreholes are likely to be affected by the sulphate pollution plume from the ash dump within 100 years after operations have commenced with the exception of the destruction of LEP2. It should be noted that other privately owned boreholes, downstream of the site, may be affected if pumping takes place, as this may accelerate groundwater flow in the identified faults and subsequently, contaminant transport.

Graaffwater Ash Dump Option

No boreholes are likely to be affected by the sulphate pollution plume from the ash dump within 100 years after operations have commenced with the exception of LEP12. It should be noted that other privately owned boreholes, downstream of the site, may be affected if pumping takes place, as this may accelerate groundwater flow in the identified faults and subsequently, contaminant transport.

13.7 Groundwater Risk Assessment

The groundwater risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor). The risk assessment approach is therefore aimed at describing and defining the relationship between cause and effect. In the absence of any one of the three components, it is possible to conclude that groundwater risk does not exist.

13.8 Water Management Options

In this section various water management options available to the proposed power station ash dump facilities during operations are discussed. The water management options are subdivided into actions that:

- Address surface- and groundwater quality issues,

Pollution prevention is the foundation of the hierarchy of decision taking used by DWA with the purpose of protecting the water resource from waste impacts. This hierarchy is based on a precautionary approach using the following order of priority for waste water:

- Pollution Prevention;
- Minimisation of Impacts though water reuse, reclamation and treatment;
- Discharge or disposal of waste water through a site specific risk based approach whereby the polluter pays.

The core of integrated water management in the first instance is to seek to optimally implement pollution prevention measures. If these measures do not address all the water management issues, then the operation should secondly develop and implement appropriate water reuse and reclamation strategies. These strategies may include a greater or lesser degree of water treatment in order to render the water suitable for reuse. If there is still a residual water management problem, then the operation could evaluate and negotiate options with DWA for the discharge of such water to the water resource. The above-mentioned fundamental principle of pollution prevention can be elaborated upon by way of defining a number of secondary principles:

- Prevention is better than cure and good planning reduces the environmental and financial liabilities.
- Sustainability is a key principle, as it would ensure a positive legacy for future generations, not a liability.
- Use and impact on as little water as is practically possible.
- The closer a pollution prevention system is to the source, the more effective it is likely to be.
- Pollution prevention is a planning and design process that is considered and applied for each life-cycle phase of the operation through to post-closure.
- Pollution prevention measures must be considered and applied throughout the entire operation process chain to waste disposal.
- Passive pollution prevention systems are preferred to active systems due to their generally more robust nature, often with a lower risk of failure.
- If measures are properly applied during the full life cycle, risks and liabilities are reduced.
- Pollution prevention is not the end point and minimisation of residual impacts through recycling, treatment and/or safe and secure disposal will most likely be required.
- Apply closure pollution prevention measures during the operational phase and monitor the performance in order to validate pollution prevention performance.
- Continuous improvement, pollution prevention systems should be monitored, assessed and improved on an ongoing basis.

Pollution source management should be based on passive management principles, i.e. the need for ongoing intervention and active management is minimal, but not zero. Examples of passive measures include storm water diversion berms and drains, lining of pollution control dams, finger drains under ash disposal facilities and toe paddocks around such facilities, etc. Passive pollution prevention measures are essentially based on good planning and design to prevent a pollution problem from arising, rather than relying on active intervention to intercept and treat contaminated water. However, situations are often encountered where active impact minimisation management measures are required to supplement the passive pollution prevention measures.

13.9 Pre-establishment of the Operation

Pollution prevention starts in the planning phase of an operation through evaluation of plans and, aimed at understanding the potential impacts of alternative working methodologies and a conscious effort to select, design and implement the alternatives that maximise the ability to prevent pollution. Pre-establishment of an operation, typical pollution prevention considerations include those shown below:

- Waste residue deposits should be located as far away from surface water bodies as possible.
- Water management facilities should be designed to intercept and contain as much contaminated runoff and/or seepage as possible. The following facilities should be lined:
    - Ash dumps
- Apply effective storm water management principles to ensure that clean runoff is maximised and diverted to the receiving water resource, while contaminated runoff is minimised and contained for reuse within the operation.
- Monitoring boreholes as discussed in the following sections will be required in strategic locations near the pollution source, to obtain information on the groundwater regime as well as for future monitoring purposes.
- Construct detailed water and salt balances that take account of climatic and operational variability, as a planning tool to ensure that all pollution control dams are adequately sized and that they are integrated into a robust water reuse and reclamation strategy to ensure that captured contaminated water is effectively reused within the operations and that system spillages to the environment are avoided.
- Proper storage, handling and monitoring of fuel and chemicals used on site to minimize the risk of spillages to the environment.
- Institute detailed monitoring systems that are capable of detecting pollution at the earliest possible stage, at all facilities where significant pollution potential exists, in order that this can lead to rapid and effective management actions to address the pollution source and minimize it to the full extent possible.
- Safety measures such as freeboard allowances etc should be included in designs of storm water control facilities to allow for sufficient storage capacity and to ensure that risks of overflows or spillages are minimized and environmental impacts are therefore avoided.
- Design, construct, maintain and operate any clean water system at the site so that it is not likely to spill into any dirty water system more than once in 50 years;
- Design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years.

13.9.1 Key considerations

There are three key considerations that prior to development:

- Pollution prevention consideration. Deterioration of water quality must be prevented wherever possible and minimised where complete prevention is not possible.
- Conservation consideration. Losses of water and consumptive use of water must be minimised.
- The plan must be sustainable over the life cycle of the operation and over different hydrological cycles.

13.10 During Operations

13.10.1 Surface Water Management

The following surface water management options are recommended during operations:

13.10.1.1 General

- Ensure that clean storm water is only contained if the volume of the runoff poses a risk, if the water cannot be discharged to watercourses by gravitation, for attenuation purposes, or when the clean area is small and located within a large dirty area. This contained clean water should then be released into natural watercourses under controlled conditions.
- Ensure the minimisation of contaminated areas, reuse of dirty water wherever possible and planning to ensure that clean areas are not lost to the catchment unnecessarily.
- Ensure that seepage losses from storage facilities (such as polluted dams) are minimised and overflows are prevented.
- Ensure that all possible sources of dirty water have been identified and that appropriate collection and containment systems have been implemented and that these do not result in further unnecessary water quality deterioration.
- Ensure that less polluted water or that moderately polluted water is not further polluted. Where possible less and more polluted water should be separated. This will assist in the reuse water strategy and improve possibilities for reuse based on different water quality requirements by different mine water uses.
- Where contaminants are transported along construction roads, emergency containment and mitigation measures must be developed to minimize impacts should accidental spillages occur along the transport routes.
- Store all potential sources of contamination in secure facilities with appropriate Storm Water management systems in place to ensure that contaminants are not released to the water resource through Storm Water runoff.
- Separate and collect all storm water that has a quality potentially poorer than the water quality specified and negotiated for the specific catchment into dirty water storage facilities for reuse within the mining operations.
- Ensure that all storm water structures that are designed to keep dirty and clean water separate can accommodate a defined precipitation event. (The magnitude of the precipitation event used in such an objective statement must, as a minimum, adhere to the relevant legal requirements.)
- Route all clean storm water directly to natural watercourses without increasing the risk of a negative impact on safety and infrastructure, e.g. loss of life or damage to property due to an increase in the peak runoff flow.
- Ensure that the maximum volume of clean water runoff is diverted directly to watercourses and the minimum amount of storm water reports to the pit floor of an open cast mine.

- Develop and implement proper environmental management and auditing systems to ensure that pollution prevention and impact minimisation plans and measures developed in the design and feasibility stages are fully implemented.
- Every effort should be made to maximise the clean area and minimise the dirty area when locating the diversion berms, channels and dams.

13.10.1.2 Ash deposits and pollution control dams

- Monitoring of water storage facilities, particularly pollution control dams, is imperative to manage the risk of spillage from the dams. Stage-storage (elevation-capacity) curves are useful tools to monitor the remaining capacity within a water storage facility.
- Prevent the erosion or leaching of materials from any ash deposit from any area and contain material or substances so eroded or leached in such area by providing suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources.
- Water quantity and quality data should be collected on a regular, ongoing basis during operations. These data will be used to recalibrate and update the water management model, to prepare monitoring and audit reports, to report to the regulatory authorities against the requirements of the IWMP and other authorisations and as feedback to stakeholders in the catchment, perhaps via the CMA.
- Water that has been in contact with ash, and must therefore be considered polluted, must be kept within the confines of the ash deposit until evaporated, treated to an acceptable quality for release, or re-used in some other way.
- A system of storm water drains must be designed and constructed to ensure that all water that falls outside the area of the ash deposit is diverted clear of the deposit. Provision must be made for the maximum precipitation to be expected over a period of 24 hours with a probability of once in one hundred years. A freeboard of at least 0.5 m must be provided throughout the system above the predicted maximum water level.
- Ensure that the water use practices on and around the ash deposit do not result in unnecessary water quality deterioration, e.g. use of the return water dam for storage of poorer quality water.
- Lining of the ash disposal facility must be considered to avoid seepage of contaminated water into the subsurface. Capturing contaminated water in the subsurface will be especially challenging due to the thick unsaturated zone underlying the proposed sites. In the event of a leakage from these facilities, a pump and treat system will most likely be required to address contamination issues.

13.11 Recommendations

The following recommendations are put forward:

- Update the numerical model against monitored data during operations.
- Water quantity and quality data should be collected on a regular, ongoing basis during operations. These data will be used to recalibrate and update the water management model, to prepare monitoring and audit reports, to report to the regulatory authorities against the requirements of the IWMP and other authorisations and as feedback to stakeholders in the catchment, perhaps via the CMA.
- The monitoring as recommended in the report should be established prior to operation. Borehole construction details are provided in Appendix IV.

- Geochemical analyses and modelling must be conducted on the material during operations to update the transport model and refine geochemical predictions.

APPENDIX I: HYDROCENSUS INFORMATION

APPENDIX II: LABORATORY CERTIFICATE OF ANALYSIS

APPENDIX III: NUMERICAL MODEL METHODOLOGY AND SETUP

In this paragraph the setup of the flow model will be discussed in terms of the conceptual model as envisaged for the numerical model, elevation data used, boundaries of the numerical model and assumed initial conditions.

SOFTWARE USED

Numerical groundwater modelling is considered to be the most reliable method of anticipating and quantifying the likely impacts on the groundwater regime. The model construction will be described in detail in the following paragraphs, followed by predicted impacts in terms of groundwater quality and quantity for all the relevant phases.

The finite difference numerical model was created using Aquaveo's Groundwater Modelling System (GMS10) as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes.

MODFLOW is a 3D, cell-centred, finite difference, saturated flow model developed by the United States Geological Survey. MODFLOW can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options. It was developed by McDonald and Harbaugh of the US Geological Survey in 1984 and underwent eight overall updates since. The latest update (Modflow-NWT) incorporates several improvements extending its capabilities considerably, the most important being the introduction of the Newton formulation of Modflow. This dramatically improved the handling of dry cells that has been a problematic issue in Modflow in the past.

MT3DMS is a 3-D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure similar to the structure utilized by MODFLOW, and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation.

ELEVATION DATA

Elevation data is crucial for developing a credible numerical model, as the groundwater table in its natural state tends to follow topography.

The best currently available elevation data is derived from the STRM (Shuttle Radar Tomography Mission) DEM (Digital Elevation Model) data. The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000, during which elevation data was obtained on a near-global scale to generate the most complete high-resolution digital topographic database of Earth[13]. Data is available on a grid of 30 metres in the USA and 90 metres in all other areas.

Several studies have been conducted to establish the accuracy of the data, and found that the data is accurate within an absolute error of less than five metres and the random error between 2 and 4 metres for Southern Africa[14]. Over a small area as in this study, the relative error compared to neighbouring point is expected to be less than one metre. This is very good for the purpose of a numerical groundwater model, especially if compared to other uncertainties; and with the wealth of data this results in a much improved model.

[13] http://www2.jpl.nasa.gov/srtm/

[14] Rodriguez, E., et al, 2005. An assessment of the SRTM topographic products. Technical Report JPL D-31639, Jet Propulsion Laboratory, Pasadena, California.

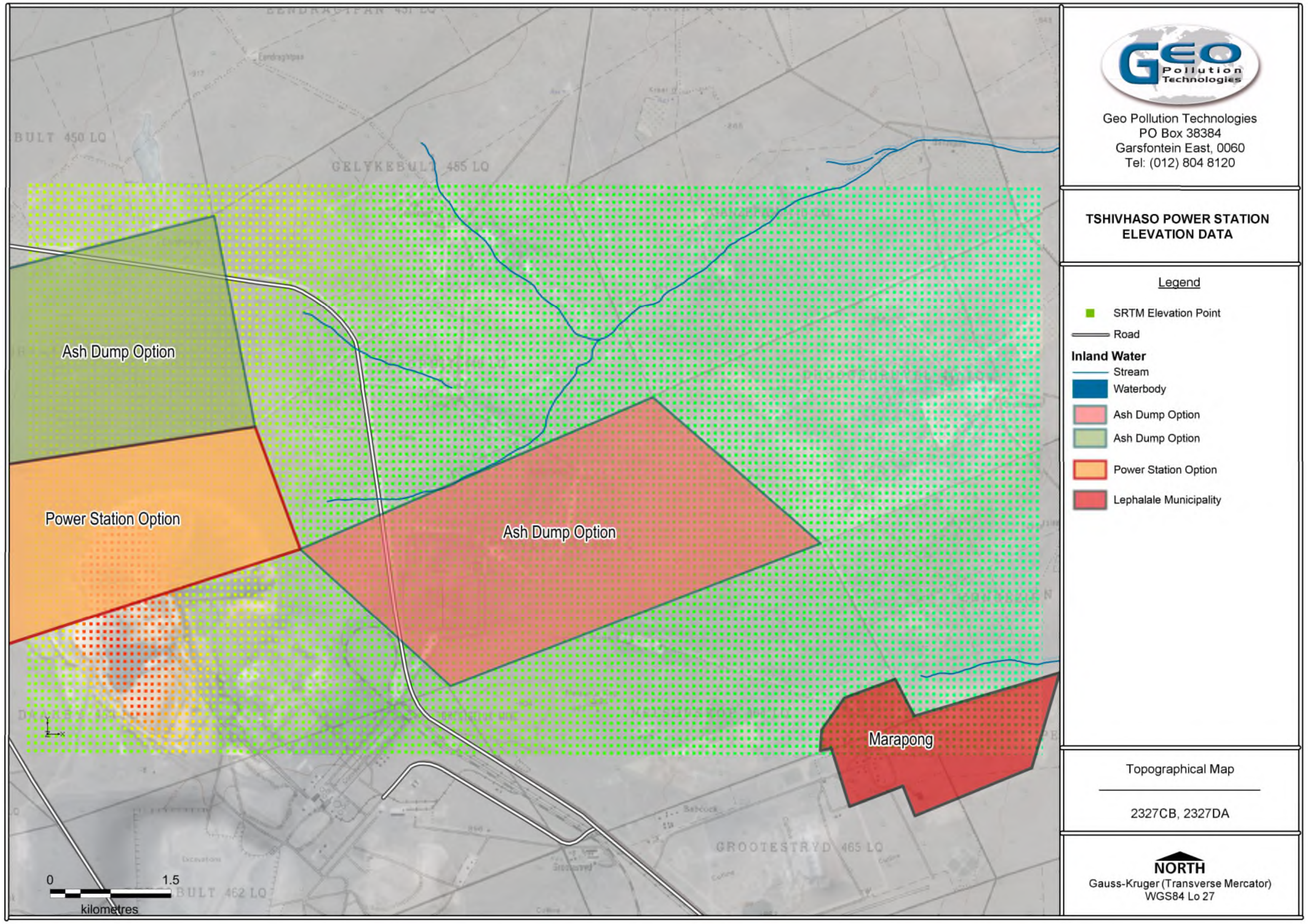


Figure 21: Elevation Data Power station to be established on Farm Graaffwater. Revise accordingly

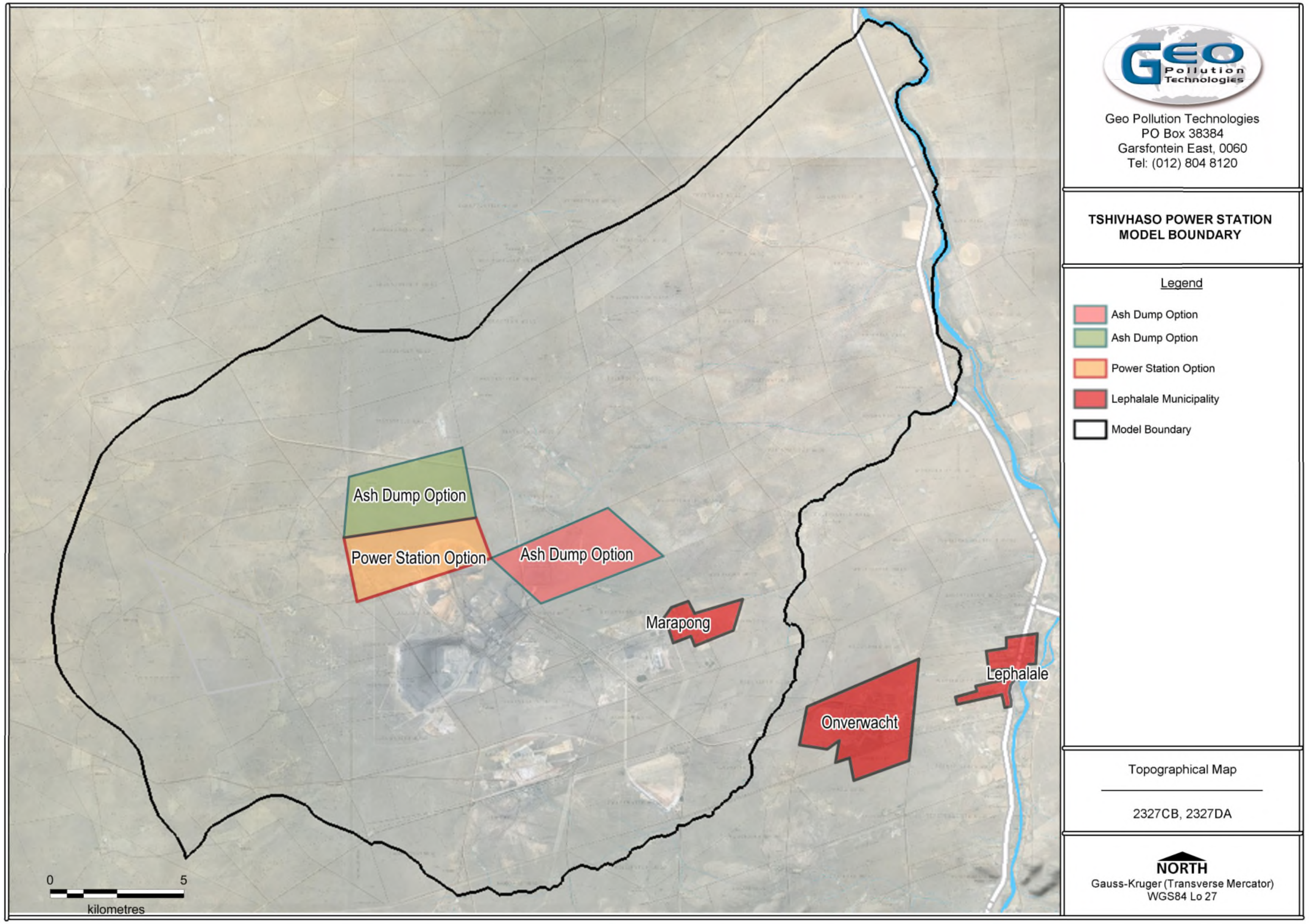


Figure 22: Model Boundaries- Power to be established on Farm Graaffwater. Revise accordingly

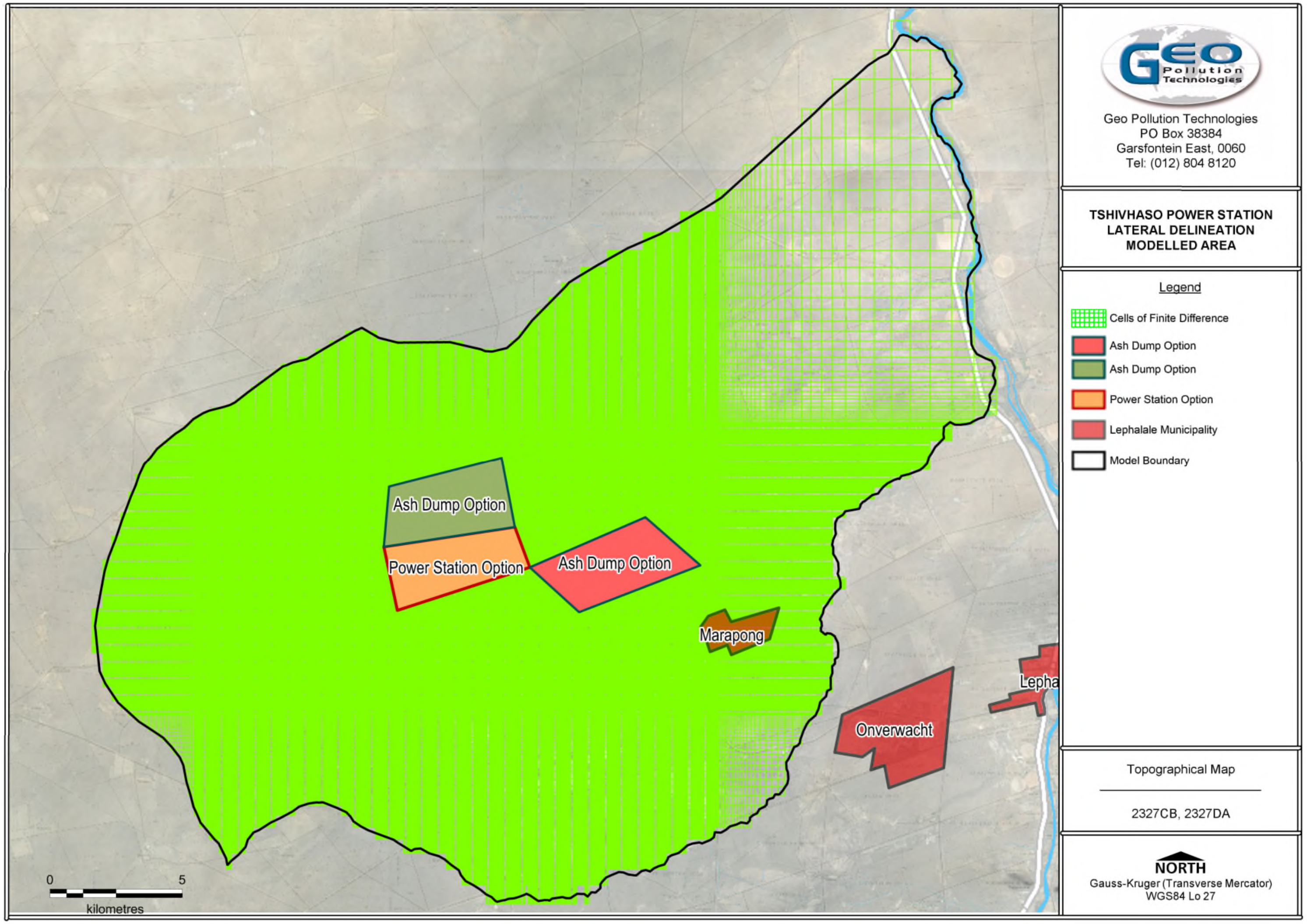


Figure 23: Lateral Delineation Of The Regional Model

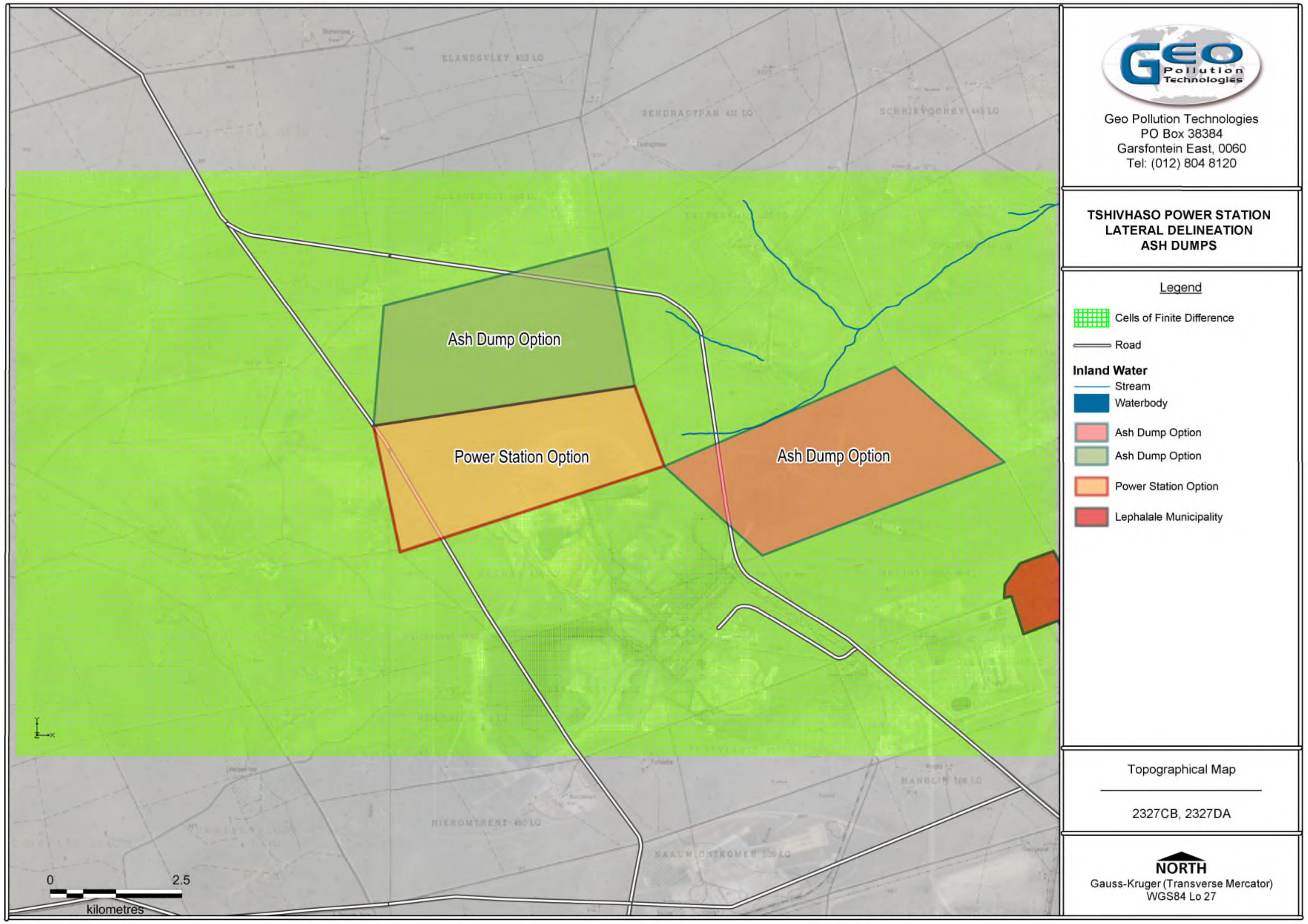


Figure 24: Lateral Delineation In The Power Station Area

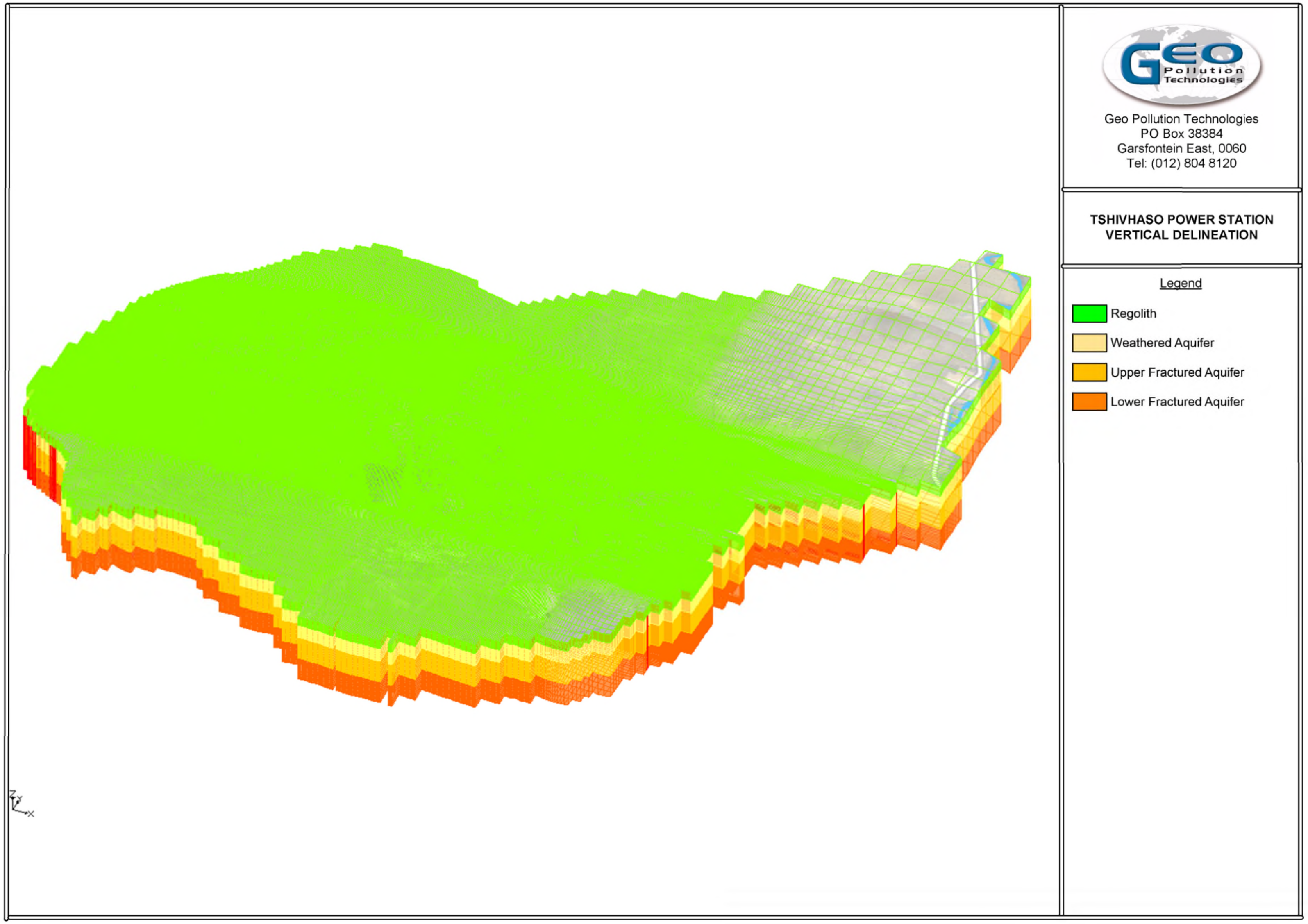
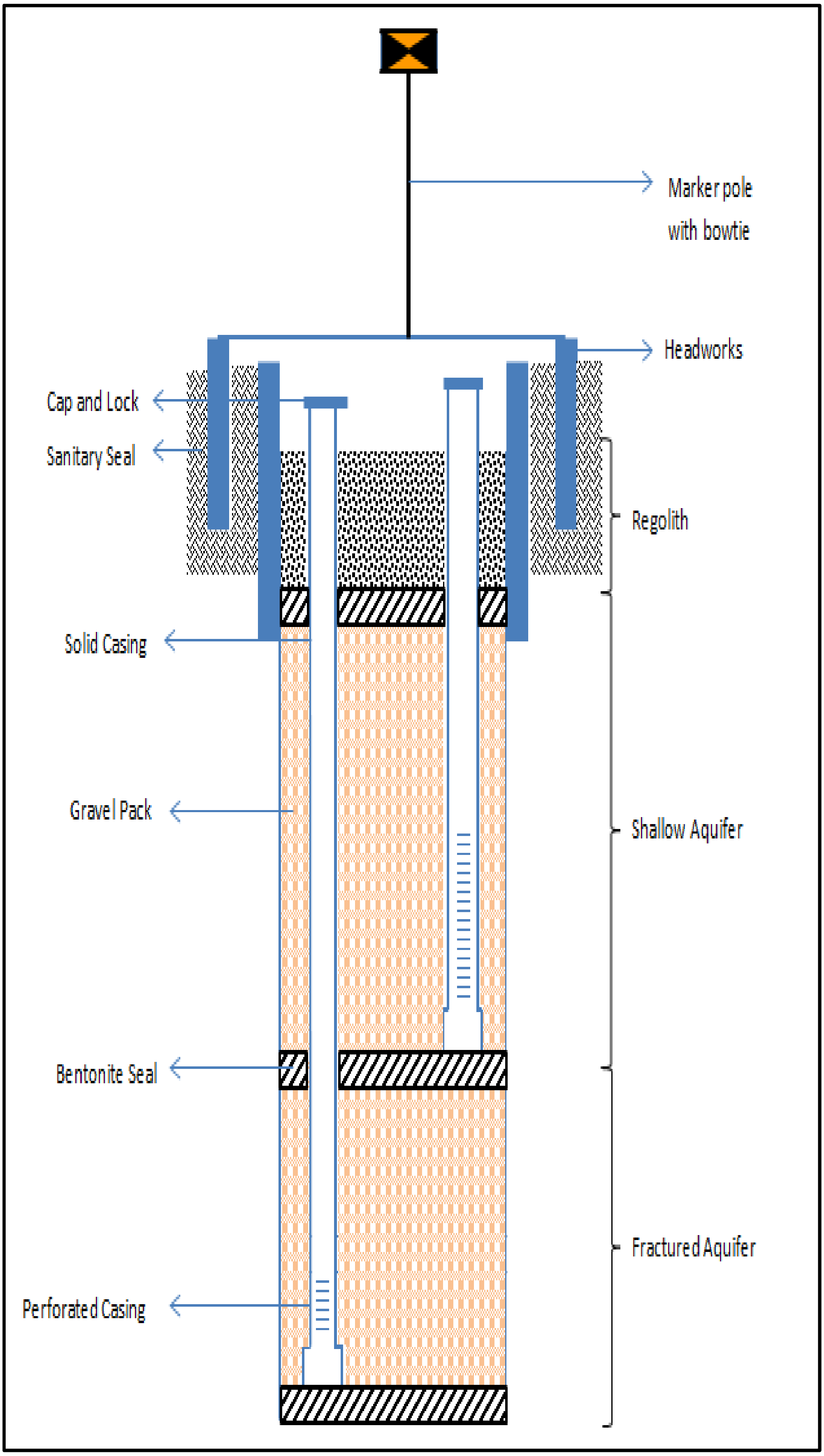


Figure 25: Vertical Delineation Of The Modelled Area

APPENDIX IV: PROPOSED BOREHOLE CONSTRUCTION


Marker pole
with bowtie
Headworks
Cap and Lock
Sanitary Seal
Regolith
Solid Casing
Gravel Pack
Shallow Aquifer
Bentonite Seal
Fractured Aquifer
Perforated Casing