Traverse 1b

This traverse extends northwest-southeast along a planned opencast area. A possible structure may be present around 50 to 200m, which is indicated by a divergence of the HD and VD readings. However, no changes in magnetic readings were observed around this area, possibly ruling out the possibility of a dyke structure.

Traverse 2

This Traverse is in a northeast-southwest trending direction, adjacent to a planned opencast area. The data of the HD and VD show a sharp dip at approximately 300m with the magnetic data showing elevated readings in this area. This may be indicative of a possible structure such as a dyke in this area. The remaining data show periodic spikes but not enough to conclusively indicate any significant structures. No other significant structures were therefore encountered in this traverse.

Traverse 3a

This traverse trends from the southwest to the northeast. According to the EM data, a possible structure may exist at approximately 200m where the HD and VD sharply rise and dip respectively. Another structure is possibly indicated by the EM data at approximately 580m where the HD and VD are once again widely separated. The magnetic data, however, do not indicate this, possibly ruling out the presence of a dyke structure.

Traverse 3b

This traverse trends towards the east-northeast direction parallel to the river. According to the EM data, a possible structure is indicated at 60m where the HD and VD sharply rise and dip respectively. This is also indicated at 150m where another possible structure might be located. However, these structures are not indicated by magnetic data which may possibly rule out the presence of a dyke structure.

Traverse 4

This traverse trends in the southeast-northwest direction. Two possible structures exist at approximately 50 and 250m as indicated by the EM data, which shows a distinct parting of the HD and VD in these areas. The magnetic profile indicates a sharp spike and dip in the data at approximately 600m which may indicate a possible dyke structure in this area.

Traverse 5

This traverse trends in a northeast-southwest direction. A possible structure may exist at approximately 230m as indicated by a sharp dip of the VD and a parting from the HD data. This may possibly be supported by a sharp spike in the magnetic data. However, the magnetic data do not show any significant structures conclusively.

Traverse 6

This traverse trends in a southwest-northeast direction. The EM data and magnetic data both show relatively straight trends and no significant structures could be identified in the data. However, a slight possibility of a potential structure may exist at approximately 260m.

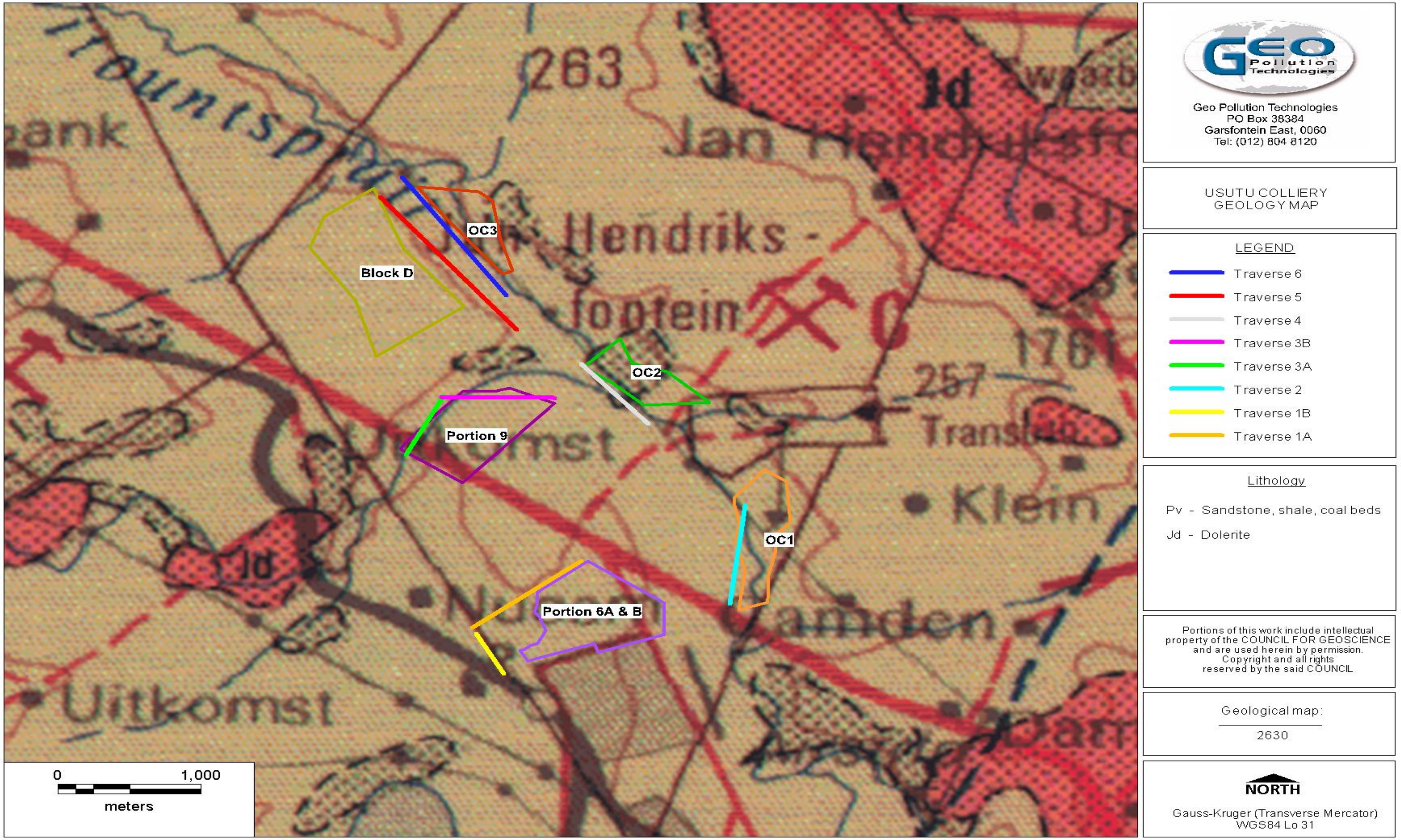

Figure 13: Geophysical Traverses

6 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.

6.1 GROUNDWATER VULNERABILITY

According to Lynch et al. aquifer vulnerability is defined as the intrinsic characteristics that determine the aquifer's sensitivity to the adverse effects resulting from the imposed pollutant[7]. 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 contaminants7.

The Groundwater Decision Tool (GDT) was used to quantify the vulnerability of the aquifer underlying the site. The depth to groundwater below the site was estimated from water levels measured during the hydrocensus inferred to be ~3 mbgl. A groundwater recharge of ~22 mm/a, a sandy clay-loam soil and a gradient of 1% were assumed and used in the estimation. The GDT calculated a vulnerability value of 56%, which is moderate or medium. This implies that the aquifer is reasonably sensitive to contamination and care should be taken with any activities that could generate pollutants.

6.2 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[8]. 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

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

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

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 dependent on groundwater. Furthermore the area is characterised a number of surface water features which can be used if necessary. The aquifer is also important for supplying base flow to the rivers and streams.

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 8 and Table 9 was used.

Table 8: 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 9: 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 10.

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** (See section 6.1).

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 10: 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	

6.3 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 fractured aquifer. Reasonable and sound groundwater protection measures are recommended to ensure that no cumulative pollution affects the aquifer, even in the long term.

DWA's water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that if any potential risk exists, measures must be taken to limit the risk to the environment, which in this case is:

- The protection of the underlying aquifer.
- The Witpuntspruit which flows in a south-easterly direction in between the opencast mining areas.
- The wetland area between Portion 6A, 6B and Portion 9.

7 MODELLING

It is the aim of this chapter to assess the likely hydrogeological impact that the proposed mining of the Usutu Colliery opencast areas might have on the receiving environment through numerical modelling. The typical mining stages that will be considered in this section are:

- **Pre-Mining Phase:** Mining activities have been observed in the immediate vicinity of proposed Usutu opencast, groundwater condition in the area is probably not pristine. The pre-mining conditions of the opencast are thus described.

- **Operational Phase:** This phase will be the groundwater conditions expected during the mining of the proposed Usutu opencasts mining.

- **Decommissioning Phase:** This is the closing of mining operations, site cleanup and rehabilitation of the opencast mining areas.

- **Post-mining Phase:** This phase relates to the steady-state conditions following closure of the opencasts areas. It is assumed for the purpose of this study that the opencasts will be will be backfilled, rehabilitated and allowed to flood.

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 mining phases.

The finite difference numerical model was created using the US Department of Defence Groundwater Modelling System (GMS8.1) 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 2000) incorporates several improvements extending its capabilities considerably, the most important being the introduction of the new package called the Layer-Property Flow Package.

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.

7.1 FLOW MODEL SET-UP

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.

7.1.1 Elevation Data

Elevation data is crucial for developing a credible numerical model, as the groundwater table in its natural state tend 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[9]. Data is available on a grid of 30 metres in the USA and 90 metres in all other areas. The data points in the study area are shown in Figure 14 below.

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[10]. 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 result in a much improved model.

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

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

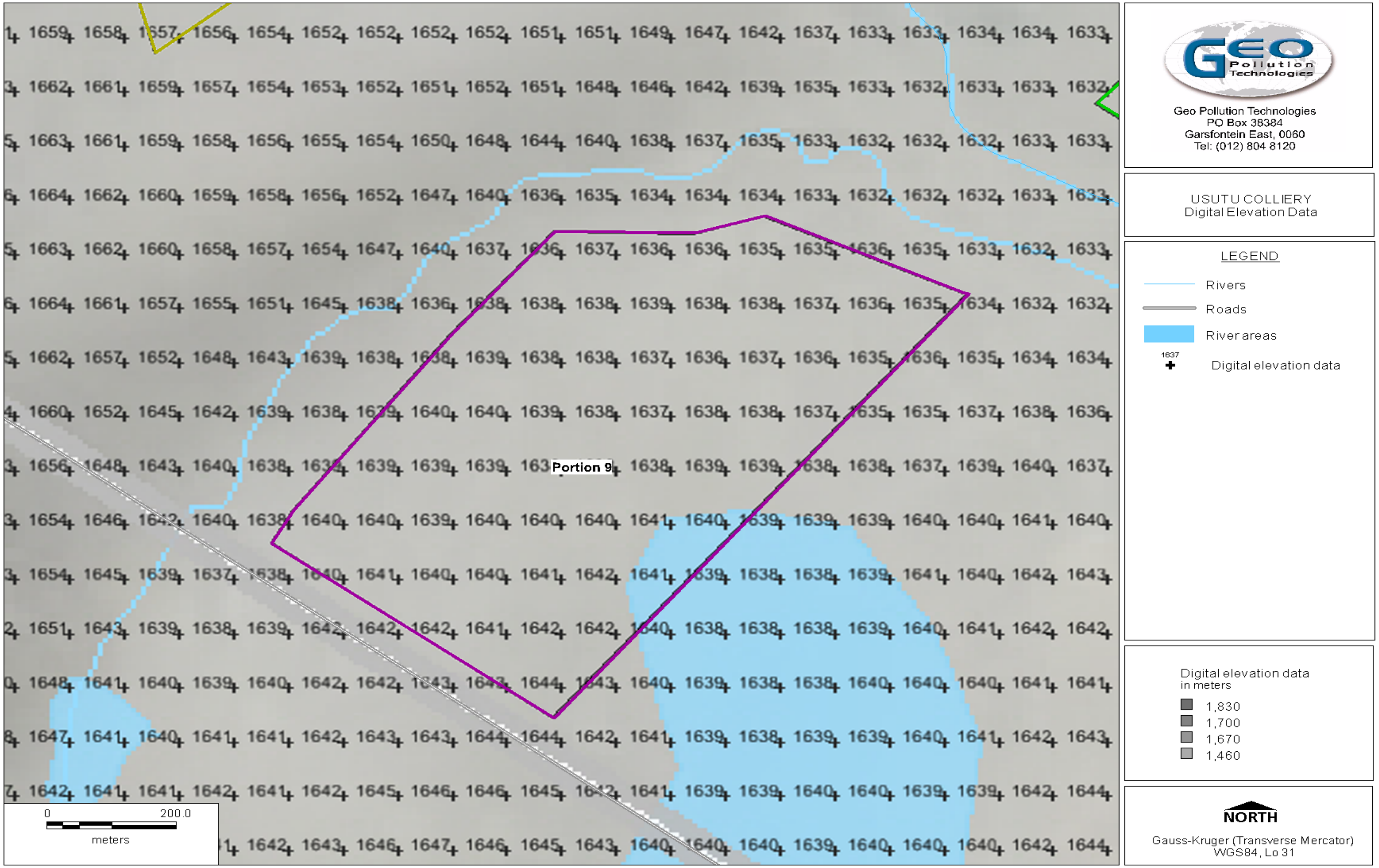

Figure 14: STRM Elevation Points and Data

7.1.2 Conceptual Model

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 reasonable high hydraulic conductivity, but in general unsaturated. However, a seasonal aquifer perched on the bedrock probably does form in this layer, especially after high rainfall events. Flow in this perched aquifer is expected to follow the surface contours closely and emerge as fountains or seepage at lower elevations.

- The next few tens of meters are slightly weathered, highly fractured shale/sandstone bedrock with a low hydraulic conductivity. The permanent groundwater level resides in this unit and is about 1 to 10 meters below ground level. The groundwater flow direction in this unit is influenced by regional topography and for the site flow would be in general from high lying areas to the Witpuntspruit.

- Below a few tens of meters the fracturing of the aquifer is less frequent and fractures less significant due to increased pressure. This results in an aquifer of lower hydraulic conductivity and very slow groundwater flow velocities. The flow direction is expected to be mostly northerly. This trend was confirmed by modelling.

Fracturing of the bedrock could consist of both mayor fault structures and/or minor pressure-relieve joints. On a large enough scale (bigger than the Representative Elemental Volume) the effect of these structures become less important and has been considered as a homogeneous aquifer in this study.

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 perched in the bedrock is mostly unsaturated. It is thus not an important part of the hydrogeological system in this area, and it has thus not been modelled as a separate component. It is very thin in comparison to the fractured bedrock aquifer and of little consequence at the depth of mining. It has thus been grouped into the upper layer of the 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].

- It is generally known and confirmed by the mining experience that only the upper 30 - 50 meters of the Ecca contains significant groundwater. Thus, an upper model layer of up until the B coal seam has been modelled as a separate layer, 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 Pretoria Group 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

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

thus reasonably be assumed that the hydraulic properties are reasonable similar to that of the fractured Ecca rock.

- The local effect of discontinuities, such as faults, fractures and intrusions, has been disregarded. The exact location and characteristics of these structures are unknown and will be difficult and expensive to determine, if at all possible. Besides, on a large enough scale the effect of these structures become less important and can be considered as part of the homogeneous aquifer, as described in paragraph 7.5.

- The coal seam could have a somewhat higher hydraulic conductivity than the surrounding bedrock and therefore has been modelled as separate layer. It would require extensive pump testing to determine the hydraulic properties; and its effect on groundwater flow is expected to relatively unimportant as it has been (or will be) extensively mined, it has not been included in this study.

7.1.3 Fixed Aquifer Parameters

Although the most relevant aquifer parameters are optimised by the calibration of the model (paragraph 7.2), 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 = 35 mm/a ≈ 0.0001 m/d. This value was calculated using the RECHARGE program[12] (Table 11 below). This value relates to a recharge percentage of 5%, the general accepted value of for the Karoo sediments[13]. 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 = 1332 mm/a ≈ 0.004 m/d. This value is based on the E-pan evaporation data for this area[14] as shown in Table 1: Climatic Data for the Ermelo Area. 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.

- Horizontal Hydraulic Permeability of the bedrock = 0.01 m/d as an initial value, declining with depth by an order of magnitude at the third layer due to decreasing weathering of the bedrock and increased pressure that tend to close fractures, as described in paragraph 7.1.2 (Conceptual Model).

- Hydraulic Permeability of the flooded underground mined areas = 10 m/d, with a vertical hydraulic anisotropy (K_H/K_V) = 1000 to ensure that vertical hydraulic conductivity between layers does not exceed 0.01 m/d.

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

[13] Vermeulen P D, Usher B H: An investigation into recharge in South African underground collieries. The Journal of the Southern African Institute of Mining and Metallurgy, Vol. 106 Nov 2006.

14 http://www.dwaf.gov.za/hydrology

- Hydraulic Permeability of the mined out and rehabilitated opencast areas = 10 m/d. This is two orders of magnitude larger than the pre-mining conditions, and typical that of a sandy gravel.

- Vertical Hydraulic Anisotropy (K_H/K_V) of the bedrock = 10. By nature of the pronounced horizontal layering, this value is commonly used in the Karoo sedimentary layers.

- Vertical Hydraulic Anisotropy (K_H/K_V) of the backfilled opencast = 1000, to ensure that vertical hydraulic conductivity between layers does not exceed 0.01 m/d.

- The effective porosity value 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 were 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.

- Underground mining areas were modelled as drains. A value of 1.0e-6 $m^2/day/m^2$ was used for the drain conductance. This value was calculated from measured inflow into underground mines in the Mpumalanga coal mining areas.

- Similarly, opencasts were simulated as drains, with a conductance of 0.1 $m^2/day/m^2$. This value was found to be just enough to lower the groundwater level to the coal floor during mining.

Table 11: Recharge calculation

Recharge Estimation			
Method	**mm/a**	**% of rainfall**	**Certainty (Very High=5 ; Low=1)**
Chloride	35	5	4
Qualified guesses			
Soil	19.8	3.0	3
Geology	28.4	4.3	3
Vegter	20.0	3.0	3
Acru	15	2.3	3
Harvest Potential	25	3.8	3
Expert's guesses			3
Annual Rainfall= approx 632 mm per annum/ Annual Evaporation= approx1332 mm per annum			

7.2 CONSTRUCTION OF THE MODEL

Construction of the numerical model consists of selecting natural boundaries for the model, discretisation of this area in finite elements, and calibration against measured groundwater levels and/or flow.

7.2.1 Model Boundaries and Discretisation

Boundaries for the numerical model have to be chosen where the groundwater level and/or 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 mining 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 mining boundaries not to be affected by groundwater abstraction in the mine.

Wherever practical, natural topographical water divides has been used as a 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 west and south whereas the Holbankspruit served as a boundary to the north and to the east the Vaal River.

These boundaries resulted in an area of about 5 to 13 km around the proposed mining area, which is considered far enough for the expected groundwater effects not to be influenced by boundaries.

The modelling area was discretizised by a 193 by 168 grid, refined at the mining areas as depicted in Figure 16 below, resulting in finite difference elements of about 20 by 20 meters at the mining areas and up to 200 meters at the edges of the model. All modelled features, like mining areas etc., 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 110 000 cells, resulting in a relative large model.

7.2.2 Calibration of the Model

As the depths to nine boreholes were measured during a complete hydrocensus of the area in October 2011, the numerical model could be calibrated using this data. In addition to this data, water levels from the NGDB were also used in the calibration. Most hydrocensus data is concentrated around the area of the proposed mining area. Some of the boreholes such as BH9 were affected by groundwater extraction and were ignored for calibration. The hydraulic conductivity was estimated by manual adjustment.

A good fit was obtained for the measured groundwater levels, as can be visualised through the vertical bars in Figure 19(calibration interval = 10 metres, that is about 2% of altitude differences over the modelled area). The final optimised parameters were:

- Horizontal hydraulic conductivity Layer1= 0.01
- Horizontal hydraulic conductivity Layer2= 0.001
- Horizontal hydraulic conductivity Layer3= 0.0001

All other parameters were unchanged, with values as listed in the paragraph 8.5 above. The calibration error statistics and graph can be seen in and Figure 20 respectively. The head error was below 4, which can be regarded as acceptable.

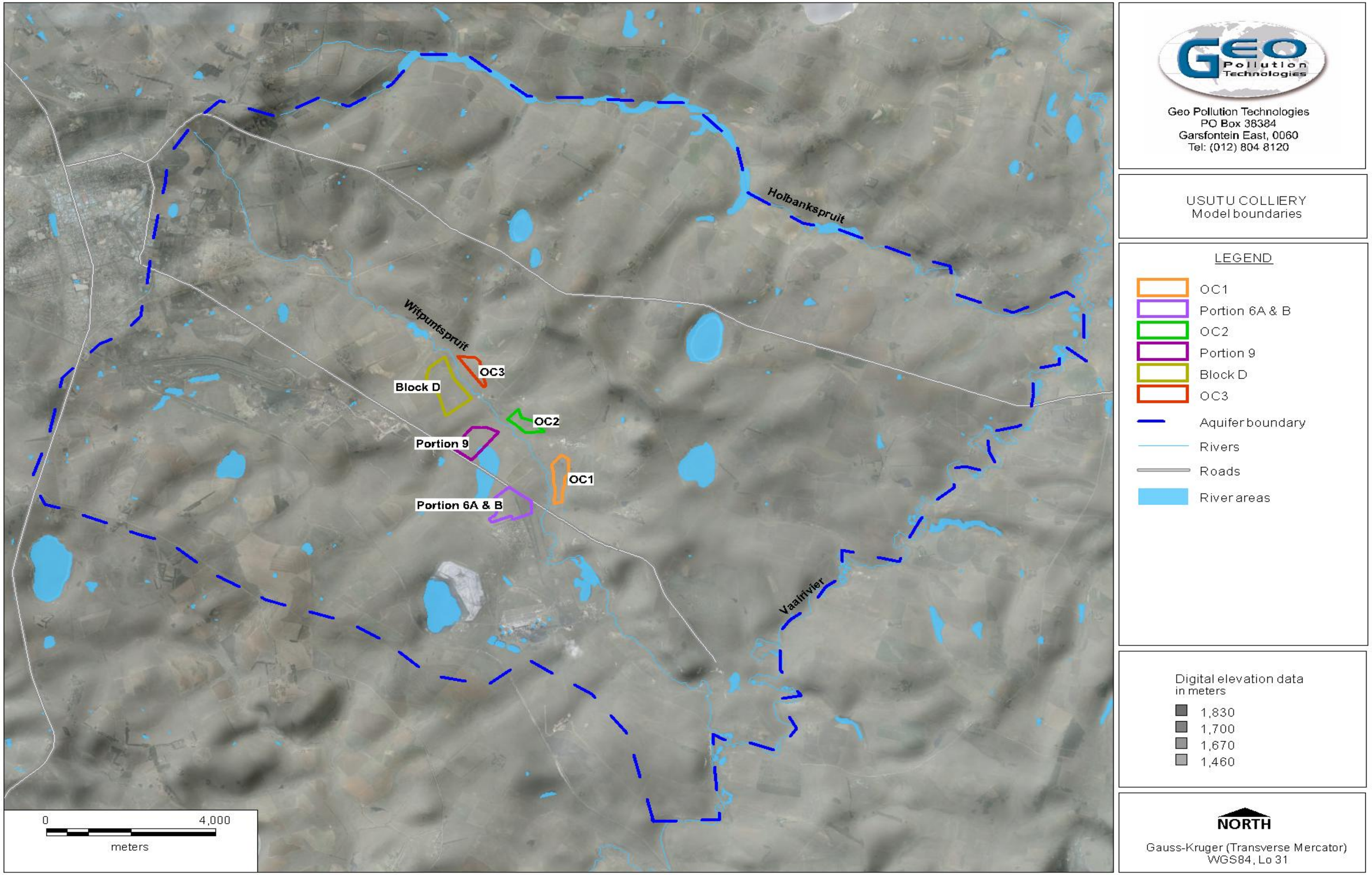

Figure 15: Model Boundaries

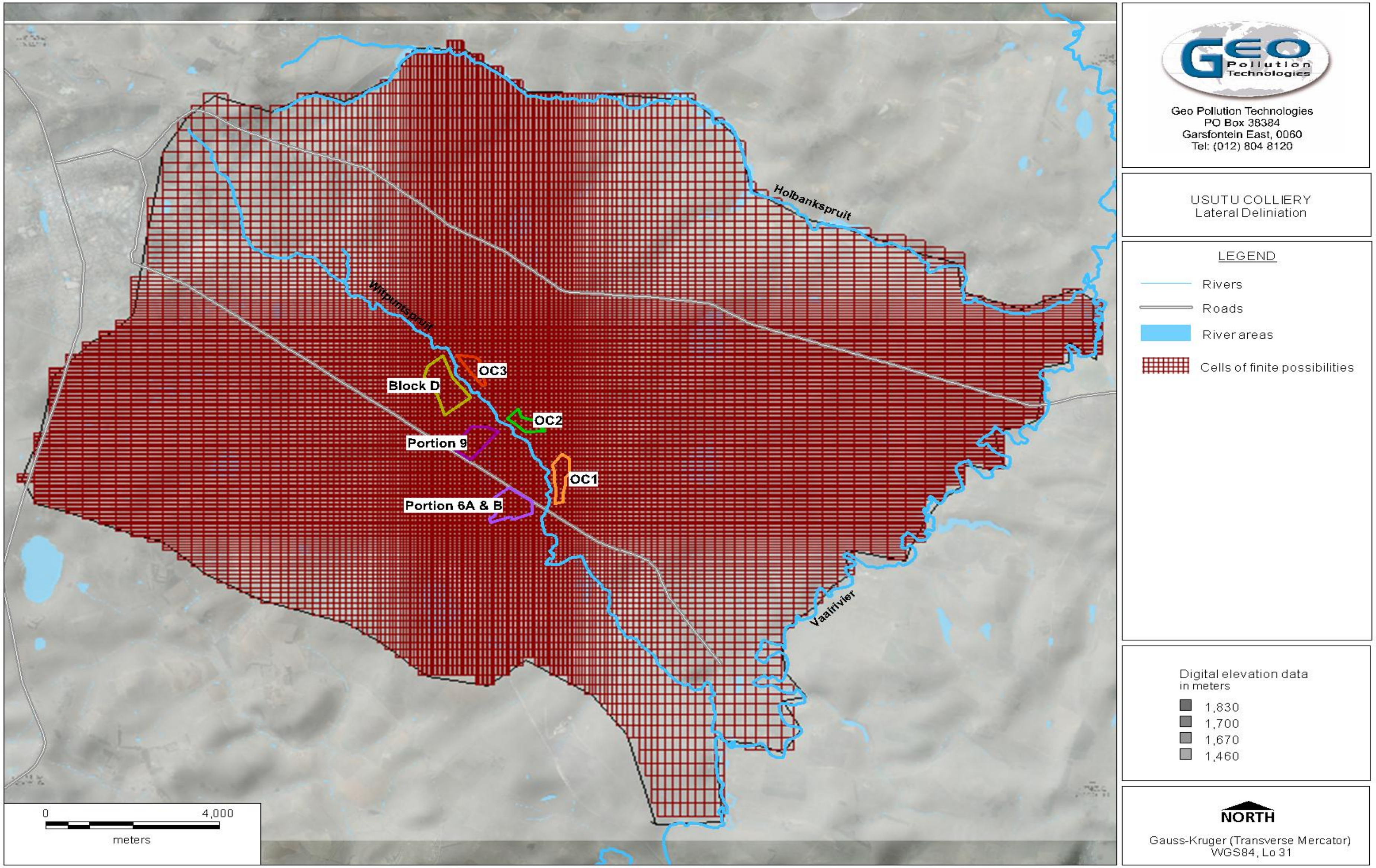

Figure 16: Lateral Delineation of the Regional Model

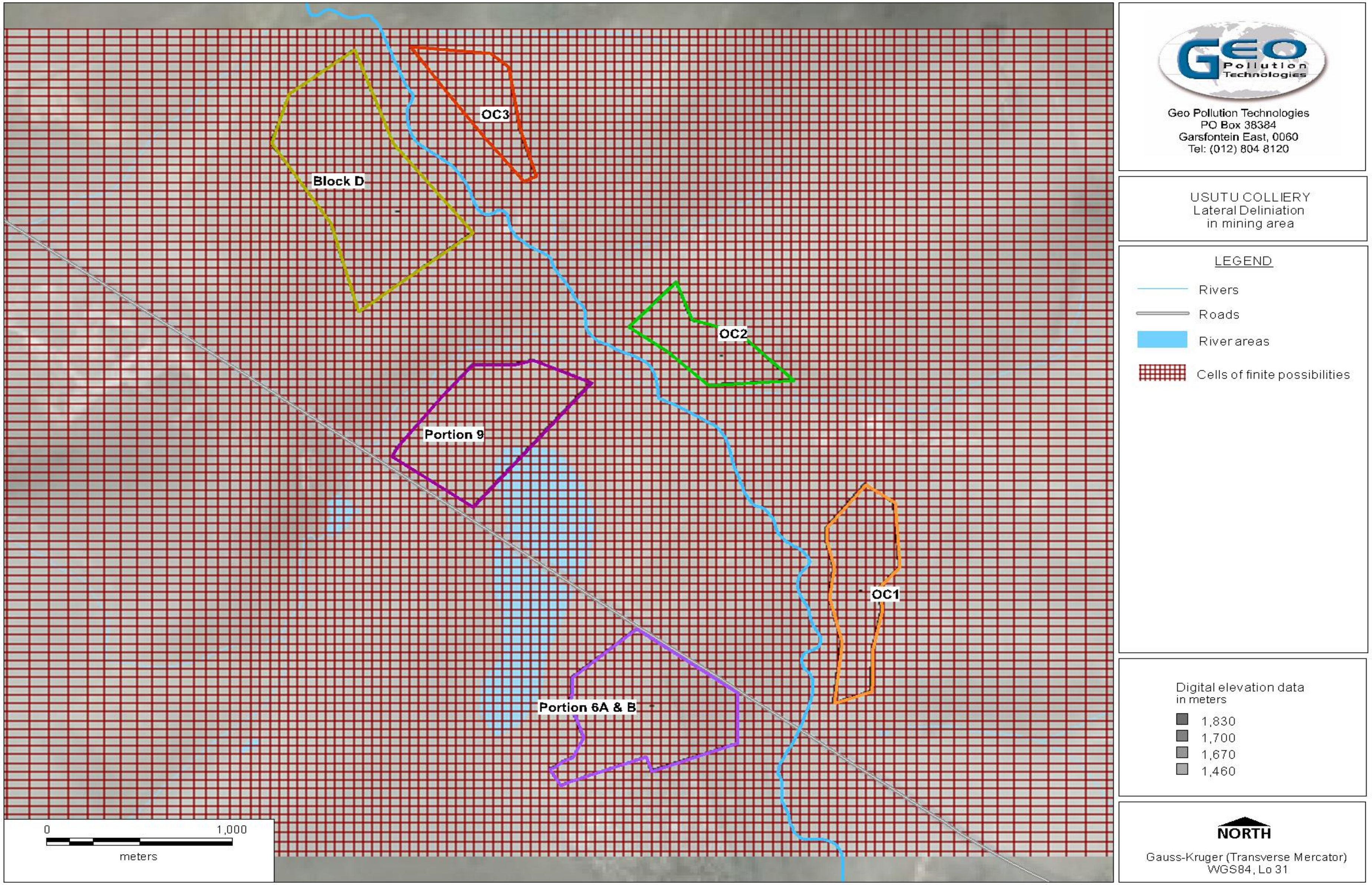

Figure 17: Lateral Delineation in the Mining Area

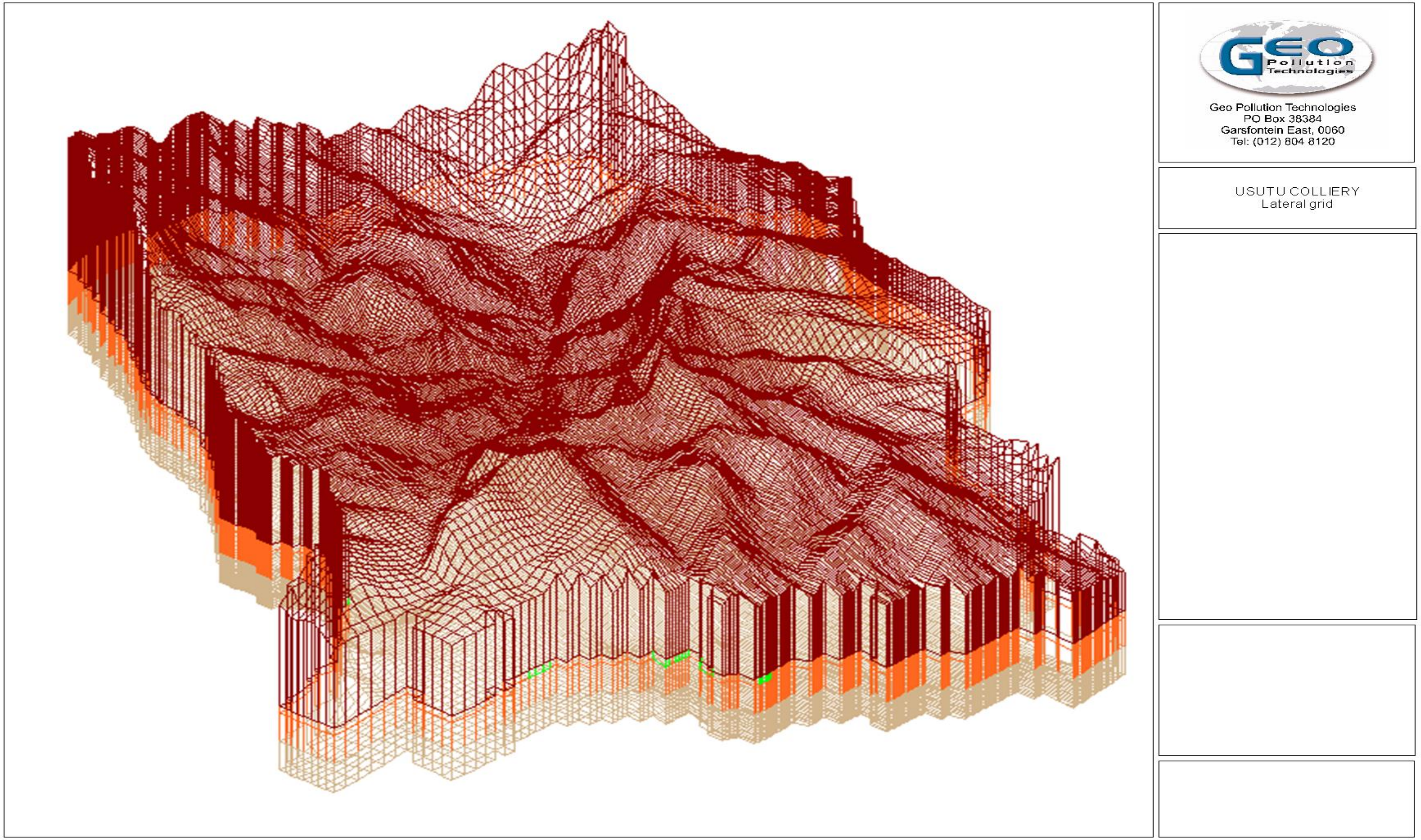

Figure 18: Vertical Delineation of the Modelled Area

[Vertical Exaggeration = 20]

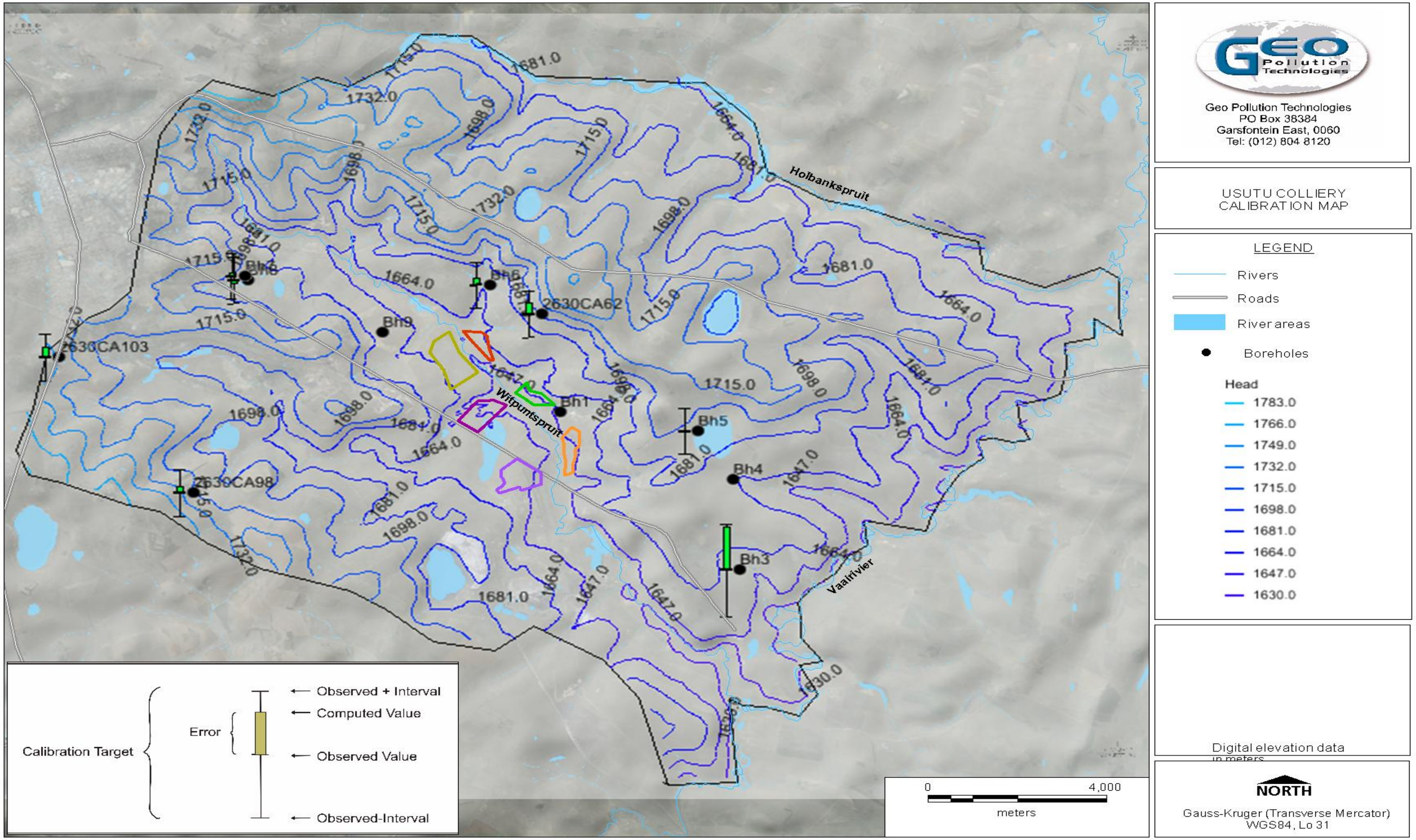

Figure 19: Calibration of the Numerical Model

Table 12: Calibration Statistics

Description	Value
Mean Residual (Head)	-4.390326056
Mean Absolute Residual (Head)	7.6999235
Root Mean Squared Residual (Head)	12.84202783
Mean Weighted Residual (Head+Flow)	-14.48487303
Mean Absolute Weighted Residual (Head+Flow)	15.09167697
Root Mean Squared Weighted Residual (Head+Flow)	25.17008672
Sum of Squared Weighted Residual (Head+Flow)	5701.799392

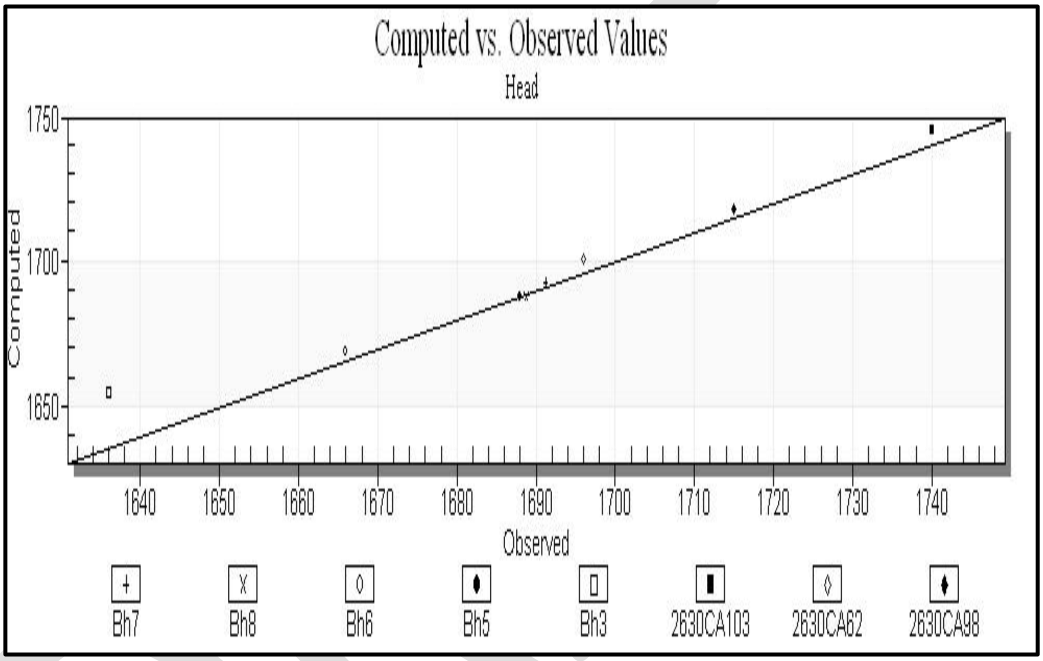

Figure 20: Calibration Graph for the Numerical Model

7.3 SOLUTE TRANSPORT MODEL

The migration rate of a pollution plume was estimated by means of the numerical mass transport model MT3DMS as described in the introduction to this section. Advection and hydrodynamic dispersion are the two main processes that control contaminant transport through a porous medium. Advection is the flow component, while hydrodynamic dispersion refers to mechanical dispersion and molecular diffusion.

The same input parameters as previously stated for the flow modelling were chosen for the numerical model. In addition, the following assumptions were made for the transport modelling:

- The *total and effective porosity* values of the aquifer was taken as 0.05 (5%), decreasing to 0.0 (1%) at depths of more than 100m. These are estimated reasonable values for the fractured bedrock, decreasing by the square root of the hydraulic conductivity[15].

[15] Institute for Groundwater Studies, University of the Free State. Class notes

- Only *sulphate* was considered for solute transport calculations as it is the main chemical of concern in coal mining.

- An *initial concentration* of 2000 mg/litre was assumed for the sulphate levels in the flooded mines. This is probably an overestimation, and should present a worst case scenario.

- It was assumed that the sulphate will behave as a conservative tracer, that is no decay and no retardation of contaminates occur while the plume is migrating.

- Only advection and hydrodynamic dispersion was therefore modelled, assuming:

  - Longitudinal dispersion of 50m.

  - Ratio of transverse to dispersion = 0.1.

  - Ratio of vertical to longitudinal dispersion = 0.001.

- It was furthermore assumed that no pollution could migrate to the surrounding aquifer before the post-mining water level has not recovered, as negative water level gradients will prohibit any movement of groundwater from the mining void.

- The calculated water levels as simulated for the post-mining scenario were used as hydraulic heads in the mass transport model.

This methodology was selected to provide worst-case scenario results within the limitations of homogeneous assumptions, which is consistent with the approach followed with the remainder of the report.

7.4 MODEL RUNS

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

7.4.1 Pre-Mining

This scenario represents the current situation. This scenario, and the assumptions made for modelling purposes, was described in detail in the previous two paragraphs, and the reader is referred to these sections for detail.

7.4.2 During Mining

This model represents the groundwater situation during mining of the proposed opencast. For the purposes of this model a worst-case scenario was assumed, namely that the whole mine will be dewatered during the mining period. A drain was thus imposed under the mining area at the coal floor elevation of 1632 mamsl.

7.4.3 Post Mining

This models the post-mining scenario, assuming that the most likely recharge over the rehabilitated opencast will be 0.0004 m/d. This amounts to a recharge of about 20% of rainfall, which is probably a realistic, if not worst case scenario[16].

[16] Grobbelaar, R et al: Long-Term Impact of Intermine Flow from Collieries in the Mpumalanga

7.5 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 can lead to error. However, on a large enough scale (bigger than the REF, Representative Elemental Volume) this assumption should hold reasonable well.

Coalfields, Sept 2004. Institute for Groundwater Studies, University of the Free State, Bloemfontein RSA.

8 GEOHYDROLOGICAL IMPACTS

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

- Construction Phase: Start-up of mining operations at the specific site before actual mining operations commences.
- Operational Phase: The conditions expected to prevail during the mining of the new opencast.
- Decommissioning Phase: The closing of mining operations, site cleanup and rehabilitation of the mining area.
- Post-mining Phase: This relates to the steady-state conditions following closure of the opencast and underground mines. A period will be considered after which it is assumed that impacts will steadily decrease and start returning to normal.

8.1 CONSTRUCTION PHASE

8.1.1 Impacts on Groundwater

It is accepted for the purposes of this document that the construction phase will consist of preparations for the opencast, which is assumed to consist mainly of establishment of infrastructure on site, the mobilisation of earth moving equipment and the opening of the boxcut.

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.

8.1.2 Groundwater Management

As only diesel and oil spills have been identified as potential groundwater pollutants during this phase, measures to prevent and contain such spills should be introduced. The following is suggested:

- It must be ensured that a credible company removes used oil after vehicle servicing.
- A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills.
- Used absorbent fibre must be land-farmed, using approved methodologies.

8.2 OPERATIONAL PHASE

The operational phase is interpreted as the active mining of the proposed Usutu opencast Portions 6A, 6B, Portion9, Block D, opencasts OC1, OC2, and OC3. It is inevitable that these effects will impact on the groundwater regime. The potential impacts that will be considered are the groundwater quantity and quality.

Mining plans were made available at the time of this study, and conservative assumptions were thus made regarding mining planning. The mining depth was taken as the floor coal seam to be mined, supplied by the mine.

It is recognised that the mining layout might be simplistic, and is essential that this model is updated once final information is available.

8.2.1 Impacts on Groundwater Quantity

During the operational phase, it is expected that the main impact on the groundwater environment will be de-watering of the surrounding aquifer. Water entering the mining areas will have to be pumped out to enable mining activities. This will cause a lowering in the groundwater table, in and adjacent to the mine.

The dewatering of the aquifer has been calculated for the opencast using the calibrated numerical model as described above. The mining sequence was also taken in consideration when calculating the drawdown. A worst-case scenario has been modelled, assuming that all opencasts would be dewatered. This will obviously not be the case, and the actual drawdown could thus be less. However, as the recovery of groundwater is expected to be very slow, it could well be that the first boxcut in the opencast is still in an early stage of recovery. Thus, the worst case scenario could also be close to the actual scenario.

- Based on the mining schedule the following sequence of dewatering (starting with Portions 6A and B and ending OC2) has been modelled as seen in the figures below. The calculated drawdown of the worst case scenario is depicted in Figure 21 below, as contours of drawdown for the opencasts. It follows from this figure that:It is evident that a large portion of the wetland situated between Portions 6A and B and Portion 9, could be affected. If the wetland does not have a clayey bottom and a reasonable inflow of groundwater, it will most likely be largely dewatered.

- Base flow of the Witpuntspruit could also be affected due to the cumulative effect of drawdown resulting from the dewatering of the opencasts.

- There are no privately owned boreholes in the potential affected area that might experience a decline in water levels of approximately 5 metres or more. The small settlement of Camden directly to the south of the proposed opencast could be affected by the drawdown if there are any unknown boreholes. The impact will however be minimal.

- A summary of each individual opencasts modelling result can be seen in Table 13.

Despite the modelled predictions, it must again be stressed that structures of preferred groundwater flow have not been modelled. It is known by experience that dolerite will most likely transgress the area, but details are limited and not adequate to model this structure(s). If such a structure is dewatered through mining, any boreholes drilled into the structure might be seriously affected. These effects cannot be predicted with the current knowledge, and can only be established through continuous groundwater level monitoring.

It is also possible to calculate the inflow into the opencasts for each mining cut from the numerical model. However, detailed mining plans and schedules have not been finalised at the time of this report, and no detailed inflow per mining cut could thus be calculated. However, the computed inflow to the total opencast, assuming that all areas is dewatered simultaneously, was calculated as tabled below in Table 13 below.

However, these figures are overestimations and probably reflect worst-case scenarios. The actual inflow will depend on the area being mined at any one moment in time. However, at the last boxcut, the inflow from the backfilled portion of the opencast could be substantial and the above inflows can be approached.

It is important to view these numbers for the water make of the mine in relation to natural evaporation, as listed in the table. Illustrative volumes are included in the table as if the evaporation will take place over the whole opencast, for comparative purposes. As the whole opencast will not be open at any one time, this is obviously an overestimate. Nevertheless, it is illustrative that evaporation can contribute considerably to the removal of groundwater seepage into the opencast.

Furthermore, it should be realised that evaporation is a seasonal effect. It is essential that more realistic volumes be calculated once detailed mining plans are available. Direct recharge from rainfall will in turn add to these volumes. The amount of direct recharge will depend on the season as well as the details of the mining plans and storm water management. It is suggested that this is calculated as part of the surface water study.

It must be cautioned that these calculations have been done using simplified assumptions of homogeneous aquifer conditions. The reality could deviate substantially from this and the model should thus be updated as more information becomes available.

8.2.2 Impacts on Groundwater Quality

The flow in the aquifer will be directed towards the opencast during this stage of mining, and very little groundwater pollution is thus expected.

8.2.3 Impacts on streams/wetlands

Although surface water as such is not part of this study, the impact of the proposed opencast on streams in the area can be estimated qualitatively from the model in so far as the groundwater component (base flow) of the stream is concerned. Such an impact assessment will not include possible surface runoff influences caused by the opencast, but merely address the base flow component due to gaining (or losing) of groundwater by the stream.

It can be deduced from in the figure depicting drawdown during mining () that the cumulative groundwater drawdown at the streams/wetlands close to the opencast will have an impact. In particular the wetland situated between Portion 6A and B and Portion 9 opencast where the cumulative drawdown could affect the wetlands base flow. The cumulative drawdown may also have an influence on the general flow of the Witpuntspruit. However known historic mining north of the opencast could have already affected the flow in the Witpuntspruit and therefore the effect of the opencast on the wetland could be minimal if previous mining is considered.

Groundwater Management

A substantial drop in groundwater level is expected, but it is confined to no more than 200 metres around the any specific opencast. As a drawdown of 5 metres and more is needed to seriously affect the yield of boreholes, thus no negative quantity impact on any current private groundwater users is predicted as previously discussed. However, the base flow feeding the wetland could be affected, as discussed in the previous paragraph.

It is important to monitor static groundwater levels on a quarterly basis in all boreholes within a zone of two kilometres surrounding the opencasts to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time and can be reacted on appropriately. Preferred flow structures (dykes, sills, faults, etc) have not been included in the model due to the unknown hydraulic characteristics, and these structures could alter the actual effects considerably.

If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, the affected parties should be compensated. This may be done through the installation of additional boreholes for water supply purposes, or an alternative water supply.

Furthermore, if flow in the streams is found to decrease, it will be necessary to mitigate this effect. As this opencasts are not situated directly within the Witpunt or Humanspruit`s path, there are no upstream flow that needs to be routed, and suitable canalisation of rainfall runoff should be able to restore stream flow to very close to undisturbed conditions although previous mining may have already disturbed the flow. Therefore the canalisation would not restore the loss of flow due the water being absorbed into the historic underground mine workings. However, it will be important to measure stream flow on a regular basis (even well before mining) to quantify the effect on the river.

As it was found that the drawdown cone does not extend to more than 200 metres from the opencasts, positioning the edge of the opencast no closer than this save distance from the streams, is highly recommended.

Another very important aspect to consider is the layout and order of the opencast cuts. The best possible scenario for minimising impacting on the wetland/stream is to start the boxcut parallel to the wetland/stream and at the farthest point from the wetland. In such a mining scenario the impact on the wetland will be delayed to the latest possible time before closure of the opencast.

Although little or no groundwater contamination is expected during this stage due to the cone of depression, it is nevertheless also recommended that groundwater quality be monitored on a quarterly basis. This is essential to provide a necessary database for future disputes.

Water samples must be taken from all the monitoring boreholes by using approved sampling techniques and adhering to recognised sampling procedures. Samples should be analysed for both organic as well as inorganic pollutants, as mining activity often lead to hydrocarbon spills in the form of diesel and oil. At least the following water quality parameters should be analysed for:

- Major ions (Ca, K, Mg, Na, SO4, NO3, Cl, F)
- pH
- Electrical Conductivity (EC),
- Total Petroleum Hydrocarbons (TPH)
- Total Alkalinity

These results should be recorded on a data sheet. It is proposed that the data should be entered into an appropriate computer database and reported to the Department of Water Affairs and Forestry.

Table 13: Predicted modelling results and impacts of each individual opencast

Opencast Mining Area	Area in m^2	Mining Seam	Maximum Drawdown in m	Cone of depression in m from edge of pit	Estimated Inflow (m3/day)	Evaporation (m3/day)	Potential Impacted Receptor
6A and B	548089	B Lower and C Upper	25	200	400	2192.356	Wetland/Witpuntspruit
PTN9	454099	B Lower seam	10	150	260	1816.396	Wetland/Witpuntspruit
Block D	751889	B Lower seam	25	200	1200	3007.556	Witpuntspruit
OC1	315872	B Lower and C Upper	25	130	300	1263.488	Witpuntspruit
OC2	214751	B Lower	18	130	280	859.004	Witpuntspruit
OC3	209317	B Lower	22	130	230	837.268	Witpuntspruit

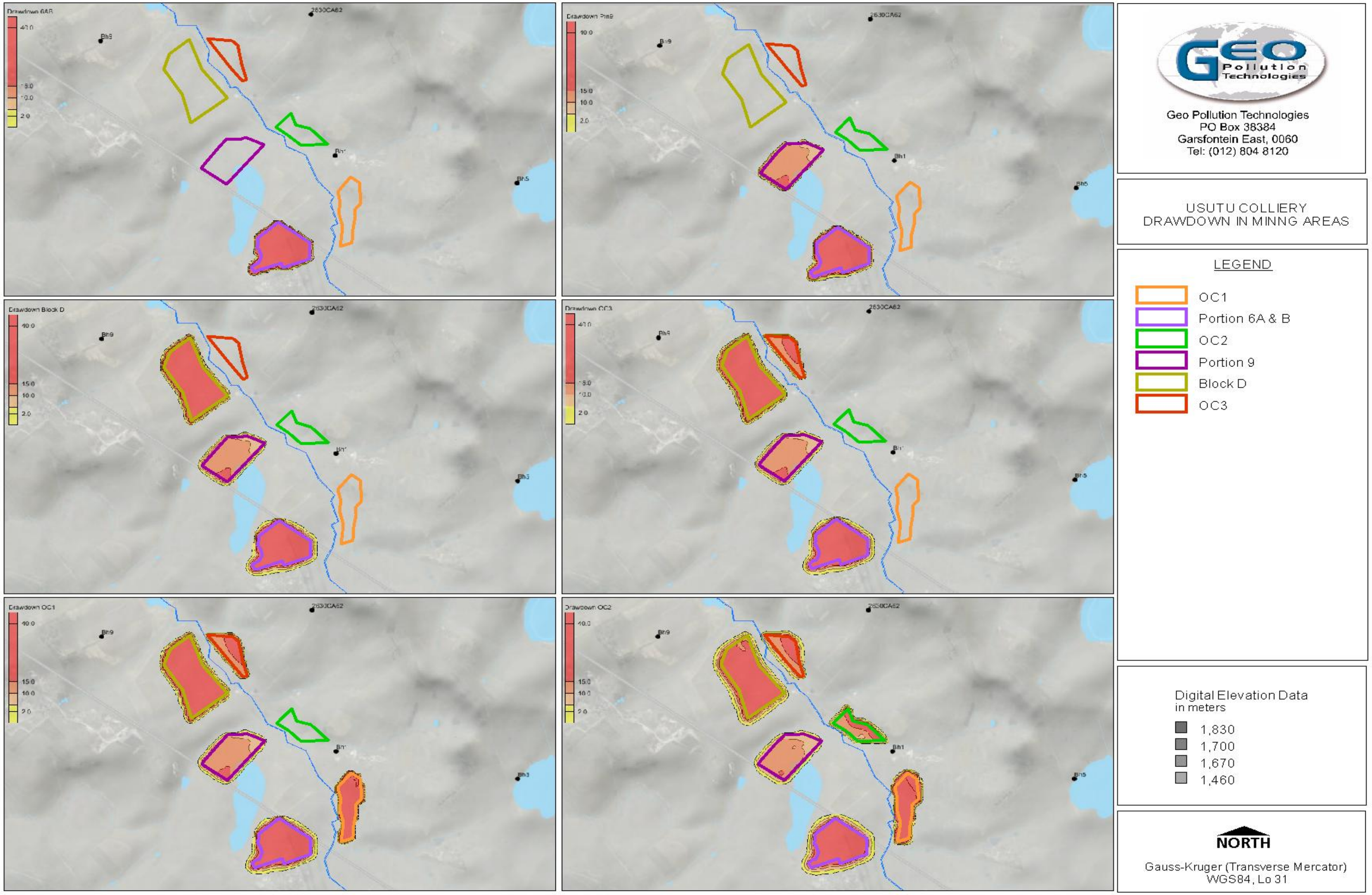

Figure 21: Groundwater Drawdown during Mining – Opencasts (Mining sequence left to right)

8.3 DECOMMISSIONING PHASE

During this phase of mining it is assumed that dewatering of the opencast will be ceased, and the surface of the opencast will be rehabilitated. The groundwater regime will return to a state of equilibrium once mining has stopped and the removal of water from the mining void has been discontinued.

The rise in groundwater level is predicted to be relatively slow and the water levels are expected to recover only in about 10 - 20 years. The slow recovery is ascribed to the low hydraulic conductivity of the surrounding bedrock.

No additional impacts on the groundwater of the study area other than the impacts discussed in paragraph 8.2 are expected during the decommissioning phase of the project.

8.4 POST-MINING PHASE

This phase of the mining process is the period following the completion of mining and rehabilitation of the proposed opencast. The following possible impacts were identified at this stage:

- Following closure of the opencast, the groundwater level will rise to an equilibrium that will differ from the pre-mining level due to the disturbance of the bedrock and increase in recharge from rainfall.

- Groundwater within the mined areas is expected to deteriorate due to chemical interactions between the geological and the groundwater. The resulting groundwater pollution plume will commence with downstream movement.

These impacts are discussed separately below and the significance of each impact is discussed.

8.4.1 Groundwater Quantity

After closure, the water table will rise in the rehabilitated opencasts to reinstate equilibrium with the surrounding groundwater systems. However, the mined areas will have a large hydraulic conductive compared to the pre-mining situation. This will result in a relative flattening of the groundwater table over the extent of mining, in contrast to the gradient that existed previously.

The end result of this will be a permanent lowering of the groundwater level in the higher topographical area and a rise in lower lying areas.

Intuitively, it would be expected that this raise in groundwater could result in decanting of the opencasts. Indeed, the predicted groundwater levels indicate that decanting will most probably occur, as seen in Figure 22(the blue triagles in this figure denotes “wet” cells, where the groundwater level is above surface). It follows from the figure that all the opencast is likely to decant, and that the decant could entail considerable volumes based on the amount of blue triangles.

8.4.2 Groundwater Quality

Once the normal groundwater flow conditions have been re-instated, polluted water can migrate away from the rehabilitated areas. As some coal and discards will remain in the mine, this outflow will be contaminated as a result of acid or neutral mine drainage. As sulphate is normally a significant solute in such drainage, it has been modelled as a conservative (non-reacting) indicator of mine drainage 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 mining area has been modelled as described, and the results are presented in Figure 23in terms of the extent of the pollution plume 10, 25, 50 and 100 years after the opencasts has been closed. Experience has shown that the plume stagnates after about 100 years, and no further movement after such time is expected.

As stated previously, the results must be viewed with caution as a homogeneous aquifer has been assumed. Heterogeneities in the aquifer are unknown and the effect of this cannot be predicted. 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, it is hoped that this prediction will represent a worst-case scenario.

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

- The sulphate pollution plume emanating from the opencasts, are predicted to reach the wetland between Portions 6A,B and Portions 9 as well as the Witpuntspruit in about 10 years after mine closure and rebound of the groundwater levels.
- Following this eventual period, seepage of AMD will increase in concentration and could reach very high levels in the wetland and Witpuntspruit surrounding the opencast, due to evapotranspiration.
- No privately owned boreholes is likely to be affected by sulphate pollution plume. The small settlement of Camden directly to the south of Portion 6A and B could be affected by the plume movement in 25 years.

8.4.3 Cumulative Effects

The cumulative pollution impacts of all current and historic mining in addition to the proposed new opencasts could not be calculated as any data on surrounding mines is not available. However it is highly recommended that a regional study be undertaken to quantify impacts on at least a quaternary scale.

8.4.4 Groundwater Management

From the modelling results obtained, it seems as if the opencasts might decant. Some mitigation measures can be considered:

- Reducing the extent of the opencasts at the decant areas. This will decrease the severity of decanting as well as improving the impact of the plume. The previous recommendation that opencasts should be no closer than 200 metres from the streams, will also reduce the decanting and will also create space for structures (such as berms and/or trenches) to intercept the decant.
- Mining should remove all coal from the opencasts and as little as possible should be left.
- Remaining acid producing material should be placed as low in the pit as possible to ensure fast flooding of the material. All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite[16].
- The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas.
- The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts.

- Leaving a final void in the opencast areas must be investigated. Once final mining plans are available, it will be essential to model this option.

- Quarterly groundwater sampling must be done to establish a database of plume movement trends, to aid eventual mine closure.

As more groundwater contamination is expected during this stage, it is even more important that groundwater quality be monitored regularly, at least on a quarterly basis. This is essential to provide a reliable database to facilitate eventual closure of the mining operation. The sampling methods and substances to be sampled for are similar to those recommended in the previous paragraph.

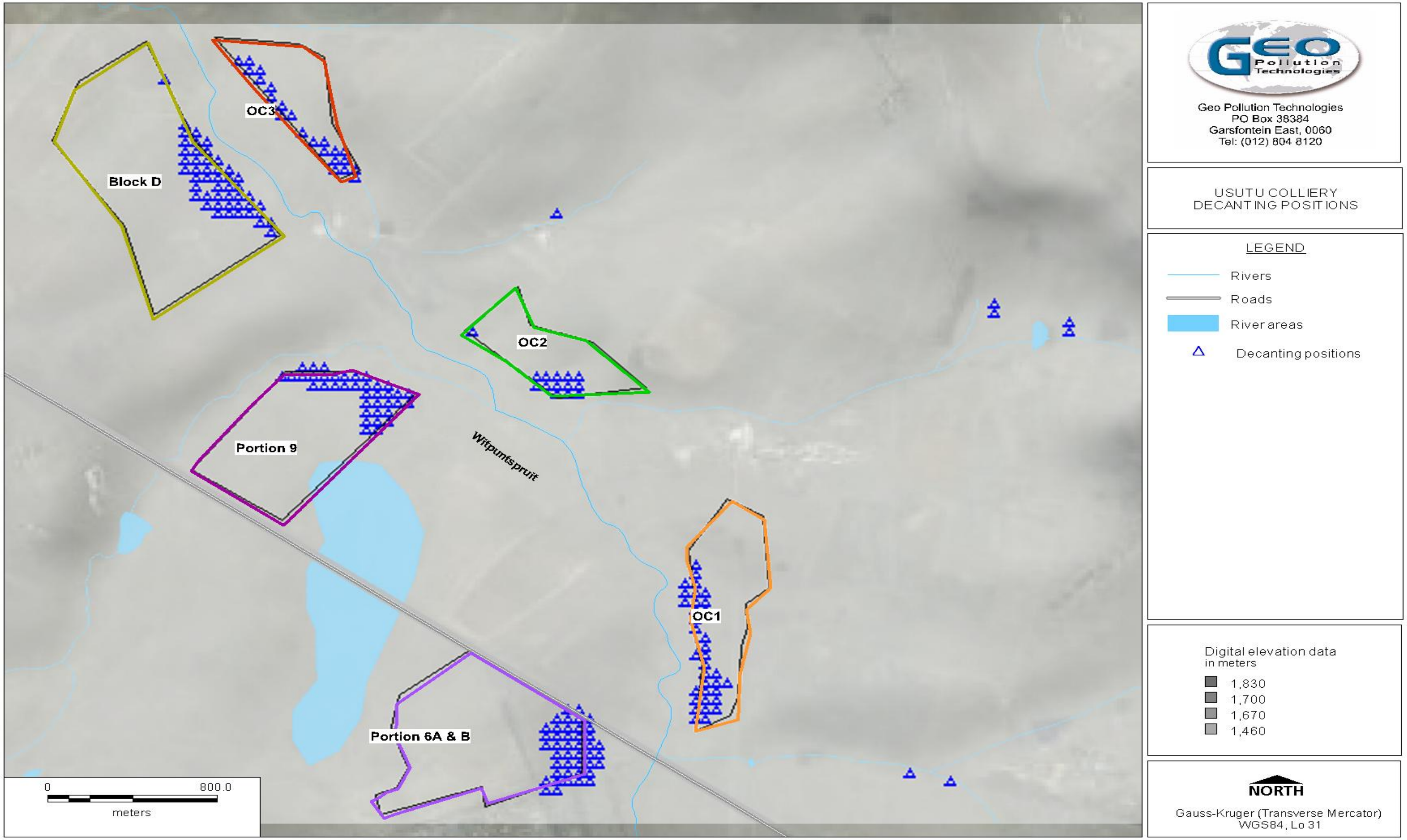

Figure 22: Predicted decanting positions

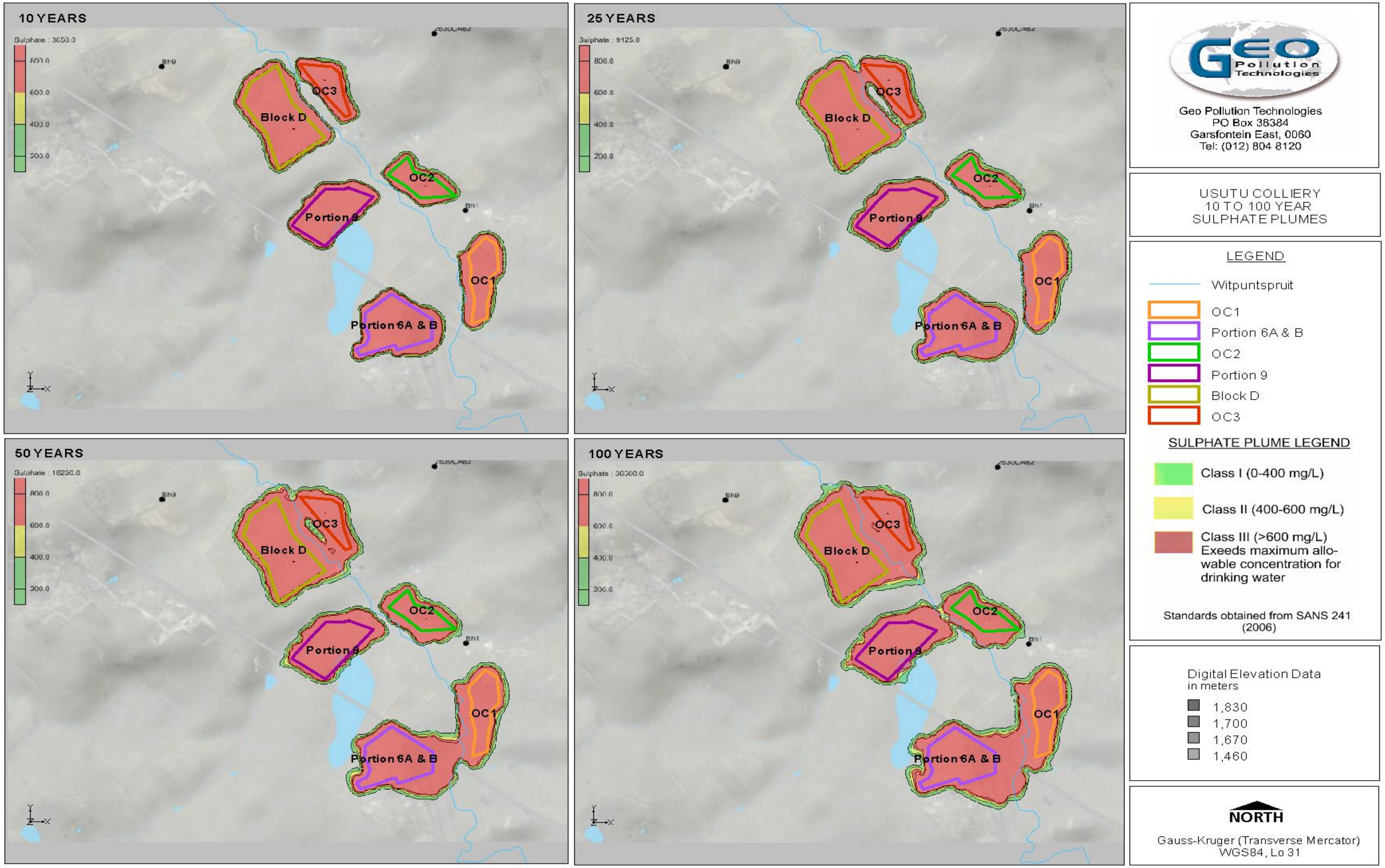

Figure 23: Plume Migration after 10, 25, 50 and 100 years.

9 GROUNDWATER MONITORING SYSTEM

9.1 GROUNDWATER MONITORING NETWORK

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

9.1.1 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.

9.1.2 System response monitoring network

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

9.1.3 Monitoring frequency

In the operational phase and closure 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.

9.2 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.

9.2.1 Abbreviated analysis (pollution indicators)

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
  - pH, EC
- Laboratory analyses:
  - Major anions and cations (Ca, Na, Cl, SO_4)
  - Other parameters (EC)

9.2.2 Full analysis

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
  - pH, EC
- Laboratory analyses:
  - Anions and cations (Ca, Mg, Na, K, NO_3, Cl, SO_4, F, Fe, Mn, Al, & Alkalinity)
  - Other parameters (pH, EC, TDS)
  - Petroleum hydrocarbon contaminants (where applicable, near workshops and petroleum handling facilities)
  - Sewage related contaminants (*E.Coli*, faecal coliforms) in borehole in proximity to septic tanks or sewage plants.

9.3 MONITORING BOREHOLES

There are no source/plume monitoring boreholes that matches the criteria as mentioned in the preceding paragraphs. Therefore at least 4 to 6 monitoring holes is recommended to be constructed around each opencast upstream and downstream of the site.

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."[17] Therefore it is recommended that boreholes be drilled on the positions as mentioned in the paragraph. These boreholes should be drilled as close possible to the opencast and monitored appropriately. Construction of these boreholes should be overseen by a qualified hydrogeologist to monitor the upper weathered as well as lower fractured aquifer.

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

[17] Department of Water Affairs and Forestry (DWAF). (1998). Minimum Requirments for the Water Monitoring at Waste Managmenet Facilities. CTP Book Printers. Capetown.

infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually.

The wetland should also be measured for flow upstream and downstream to determine the effect that the dewatering of the opencast has on the wetland before mining commences.

In both cases the monitoring should commence before mining to establish background values for future reference. In Table 14 a proposed monitoring network extension is proposed, based on the geophysics. These boreholes should be added to boreholes mentioned in Table 4 as part of an extended monitoring network.

Table 14: Proposed monitoring network based on geophysics

Name	X-coord	Y-coord	Monitoring Requirement
DP1 TR1a	30.079577°	-26.593738°	Source/Plume Monitoring
DP2 TR1b	30.080276°	-26.592607°	Source/Plume Monitoring
DP3 TR2	30.097642°	-26.589481°	Source/Plume Monitoring
DP4 TR3a	30.075006°	-26.577303°	Source/Plume Monitoring
DP5 TR3a	30.077117°	-26.574525°	Source/Plume Monitoring
DP6 TR3b	30.080598°	-26.573560°	Source/Plume Monitoring
DP7 TR3b	30.081436°	-26.573638°	Source/Plume Monitoring
DP8 TR4	30.087408°	-26.571855	Source/Plume Monitoring
DP9 TR4	30.088967°	-26.572973°	Source/Plume Monitoring
DP10 TR4	30.091109°	-26.575475°	Source/Plume Monitoring
DP11 TR5	30.073618°	-26.558363°	Source/Plume Monitoring
DP 12 TR6	30.075668°	-26.558031°	Source/Plume Monitoring

10 GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAMME (EMP)

The table summarised all the groundwater related EMP's and should be implemented during the various phases of mining. The EMP's were developed in accordance with the DWA Best Practice Guideline series.

Table 15: Groundwater Related EMP

Activity/phase	Aspect	Impact	Actions/Mitigations
Construction Phase	Deterioration of groundwater quality	Oil, diesel and chemical spills from machinery	• It must be ensured that a credible company removes used oil after vehicle servicing. • A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills • Store all potential sources in secure facilities with appropriate storm water management, ensuring contaminants are not released into the environment.
		Contamination potential of mine material exposed during mine construction	• Ensure that the appropriate design facilities (berms, storm water channels etc.) are constructed before constructing the coal handling facilities and adit(s). • Implement the EMP's of other environmental related aspects, including pollution prevention and impact minimisation. • 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. • Groundwater monitoring boreholes should be installed to comply with the minimum requirements as set by governmental guidelines.
Operational Phase	**Groundwater quantity-lowering of groundwater table**	Impact on water supply of groundwater users surrounding mine	• Monitor static groundwater levels on a quarterly basis in all boreholes within a zone of one to two kilometres surrounding the opencasts to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time and can be reacted on appropriately. • If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, the affected parties should be compensated. This may be done through the installation of additional boreholes for water supply purposes, or an alternative water supply. • The numerical model should be updated during mining by using the measured water ingress, water levels, mining and geophysics information to re-calibrate and refine the impact prediction
		Potential impact on base flow of streams/wetlands	• Various options should be investigated such as if clean discharge is available to be pumped back into the wetland although the effectiveness of this is debatable due to previous underground mining activities • Keep a buffer distance of at least 150m from the edge of the wetland and Witpuntspruit • Another very important aspect to consider is the layout and order of the opencast cuts. The best possible scenario for minimising impacting on the wetland/stream is to start the boxcut parallel to the wetland/stream and at the farthest point from the wetland. In such a mining scenario the impact on the wetland will be delayed to the latest possible time before closure of the opencast.
	Groundwater quality -	Deterioration of groundwater quality down gradient of the mining	• Groundwater quality must be monitored on a quarterly basis as mention in section 9.

	Contamination of groundwater	operations	• 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. • Pollution control dams should be lined to prevent ingress of contamination • Mine sections should be sealed where possible during mining to reduce the contact of water and air with remaining sulphides. • Install water collection and pumping systems within the mining areas capable of rapidly pumping water out, so minimising contact of water the geochemically reactive material. • Assess the impact of the neighbouring mines on this colliery and vice versa. This is best done by pooling measured groundwater data to update and expand the current numerical model • Kinetic testing of the pillar material should be conducted to aid in the prediction of post mining geochemical conditions. • Process water must be stored in a lined pollution control dam and the processing areas should be designed to prevent standing water. • Clean and dirty water systems should be separated.
		Oil, diesel and chemical spills/leaks from machinery and storage facilities	• It must be ensured that a credible company removes used oil after vehicle servicing. • A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills • Store all potential sources in secure facilities with appropriate storm water management, ensuring contaminants are not released into the environment.
		Sewage related groundwater contamination	• Sewage effluent emanating from latrines or ablution blocks should be treated to acceptable levels before discharge into the environment
Decommissioning and post mining Phase	**Groundwater quantity - change in groundwater level**	Decant volume	• All sulphate containing waste material should be stored underground and flooded as soon as possible to exclude oxygen. • Treatment of the decant may be viable, however all passive methods should be investigated first during the operational phase of the mine • Major underground fractures encountered while mining must be sealed by grouting, both on inflow and outflow areas
		Potential (positive) impact on base flow of streams-(not predicted)	
	Groundwater quality - Contamination of groundwater	Deterioration of groundwater quality down gradient of the mining operations due to plume movement	• A pollution control dam could be used to intercept polluted seepage water. This should be considered if it is found that the wetlandis indeed negatively affected by pollution. Regular sampling of the streams and wetland is essential to decide on this option if needed. • Implement as many closure measures during the operational phase, while conducting appropriate monitoring programmes to demonstrate actual performance of the various management actions during the life of mine. • All mined areas should be flooded as soon as possible to minimise oxygen from reacting with the remaining pyrite. • Mining should remove all coal from the opencasts and separate acid forming and non-acid forming material. Deposit acid forming material at the base of the pit. • The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas. • The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts. • Quarterly groundwater sampling must be conducted to establish a database of groundwater quality to assess plume movement trends.

			• Audit the monitoring network annually.
		Contaminants emanating from historic Oil, diesel and chemical spills and facilities	• Remove or remediate areas of hydrocarbon contaminated soils by following a risk based approach, take action if a negative risk is found. A risk assessment should be conducted by a qualified hydrogeologist.
All phases	**Groundwater management**		• All the monitoring data needs to be collated and analysed on at least a bi-annual basis and included in management reports. This information will also be required by government departments (Department of Water Affairs, Department of Environmental Affairs) for compliance monitoring. • After 2 years from start of mining, the monitoring information collated should be used to update the groundwater flow and geochemical models. These models should thereafter be updated so that sufficient mitigation measures can be implemented. Management and mitigation plans should be continuously adapted using the monitoring data.
Closure Phase	**Groundwater management**		• A detailed mine closure plan should be prepared during the operational phase, including a risk assessment, water resource impact prediction etc. as stipulated in the DWA Best Practice Guidelines. • The implementation of the mine closure plan, and the application for the closure certificate can be conducted during the decommissioned phase.

11 CONCLUSIONS AND RECOMMENDATIONS

This section will briefly summarise the current groundwater conditions in the area of the proposed opencasts, the expected impacts of the mine on the groundwater and the recommendations to minimise the effect of mining on the groundwater.

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

11.1 CURRENT GROUNDWATER CONDITIONS

Groundwater levels were measured in twelve boreholes during a hydrocensus conducted in November 2011 for the proposed Usutu opencast on the farm Jan Hendriksfontein portion 263 IT/6B and Transutu 257 It. The depth of the groundwater was found to vary between 1m and 10m below ground level.

A seasonal aquifer perched on the bedrock probably develops in the upper weathered soil layer, especially after high rainfall events. Flow in this perched aquifer is expected to follow the surface contours closely and emerge as fountains or seepage at lower elevations.

From the chemical analysis of the water samples an overall assumption can be made that the groundwater sampled in the proposed mining area is of poor quality and not acceptable for domestic use. It can be deduced from the water quality of the sampled boreholes that the groundwater has been negatively affected by historic mining related contaminants.

The acid base analysis (ABA) of exploration drill cores from the six opencast areas showed material that is intermediate to potentially acid forming material.

Geophysics indicated that structures such as dykes are present across the opencast mining area.

11.2 PREDICTED IMPACTS OF MINING

The impacts on the groundwater regime normally associated with mining is dewatering of the aquifer during mining and pollution of the groundwater following mine closure. The dewatering is essential to allow access to the mining areas, while the pollution is due to chemical weathering by oxidation of the sulphate containing minerals (mostly pyrite).

During mining, groundwater seeping into the opencast and underground mining areas will have to be pumped out to facilitate access. This will inevitably lead to a lowering of the groundwater table and the development of a local cone of depression. This cone of depression will also contain pollution resulting from mining. Polluted groundwater pumped from the mine will be used for mining purposes.

Post mining, following the closure of the pit and discontinuing of dewatering, the groundwater levels will return to equilibrium. The cone of depression that contained polluted groundwater will cease to exist and movement of a groundwater pollution plume will commence.

Numerical groundwater modelling is considered to be the best method of anticipating and quantifying these likely impacts on the groundwater regime. For this purpose, a numerical model was created using the Department of Defence Groundwater Modelling System (GMS) software as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes

Based on the results of the modelling, the following conclusions are made**:**

Construction Phase:

The construction phase will consist of preparations for the opencast, which is assumed to consist mainly of establishment of infrastructure on site and the mobilisation of earth moving equipment.

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.

Operational Phase:

Since the coal seam is situated below the groundwater level, the lowering of the groundwater level during mining will be important

- There are no privately owned boreholes in the potential affected area that might experience a decline in water levels of approximately 5 metres or more. The small settlement of Camden directly to the south of the proposed opencast could be affected by the drawdown if there are any unknown boreholes. The impact will however be minimal.
- It is evident that a large portion of the wetland situated between Portions 6A and B and Portion 9, could be affected. If the wetland does not have a clayey bottom and a reasonable inflow of groundwater, it will most likely be largely dewatered.
- Base flow of the Witpuntspruit could also be affected due to the cumulative effect of drawdown resulting from the dewatering of the opencasts.

All of the above conclusions were based on the assumption that the wetland/streams has not been previously affected by underground mining activities.

Post Mining Phase:

Post mining, after closure, the water table will rise to reinstate equilibrium with the groundwater systems. The mined areas will have a large hydraulic conductive compared to the pre-mining situation. This will result in a relative flattening of the groundwater table over the extent of mining, in contrast to the gradient that existed previously.

- Following closure of the opencast, the groundwater level will rise to an equilibrium that will differ from the pre-mining level due to the disturbance of the bedrock and increase in recharge from rainfall.
- Intuitively, it would be expected that this raise in groundwater could result in decanting of the opencasts as predicted by the groundwater model.
- Groundwater within the mined areas is expected to deteriorate due to chemical interactions between the geological and the groundwater. The resulting groundwater pollution plume will commence with downstream movement.
  - The sulphate pollution plume emanating from the opencasts, are predicted to reach the wetland between Portions 6A,B and Portions 9 as well as the Witpuntspruit in about 10 years after mine closure and rebound of the groundwater levels.
  - Following this eventual period, seepage of AMD will increase in concentration and could reach very high levels in the wetland and Witpuntspruit surrounding the opencast, due to evapotranspiration.
  - No privately owned boreholes might be affected by sulphate pollution plume. The small settlement of Camden directly to the south of Portion 6A and B could be affected by the plume movement in 25 years.

It must be kept in mind that the modelling was done within the limitations of the scope of work of this study and the limited 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.

11.3 GROUNDWATER MANAGEMENT AND MITIGATION MEASURES

Since it is inevitable that a mining operation of this scale will impact on the groundwater regime, measures to manage and reduce these impacts to the absolute minimum must be considered. The identified negative impacts of reduction of the groundwater levels during mining and the spread of groundwater pollution after closure of the opencast will be addressed in the following paragraphs.

11.3.1 Lowering of Groundwater Levels during Mining

Since the drawdown or the groundwater levels during mining could influence some boreholes, the following measures are recommended:

- The static level of groundwater in all boreholes within a distance of less than one kilometre must be measured regularly to establish a database against which future groundwater levels can be compared.

- Such measurements must be made preferably quarterly, but at least twice annually, following the dry and rainy seasons.

- In the event of unacceptable decrease of the yield of any affected boreholes, alternative water supply should be supplied to the affected parties until such time that the groundwater recovers following closure of the pit.

- As the wetland could be affected, monitoring of the wetland is essential. Should clean mine water be available, it is suggested that it be released in the wetland. A wetland specialist should be consulted to ensure correct volumes and timing of the added water.

- It is recommended that the closest box cut to the Witpuntspruit and wetland keep a distance of at least 150m form edge of the wetland.

- Another very important aspect to consider is the layout and order of the opencast cuts. The best possible scenario for minimising impacting on the wetland/Witpuntspruit is to start the boxcut parallel to the wetland/stream and at the farthest point from the wetland. In such a mining scenario the impact on the wetland will be delayed to the latest possible time before closure of the opencast.

11.3.2 Rise of Groundwater Levels Post-Mining

As it is predicted that there will be a rise in groundwater levels in the lower sections of the opencasts that could result in decanting, some measures are needed to mitigate this. It is thus recommended that:

- To minimise decanting in the opencast, all direct connection (if applicable) between the underground areas and opencasts should be thoroughly sealed to prevent direct groundwater seepage to the backfilled opencasts.

11.3.3 Spread of Groundwater Pollution Post-mining

Predictions in the previous sections regarding groundwater pollution have been based on the assumption that the rehabilitated pit will be a constant source of sulphate pollution of 2000 mg/l, representing a worst-case scenario. With appropriate measures, the oxidation rate of pyrite can be limited, resulting in lower starting concentrations. Furthermore, the migration of the pollution plume from the void can also be limited by surface rehabilitation measures preventing excessive infiltration of groundwater to the mined area. Thus, although it has been predicted that only a limited area of the aquifer might be polluted to such an extent that acceptable standards for domestic water is exceeded, further reduction is achievable.

To minimise the effect of groundwater pollution on the receiving environment, the following measures are suggested:

- All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite.
- Mining should remove all coal from the opencasts and as little as possible should be left.
- The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas.
- The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts..
- Leaving a final void in the opencast areas must be investigated. Once final mining plans are available, it will be essential to model this option.
- Quarterly groundwater sampling must be done to establish a database of plume movement trends, to aid eventual mine closure.
- Regular sampling and chemical analyses of the groundwater is imperative to establish a sound database:
    - Groundwater in all boreholes within a distance of less than two kilometres must be sampled regularly to establish a database against which future groundwater levels can be compared.
    - Sampling must be preferably quarterly, but at least twice annually, following the dry – and rainy seasons.
- If it is found during such a sampling event that groundwater from any extraction borehole is polluted beyond acceptable standards, alternative water will have to be supplied to the affected party.

11.3.4 Impacts indirectly related to mining

During all phases of mining, vehicles and personnel will be operative in the opencast. Minor spills such as diesel, petrol and oil could results from machinery operations. Also, domestic water and waste disposal could also affect the groundwater quality. The following is thus recommended:

- It must be ensured that a credible company removes used oil after vehicle servicing.
- A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills.
- Used absorbent fibre must be land-farmed, using approved methodologies.
- Domestic waste water, especially sewage, must either be treated at site according to accepted principles, or removed by credible contractors.
- Solid waste must similarly either be stored at site on an approved waste dump, or removed by credible contractors.

11.3.5 Further work

The following further work is recommended

- 4 to 6 monitoring holes be constructed around each opencast upstream and downstream of the site. The geophysics results obtained during this can be used to site some of these boreholes.

- 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.

- The numerical model should be recalibrated as soon as more hydrogeological data such as monitoring holes are made available. This would enhance model predictions and certainty.

- The wetland should be measured for flow upstream and downstream to determine the effect that the dewatering of the opencast has on the wetland before mining commences.

- In both cases the monitoring should commence before mining to establish background values for future reference.

- The cumulative pollution and dewatering impacts of all current mining in addition to the proposed new opencast could not be calculated as no data on surrounding mines were available. However a detailed model taking in consideration all Usutu Collieries mining activities underground and opencast will be required to estimate the cumulative impact Usutu has on the surrounding hydrogeological environment.