Stuart Coal South Block Colliery: Report on Geohydrological Investigation as part of the EMPR for the proposed mining operation

March 2010

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This report should be cited as:

Clean Stream Groundwater Services, 2010.
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Mpumalanga, South Africa,
March 2010

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Executive Summary:

Clean Stream Groundwater Services was contracted by Stuart Coal to conduct a geohydrological investigation in and around the farms Moabsvelden, Vanggatfontein, and Vogelfontein, which are situated approximately 10 km to the east of the town of Delmas in the Mpumalanga Province. The proposed project is a greenfields opencast coal mining operation, during which the conventional truck and shovel mining method will be used to extract the coal.

All the main aspects required to assess geohydrological conditions in and around the mine lease area have been addressed as part of the study, including physical properties of the groundwater domain, geohydrological features, groundwater users and uses around the mining area, geology, the hydraulic properties of the saturated zone, groundwater quality characteristics, groundwater flow velocities were calculated from first principles and all data were combined to construct conceptual and numerical models. A total of 31 hydrocensus boreholes were used for the assessment of the regional groundwater quality conditions, while 10 purpose drilled monitoring boreholes were used for the site specific assessment of groundwater conditions. Pumping tests were performed on all ten of the monitoring boreholes in an effort to determine the site specific aquifer transmissivity, which was subsequently used in the construction and calibration of the numerical flow and mass transport models.

The Stuart South Block Colliery lease area is underlain by rocks of the Karoo Supergroup on a basement of the older Transvaal Supergroup rocks. The Karoo rocks that contain the coal reserve have been preserved on the higher lying topography but have been eroded away in the valley areas where the older basement has been exposed.

Based on the geological profile descriptions, the unsaturated zone is composed of soils and colluvium underlain by sandstone, siltstone, shale, mudstone, coal, followed by tillite and older basement rocks.

On the basis of the drilling results of exploration boreholes as well as other studies in the nearby coal field area, the aquifer thickness in the region varies between approximately 10 and 30 meters. This ''thickness'' can increase in some areas where much deeper water strikes occur in other rock types such as the older Transvaal Supergroup that underlies the Karoo formations.

Under natural conditions, water entering the groundwater system will migrate vertically downwards until a more impervious layer that forms a perched aquifer is encountered. As the perched aquifer did not feature during drilling at the Stuart South Block Colliery it is likely that the majority of recharge water will migrate downwards into the saturated zone.

From there it will migrate in the direction of the hydraulic gradient until it eventually enters surface water bodies (i.e. rivers or springs) from where it will discharge as surface water.

The following main characteristics are inferred from information gathered during the study:

- The geohydrological regime in the study area is made up of three aquifer systems,
- The first, the upper, semi-confined aquifer sometimes occurs in the weathered zone but is often not a reliably and widely used aquifer,
- The second, deeper aquifer is associated with fractures, fissures and joints and other discontinuities within the consolidated Karoo bedrock and associated intrusives,
- The third aquifer is associated with dissolution cavities found within the dolomitic aquifers, which form part of the Malmani sub-group of the Transvaal Supergroup,
- Borehole yields usually vary between 0 and 2.5 l/s with static water levels between 1 and 15 meters below surface (mbs),
- The overall regional and site specific groundwater is of good quality and is suitable for human consumption,
- Natural groundwater seepage from the project area is roughly towards the east and west with average seepage velocities varying between 5 and 10 meters per year.

More significant groundwater level impacts are expected to occur in the southern corner of the Echo 1 Pit as this is the area where the coal seam occurs the deepest below surface.

Management of poor quality decant water will be complicated due to the fact that the pits are not interconnected and decant will take place at each individual opencast pit. The time to decant and decant volumes of each pit were estimated and are included in the document. A summary of estimated decant rates and time to decant is provided in the table below:

Pit	Time-to-decant (years)	Decant rate (m^3/d)
Alpha	122	207
Beta	182	462
Charlie 1	99	145
Charlie 2	38	138
Delta	74	398
Echo 1	127	465
Echo 2	82	194

1 GENERAL DESCRIPTION OF GEOHYDROLOGY

Clean Stream Groundwater Services have been contracted by Stuart Coal to conduct a specialist geohydrological study and report on findings as input to the EMP report for the proposed new Stuart Coal South Block Colliery (herein referred to as Stuart South Block). The proposed site is located approximately 10 km to the east of the town of Delmas in the Mpumalanga Province. The existing mining operations of Stuart Coal namely the Weltevreden Colliery and Stuart East Colliery are situated to the north-west of the proposed Stuart South Block Colliery.

The project involves opencast coal mining on the farms Moabsvelden, Vanggatfontein, and Vogelfontein. Coal seams number 2, number 4, and number 5 will be mined utilising a standard conventional opencast strip mining method. The mining method involves the stripping of the weathered overburden and the drilling and blasting of the hard overburden. This overburden will be rolled over to the adjacent void left by the extracted material. The extracted coal will be transported to the crushing and screening plant at Weltevreden Colliery where it will be stockpiled.

During the construction phase, the following surface infrastructure will be erected to facilitate the necessary mining operations:

- Access and haul roads to the opencast voids,
- Storm water control measures,
- Water pollution control measures (pollution control dam/s),
- Attenuation dam to accommodate the river diversions associated with the Leeuwpan Colliery and Alpha Open Pit of the proposed South Block Colliery,
- Stockpiles (topsoil, subsoil, and waste rock stockpile).

Any additional infrastructure required by the proposed mining activities will be fulfilled by the existing surface infrastructure at the existing Weltevreden and Stuart East Collieries. These infrastructure requirements include:

- Site offices,
- Workshops,
- Weighbridge,
- Beneficiation plant,
- ROM stockpiles, and
- Wash/change houses.

The location of the proposed Stuart South Block Colliery is indicated in **Figure 1.1**. This report provides methodology and findings of the geohydrological baseline study that will be used as reference for the groundwater impact assessment and management plan.

1.1 *DESKTOP STUDY*

A groundwater survey was performed for the entire mine boundary area as well as the direct vicinity of the proposed mine. The results of the survey are presented in this document.

Groundwater information for the survey was obtained mainly from three different sources:

- Existing groundwater information compiled in support of previous EMPR documents and addendums,
- The second source comprises dedicated information gathering through drilling of monitoring boreholes, groundwater quality analysis, water level and aquifer test measurements in boreholes committed for groundwater monitoring, as well as groundwater information gathered during initial and follow-up hydrocensus studies performed specifically for compilation of this EMP document. Borehole tests were performed on boreholes specifically drilled for the purpose of this study and monitoring to improve the data distribution for especially aquifer flow parameters,
- The last source involves data requested and assessed from the National Groundwater Database (NGDB) on and around the proposed Stuart South Block lease area.

For the purpose of this study, the monitoring data, hydrocensus information as well as studies and findings of previous groundwater and related investigations in the area were combined and interpreted in a holistic manner. For the purpose of compiling this specialist report the physical and chemical properties of the groundwater regime were evaluated using the following methodology:

- Topographical and geological maps, orthographic photographs as well as geophysical investigations were used to describe the **physical properties** of the groundwater domain,

- Detailed site investigations such as drilling and aquifer testing were performed during which the relevant **geohydrological features** were described and aquifer parameters calculated,

- A hydrocensus was conducted during which **groundwater users** around the mining area were identified, boreholes were surveyed in terms of positions, flow and water quality, and water **uses** were determined,

- A number of percussion boreholes were drilled and logged in the study area to determine the **geological profile** and stratigraphy of the area,

- Blow yield, constant rate pumping and recovery tests were performed on the monitoring boreholes. The pumping tests were then analysed in order to determine the **hydraulic properties** of the saturated zone,

- Groundwater **flow velocities** were calculated from first principles to use as guidelines in numerical model construction,

- All the above data types were interpreted with appropriate techniques in each case and were used to construct a **conceptual and numerical model** of the groundwater regime, and

- The numerical model was calibrated using groundwater levels, aquifer test information, and groundwater qualities to use as predictive tool for future flow and pollution migration.

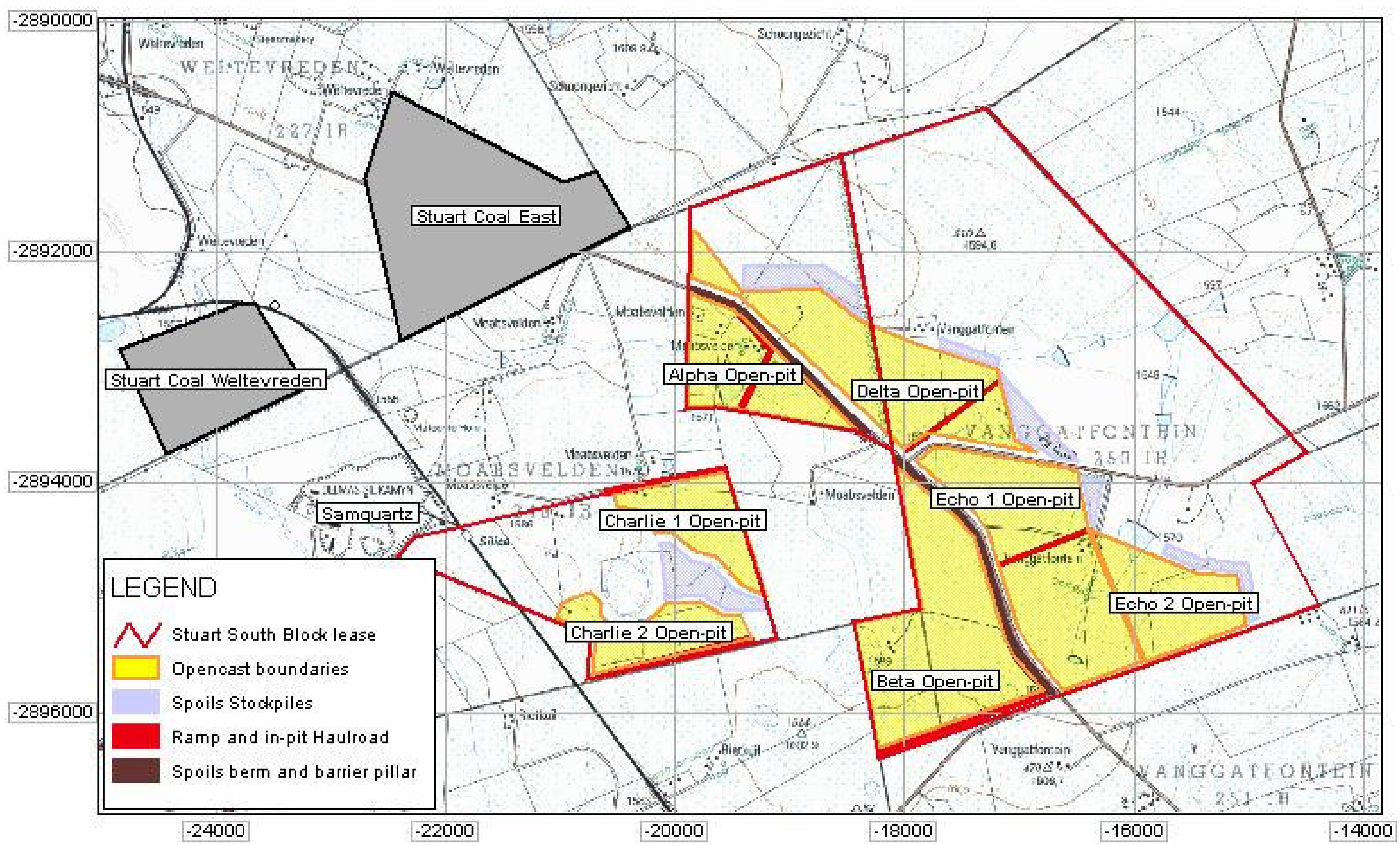


Figure 1.1: Locality map of the proposed Stuart South Block

1.2 AMBIENT GEOHYDROLOGICAL CONDITIONS

1.2.1 Groundwater use (user survey/hydrocensus results)

During the hydrocensus that was conducted in April 2009 by Clean Stream Scientific Services (CSSS) a total of 25 boreholes and one spring were located. From the hydrocensus and water user surveys conducted in the area it followed that groundwater from boreholes is used mainly for domestic supply, watering of gardens, livestock, and irrigation.

Borehole yields reported during the user survey vary between 0 and 2 l/s, which correspond well with general Karoo rock aquifer yields.

Widespread pollution or depletion of the groundwater resource will thus impact negatively not only on the resource, but also on the users depending on the source as sole source of domestic water as well as water requirements for livestock, gardening, and irrigation. These users, as well as a short summary of the hydrocensus are given in **Table 1.2.1**. The hydrocensus report compiled by CSSS is included in the document as **Appendix C**.

The positions of boreholes surveyed during the CSSS hydrocensus survey for the Stuart South Block area are presented on the map in **Figure 1.2.1**.

Figure 1.4.1-1 indicates the positions of the CSSS hydrocensus survey boreholes of which groundwater quality information is available. Boreholes recorded during previous hydrocensus surveys are included in the regional assessment of the groundwater quality and their positions are indicated in **Figure 1.4.1-1**. It is clear from the figures that a relatively good borehole distribution was obtained for geohydrological conceptualization to a high level of confidence.

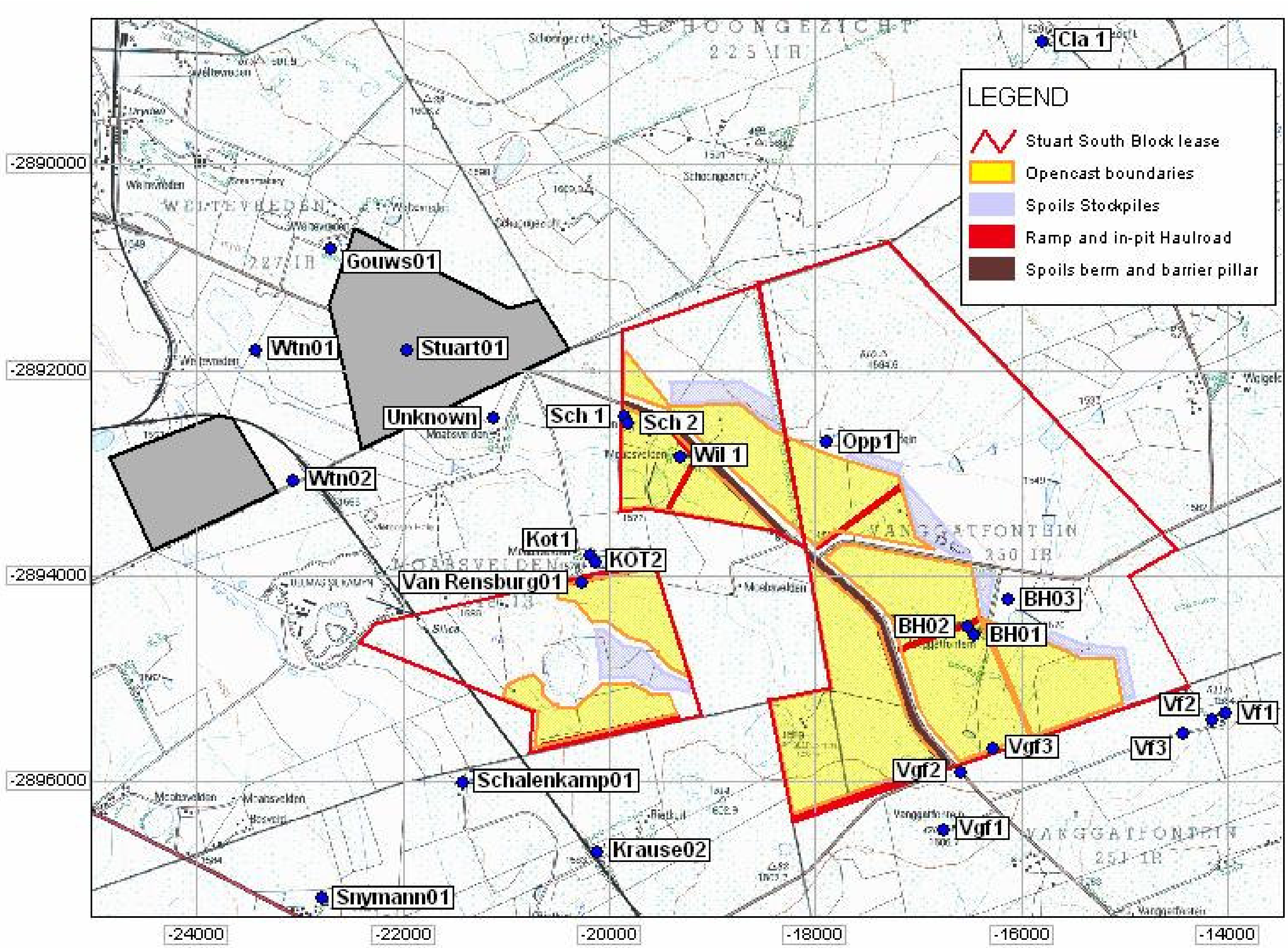


Figure 1.2.1: Boreholes recorded during the CSSS hydrocensus survey of the area

Table 1.2.1: CSSS hydrocensus survey summary

Site Name	X-coord	Y-coord	Z-coord	Site Type	Sampled	Owner	Water use
BH01	28.83544	-26.16011	1591.0	Borehole	Y	DJ Opperman	Domestic
BH02	28.83468	-26.15932	1593.0	Borehole	N	DJ Opperman	Domestic and Irrigation
Cla 1	28.84209	-26.10793	1540.0	Borehole	Y	K Claasen	Domestic
Kot03	28.79585	-26.14594	1567.0	Marsh	Y	S Kotze	Livestock
Krause01	28.80395	-26.17624	1604.0	Marsh	Y	E Krause	Livestock
Krause02	28.79870	-26.17900	1585.0	Borehole	Y	E Krause	Domestic
Opp1	28.82102	-26.14311	1616.0	Borehole	Y	DJ Opperman	Domestic and Irrigation
Sch 1	28.80143	-26.14077	1584.0	Borehole	Y	P Schutte	Domestic and Livestock
Sch 2	28.80175	-26.14144	1583.0	Borehole	Y	P Schutte	Open Hole - Not In Use
Schalenkamp01	28.78575	-26.17296	1568.0	Borehole	Y	M Schalenkamp	Domestic
Stuart01	28.78035	-26.13493	1580.0	Borehole	Y	Community	Domestic
Unknown	28.78875	-26.14087	1581.0	Borehole	Y	Vacant Residence	Not in Use
Van Rensburg01	28.79731	-26.15537	1583.0	Borehole	Y	Van Rensburg	Domestic
Wil 1	28.80697	-26.14436	1585.0	Borehole	Y	JC Williams	Livestock and Irrigation
BH03	28.83871	-26.15689	1583.0	Borehole	N	DJ Opperman	Livestock
Kot1	28.79822	-26.15293	1588.0	Borehole	Y	S Kotze	Domestic and Livestock
KOT2	28.79861	-26.15359	1586.0	Borehole	N	S Kotze	Domestic and Livestock
Vf1	28.85972	-26.16697	1594.0	Borehole	Y	K Peach	Domestic and Livestock
Vf2	28.85845	-26.16752	1596.0	Borehole	Y	K Peach	Not in Use
Vf3	28.85566	-26.16865	1593.0	Borehole	Y	K Peach	Domestic and Livestock
Vg1	28.83938	-26.15768	1580.0	Dam	Y	DJ Opperman	Livestock
Vg2	28.83948	-26.16251	1580.0	Fountain	N	DJ Opperman	Livestock
Vg3	28.84245	-26.15111	1560.0	Dam	Y	DJ Opperman	Livestock
Vgf1	28.83241	-26.17721	1621.0	Borehole	Y	J Claasens	Domestic
Vgf2	28.83404	-26.17214	1605.0	Borehole	N	J Claasens	Irrigation
Vgf3	28.83715	-26.17006	1598.0	Borehole	N	J Claasens	Irrigation
Snymann01	28.77200	-26.18300	1577.0	Borehole	Y	J Snymann	Domestic
Gouws01	28.77300	-26.12600	-	Borehole	Y	L Gouws	Domestic and Livestock

1.2.2 Groundwater zone

The following aspects would delineate the applicable "Groundwater zone":

- The thickness, soil characteristics, infiltration rate and water bearing properties of the unsaturated zone,
- The geological properties and dimensions of each unit in the geological column that could potentially be impacted upon by groundwater contamination. This includes rock type, thickness of aquifer(s) and confining units, aerial distribution, structural configuration, storativity, water levels, and infiltration or leakage rate, if appropriate,
- Aquifer recharge and discharge rates,
- The direction and rate of groundwater movement in potentially impacted units,
- Groundwater and surface water relationships,
- Background water quality of potentially impacted units, and
- Potential sources and types of contamination.

1.2.2.1 Geology of the study area

The Stuart South Block area is underlain by rocks of the Karoo and Transvaal Supergroups. The Karoo sequence comprises a sedimentary succession of sandstones, shales and coal measures. The coal measures are contained within the Middle Ecca Group. The sedimentary succession overlies the Dwyka formation, comprising of diamictites and tillites. The dolomite, as indicated in **Figure 1.2.2.1**, forms part of the Malmani Sub-group of the Transvaal Supergroup.

A number of igneous intrusives of Karoo age of which a number of dolerite dykes have the most profound impact on the geohydrology of the mining area occur to the north-east of the mine lease.

The stratigraphy of the project area may be defined by three (3) main sequences:

- A basal S2 overlain by,
- S4, and
- S5 on top.

The lowermost S1 is not well developed in the project area but has however been identified and documented in fifteen (15) boreholes. The S2 is the most consistently developed coal seam in the area. It is on average 6.5 m thick in the central portion of the coalfield and diminishes in thickness to about 3 meters to the east and west. It reaches a maximum thickness of 14.23 m in the project area of the proposed South Block Colliery. The development of S2 has been under the influence of the palaeofloor topography.

The S3, being very poorly developed in the project area, has not been included in the borehole database constructed by SRK Consultants. S4 generally begins at or close to the roof of S2 with an average thickness of 6.2m and reaching a maximum thickness of 11.9m in the project area.

A simplified geological surface map of the area is presented as **Figure 1.2.2.1**, representing geology as reproduced from the 1:250 000 scale geological map of the area.

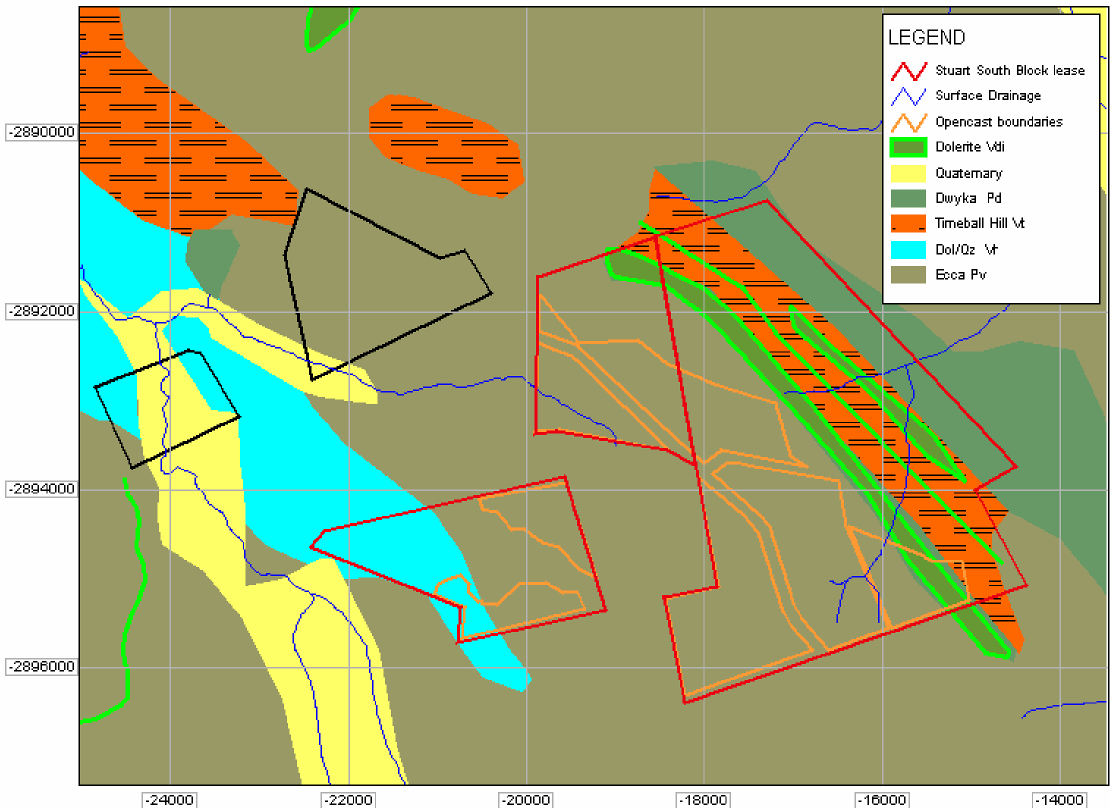


Figure 1.2.2.1: Simplified geological map (1:250 000 scale) of the Stuart South Block area

1.2.2.2 Geophysical investigations

A geophysical investigation was conducted at Stuart South Block during the geohydrological study to delineate geological structures and intrusive features like dolerite dykes. A combination of magnetic and electro-magnetic methods was used during the survey and the geophysical graphs are given in **Appendix A**. Eight monitoring boreholes were sited on anomalies that were identified during the geophysical survey.

The positions of eight geophysical lines are indicated in **Figure 1.2.2.2**.

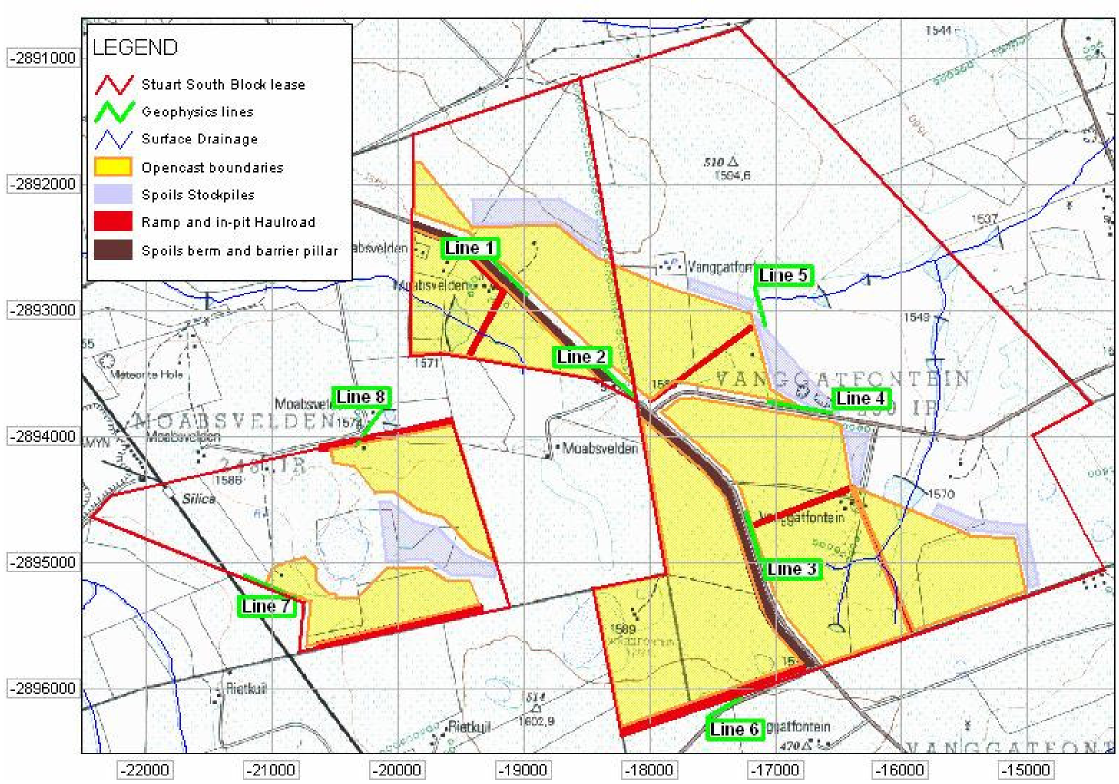


Figure 1.2.2.2: Positions of geophysical traverses

1.2.2.3 Unsaturated zone

Based on most recent geological profile descriptions, the unsaturated zone is composed of soils and colluvium underlain by sandstone, siltstone, shale and coal, followed by diamictite. The unsaturated zone impacts on the aquifer in terms of both groundwater quality and quantity.

The permeability and thickness of the unsaturated zone are some of the main factors determining the infiltration rate, the amount of runoff and consequently the effective recharge percentage of rainfall to the aquifer. The type of material forming the unsaturated zone as well as the permeability and texture will significantly influence the mass transport of surface contamination to the underlying aquifer(s). Factors such as ion exchange, retardation, bio-degradation and dispersion all play a role in the unsaturated zone.

The thickness of the unsaturated zone was determined by subtracting the pre-mining static water levels in the study area from the topography. Water level measurements **(Figure 1.3.1-1)** showed that the depth to water level, and thus the unsaturated zone, generally varies between ± 1 and ± 15 meters below surface (mbs).

Even though the proposed project is a greenfields project, active mining operations surround the mine lease area, which affects the regional groundwater level when mining occurs below the water level. Groundwater abstraction for irrigation, livestock, and domestic purposes and mining also contribute to the lowering of the groundwater level.

Therefore, groundwater levels exceeding ± 15 mbs are considered to be affected by one, or both, of the above mentioned factors.

1.2.2.4 Aquifer delineation

Aquifer delineation is conducted in an attempt to show the boundaries of the aquifer under consideration. Because the main aquifer is a fractured rock type and fractures could assume any geometry and orientation, the physical boundary or 'end' of the aquifer is very difficult to specify or quantify. More appropriately, the aquifer boundary conditions that will be considered during numerical model simulations can be described.

The Stuart South Block aquifer was delineated based on a combination of topographic (water divide) and constant head (rivers) boundaries.

Aquifer boundaries can generally be subdivided in three types, namely:

- **No-flow boundaries** or **watershed areas** (either high or low points) across which groundwater flow is not possible under natural conditions. Apart from topographically controlled no-flow boundaries, **horizontal flow barriers** can also occur in the form of intrusive dykes that are impervious towards horizontal groundwater seepage. Such dykes can form groundwater compartments that can also be considered boundaries of the aquifer,

- **Constant head boundaries** also occur where the head in the aquifer remains constant at all times. Such boundaries are formed by bodies of water that are formed on a consistent basis like large dams and perennial rivers or streams. Such boundaries will not be affected by nearby pumping or mine dewatering – water can be supplied to the aquifer or from the aquifer to the constant head boundary but the water level (head) of the boundary will not change,

- A third type of boundary, namely a **flux boundary**, across which the flow gradient and conductance can be specified, is also possible. The purpose of the flux boundary is to allow groundwater flow into and out of the model grid where it is impractical to extend the grid further away from the area of interest,

In a numerical groundwater model, the same types of boundaries can be simulated, namely no-flow boundaries (groundwater divides), constant head boundaries, and flux boundaries. No-flow boundaries are groundwater divides (high or low areas / lines) across which no groundwater flow is possible. Constant head boundaries are positions in the model where the groundwater level is fixed at a certain elevation and cannot change.

The Stuart South Block model area showing river nodes, flux boundaries, and the estimated aquifer boundary is presented in **Figure 1.2.2.4**.

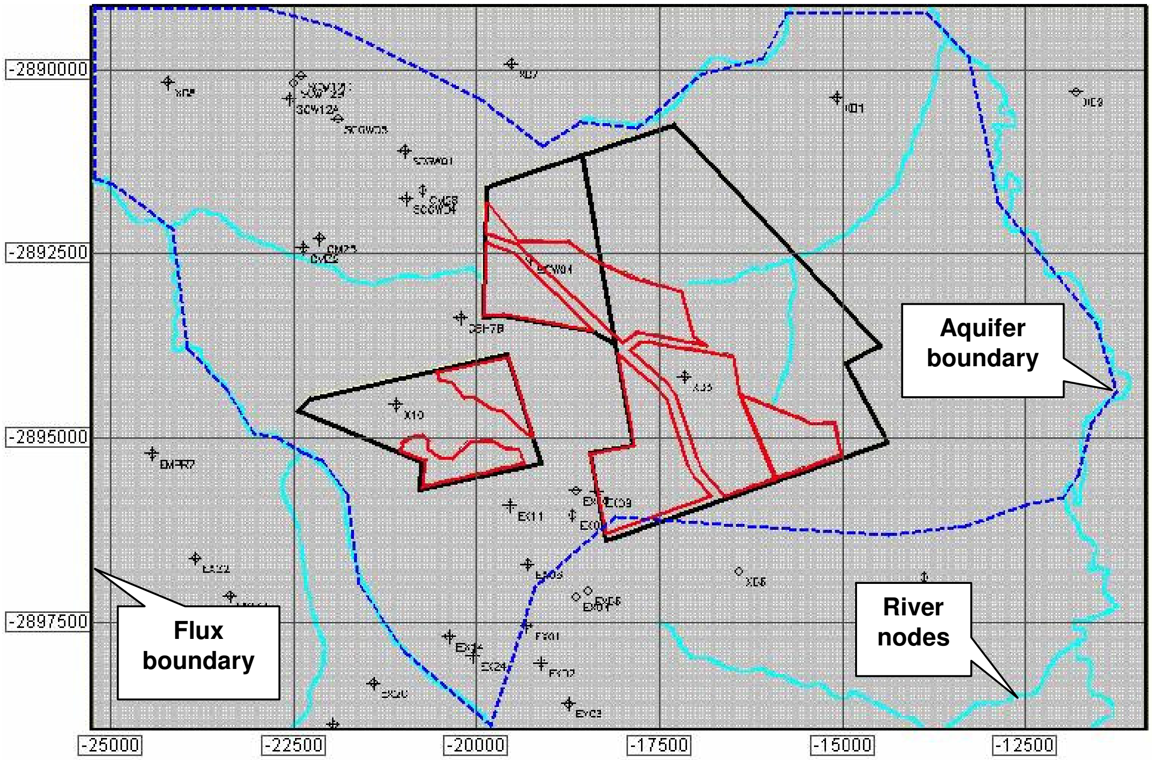


Figure 1.2.2.4: Regional Stuart South Block model area with river nodes and flux boundaries

In the model constructed for the proposed Stuart South Block mining area both flux boundaries and constant head boundaries were used for the simulation. The constant head boundaries were not inserted as constant head nodes in the model but **river nodes** were rather employed on the same elevations and positions where the streams occur near the mining area. The 'rivers' act very much the same as constant head boundaries. Water levels in the aquifer are largely fixed at these points and the river will add water to or remove water from the aquifer if the surrounding model water levels respectively decrease below or rise above the assigned elevation of the river.

1.2.2.5 Aquifer thickness

The aquifer thickness in the coal mining environment is often taken as the difference between the estimated static water level of the aquifer and the base of the lowest mined coal seam. In the vicinity of the Stuart South Block boundary area such an assumption cannot be made because of mainly two reasons:

- Only two monitoring boreholes intersected coal, and
- The main water strikes that were intersected occurred in bedding plane fractures or between rock types of differing consistence.

Additional to these facts, the nature of the fractured rock aquifers combined with the sloping topography and dip of the coal seam will result in very thick ‘aquifers’ in places where the coal is deep and in no ‘aquifer’ whatsoever where the coal reserve outcrops or occurs above the static groundwater level.

Considering the fact that the actual ‘aquifer’ consists of transmissive fractures, fissures or cracks of **any orientation, extent or aperture in any of the rock types** underlying the site, an **assumption can at best be made** on the thickness of the aquifer.

The majority of the monitoring boreholes only intersected seepage water on weathered/fresh contacts during drilling, which varied between 10 and 30 meters below surface. It is considered accurate or appropriate to calculate the aquifer thickness from the piezometric water level to the deepest water yielding fractures in the study area. On the basis of the drilling results during this investigation, the aquifer thickness in the region varies between 10 and approximately 30 meters.

1.2.2.6 Generalised conceptual model

In an attempt to predict the movement of water in the subsurface, a conceptual geohydrological model of the area was postulated. The basis of such a model is the structural geological make-up, water strikes, yields and water levels depth of the study area.

The geohydrological regime of the study area is made up of three aquifer systems. The **first**, the upper, semi-confined aquifer would occur in the relatively softer weathered zone and sometimes on deeper pedological discontinuities (e.g. hardpan ferricrete formations). This aquifer is, however, poorly developed in the study area and only seepage moisture was intersected during drilling. It is concluded that this aquifer only develops during times of high rainfall (e.g. summer months) and is not used as a reliable source of groundwater supply.

Very similar to the weathered zone aquifer in the Stuart South Block area is the abundance of water in the soil profile. If the environmental water balance is considered, it is estimated that only approximately 3% of the mean annual precipitation (MAP) ends up as effective recharge to the aquifer(s). If the direct surface run-off is considered to be in the order of 20% of MAP, it means that the remainder of the MAP exists as water retained in and migrating horizontally through the soil profile, as well as water being lost to evapotranspiration. It is also this moisture/water in the soil and unconsolidated bedrock zone that is considered to contribute most significantly to the water in the surface pans, which are prominent features of the Mpumalanga coal fields.

The **second** aquifer is associated with fractures, fissures and joints and other discontinuities within the consolidated Karoo bedrock and associated intrusives where those are present. The aquifer occurs at depths of between 10 and 30 meters below surface in the study area. Groundwater contamination resulting from the coal mining operations will to a large extent be contained in the Karoo Supergroup rocks as the Dwyka diamictite acts as a natural barrier for groundwater flow and mass transport below the Karoo sediments.

The **third** aquifer system is associated with dolomite that forms part of the Malmani Sub-group of the Transvaal Supergroup. Groundwater flow within the aquifer is restricted to open fractures, fissures, and joints. The one feature that distinguishes the dolomitic aquifer from the Karoo aquifer is its ability to form large dissolution cavities that are capable of storing large volumes of groundwater. Irrigation occurs outside of the mine lease area and is made possible by high yielding boreholes which intersect water bearing cavities within the dolomitic aquifer.

Water entering the system will migrate vertically downwards until a more impervious layer that forms a perched aquifer is encountered. The drilling results indicated that no perched aquifer system is present within the mine lease area. The minority of recharge will remain available to seep downwards into the saturated zone. From there it will migrate in the direction of the hydraulic gradient until it eventually enters surface water bodies (i.e. rivers or springs) from where it will discharge as surface water.

The lateral rate of migration usually exceeds the vertical rate, especially in a sedimentary rock environment where the layers are more or less horizontal.

1.2.3 Presence of boreholes and springs

As mentioned previously, a hydrocensus was conducted in and around the proposed new mining area. As part of the hydrocensus, boreholes and springs were mapped within a ±3 km radius of the proposed mining area. The potential radius of influence on the groundwater regime around a coal mine in Karoo sediments is usually accepted as 1 km. This is subjective, because the radius of influence depends strongly on geological structures such as faults and dykes (preferred groundwater flow paths), groundwater gradients, nearby mining operations and the presence of other groundwater production boreholes or dewatering from mining in the area.

Experience from other coal mines in similar Karoo-type aquifer conditions has, however, indicated that the influences of open pit coal mining activities on the regional groundwater levels are usually not very extensive and usually limited to as little as 0.5 km. The survey radius of around 3 km is thus considered to be totally sufficient for this area.

Different types of groundwater information were obtained for a total of approximately 40 points from a hydrocensus conducted by CSSS as well as previously conducted surveys. During the CSSS hydrocensus the water supply source of each nearby user was sampled and analyzed for macro element inorganic chemistry.

The yields of the 10 monitoring boreholes compare very well with boreholes in Karoo rock aquifer environments and vary from 0 to 2 l/s.

Although the natural trend for the groundwater level or piezometric head is to follow the surface topography, the water level is the closest to surface in the topographically low-lying areas. For this reason, springs will mostly occur in these areas, or at least on the slopes of hills. In perched and confined aquifers however, groundwater or piezometric levels may also be high in topographical higher lying areas with subsequent spring formation.

Evidence of groundwater base flow in the low-lying areas close to the rivers and drainage canals does exist in the wider Stuart Coal mining area. As evident from the topographical map of the proposed mining area, streams usually start forming at elevations between 1 565 and 1 585 mamsl.

The general spring flow discharge elevation is thus around 1 575 mamsl in this area. Please also refer to the discussion on the contribution of soil moisture and water to the environmental water balance where such water is also considered often to be the main contributor to hill-slope wetlands and spring formation.

A short summary of the 10 purpose drilled monitoring boreholes are provided in **Table 1.2.3**. Borehole logs of all the groundwater monitoring boreholes indicating the most important lithological intersections and borehole construction are included in **Appendix B**.

Table 1.2.3: Monitoring borehole summary

BH	Xcoord	Ycoord	Depth (m)	Lithology	WL (mbs)	Yield (l/s)	Water strike (mbs)	Steel casing (m)
SB01	28.80923	-26.14359	31	SOIL, COAL	5.7	0.28	26	24
SB02	28.81778	-26.15091	31	SOIL, SLSN, SNDS, SHLE	2.7	0.16	25	31
SB03	28.82815	-26.16179	31	SOIL, SLSN, SHLE	2.9	0.16	20	24
SB04	28.83169	-26.15271	31	SOIL, SLSN, SHLE	1.7	0.03	12	31
SB05	28.82839	-26.14592	31	SOIL, SNDS, SHLE	7.7	0.04	10	9
SB06	28.82590	-26.17358	31	SOIL, SLSN	6.1	0.08	30	31
SB07	28.79075	-26.16586	20	SLSN, SNDS, DLRT	13.8	0.08	20	10
SB08	28.79797	-26.15458	31	SOIL, SHLE, SLSN	6.4	0.14	25	13
SB09	28.80130	-26.14279	31	SOIL, SNDS, DLRT, COAL	0.9	0.56	11	19
SB10	28.84328	-26.15901	31	SOIL, SHLE, SLSN	5	0.08	11	5

Notes: SLSN - Siltstone
SNDS - Sandstone
SHLE - Shale
DLRT - Dolerite

This geohydrological data, together with water level information is crucial for better understanding of the geohydrological regime and processes that will determine groundwater types, flow and transport velocities and aquifer parameter distribution.

All information gathered from these boreholes was used, where available, in the compilation of applicable parts such as the conceptual and numerical modeling, impact and risk assessments.

Groundwater flow directions are indicated in **Figure 1.3.1-3** with the use of dashed blue lines. Groundwater is not expected to move north and south of the mining areas, as this is the upstream groundwater directions. Because mining will take place below the static groundwater level, groundwater movement will be from the surrounding areas towards the mine voids.

Only after the mine voids have been filled with groundwater and a new water level equilibrium has been established, will the groundwater flow direction return to its original direction. The groundwater monitoring boreholes in the proposed new mining area have therefore been sited radially around the mining areas expected to be influenced by the mining operations.

1.3 GROUNDWATER FLOW EVALUATION

1.3.1 Depth to water level

In the Stuart South Block lease area three interacting aquifer systems were identified, although they are mostly of the same aquifer type.

The **first** system is a shallow aquifer that occurs in the transitional soil and weathered bedrock zone or sub-outcrop horizon. This aquifer generally has a low yield with phreatic water levels sometimes occurring on unweathered bedrock or clayey layers. Yields in this aquifer are low (less than 0.3 l/s) and the aquifer is generally not usable as a reliable groundwater supply source. Spring seepage caused by the shallow water level discharge is sometimes used as a source of livestock water supply.

Where consideration of the shallow aquifer system becomes important is during seepage estimations into open pit voids and mass transport simulations from mine-induced contamination sources because a lateral seepage component in the shallow water table zone in the weathered zone often occurs.

According to the Parsons Classification system, the aquifer is usually regarded as a minor or even a non-aquifer system. By definition, an aquifer is a geological formation or group of formations that can yield groundwater in economical exploitable quantities. Although groundwater seepage does occur in the weathered zone, the yields are very low and this zone cannot really be defined as an ‘aquifer’ according to the true meaning of the term.

The **second** aquifer system is the fractured Karoo rock-type aquifer where groundwater yields, although more heterogeneous, can be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. Fractures may occur in any of the co-existing host rocks due to different tectonic, structural and depositional processes.

Aquifer yields in this system vary from zero to approximately 2 l/s in the Karoo rock types that occur in the Stuart South Block lease area. According to the Parsons Classification system, the aquifer could be regarded as a minor, but often a sole aquifer system.

The **third** aquifer system is associated with dolomite that forms part of the Malmani Sub-group of the Transvaal Supergroup. The one feature that distinguishes the dolomitic aquifer from the Karoo aquifer is its ability to form large dissolution cavities that are capable of storing large volumes of groundwater. Irrigation occurs outside of the mine lease area and is made possible by high yielding boreholes which intersect water bearing cavities within the dolomitic aquifer.

Although the three aquifer types are described for the area, the third deeper dolomitic aquifer will not be affected by mining since mining will occur well above this aquifer. Where the dolomitic rocks occur close to surface or as outcrop, no Karoo sediments remain due to erosion and therefore no coal and associated mining activities.

In fractured bedrock (secondary) aquifers groundwater flow and mass transport are nearly fully restricted to open fissures, cracks, fractures, and in the case of a dolomitic aquifer, in dissolution cavities, in the relatively impermeable host rock matrix. Aquifer thickness, yield and other parameters thus fully depend on the characteristics of these fractures and cavities.

Such characteristics include fracture aperture, extent, orientation, frequency and texture of the fracture-matrix interface. **Figure 1.3.1-1** indicates the positions as well as water level depths of both regional and site-specific boreholes in and around the proposed new mining areas.

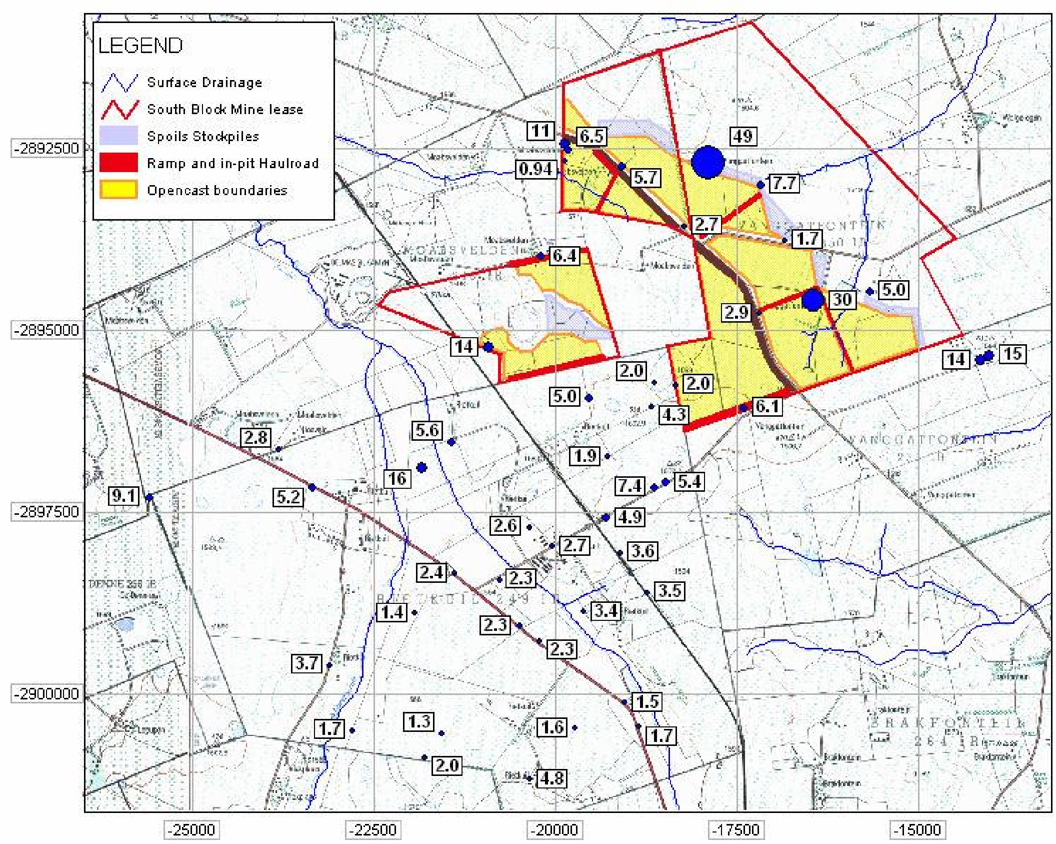


Figure 1.3.1-1: Thematic water level map for the larger Stuart South Block lease area

As evident from **Figure 1.3.1-1**, water levels vary between 1 and 15 mbs. Deeper groundwater levels varying between 15 and 60 mbs were measured towards the west of the mine lease area and are affected by groundwater abstraction for irrigation and mine dewatering.

All available water levels were considered for the surface topography and groundwater level elevation correlation. Because impacts on the natural groundwater level may exist in some areas, only boreholes where the linear correlation between borehole collar elevation exists were used in the estimation. The result of the statistical analysis is presented in **Figure 1.3.1-2**. A correlation of approximately 95% was achieved.

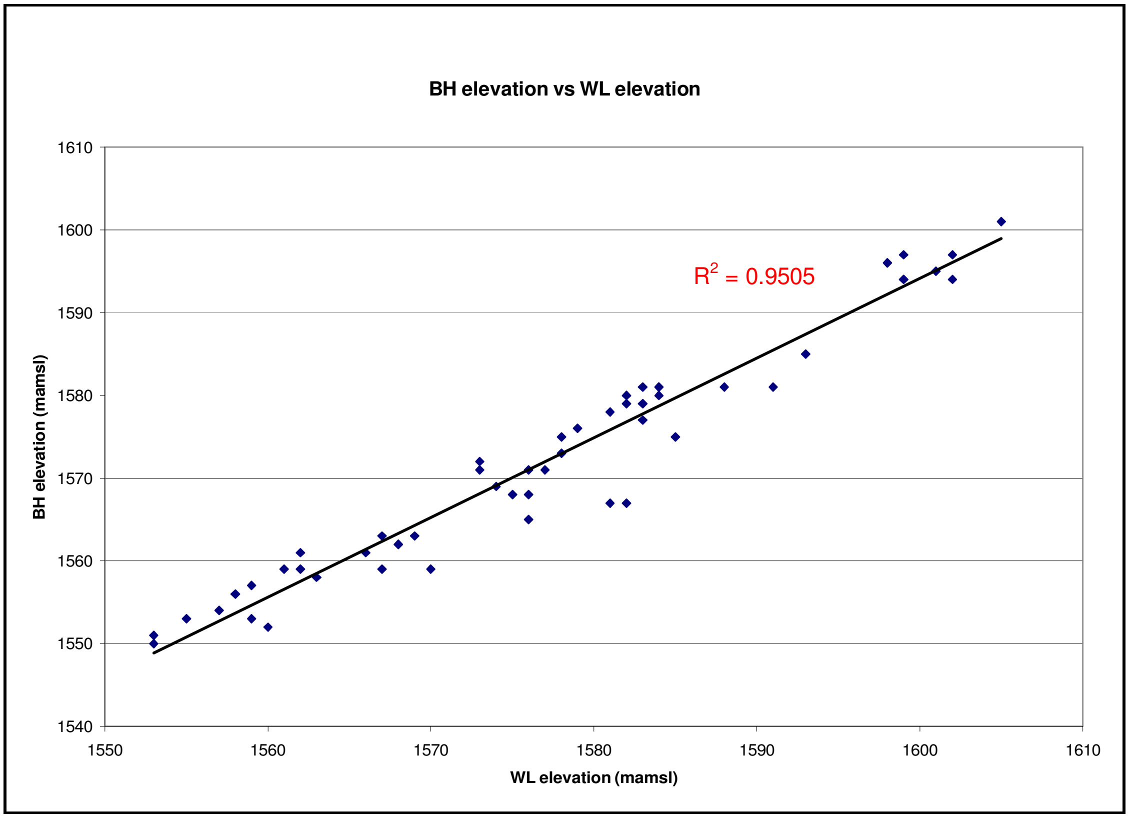


Figure 1.3.1-2: Graph of borehole elevation versus water level elevation: Karoo Aquifer

A static groundwater level map **(Figure 1.3.1-3)** of the area was constructed through the utilisation of the Bayesian interpolation technique whereby the natural relationship between surface topography and depth-to-groundwater level is used to estimate groundwater levels in areas where borehole data is scarce. Steady state calibration of the numerical flow model was also used to generate the static groundwater level map.

For the purpose of numerical modeling, however, some representative average groundwater level has to be specified as a starting point. There are also not enough groundwater level measurements available in each of the co-existing aquifer systems to produce a separate water level contour map for each system.

It is thus likely that over-estimation in some areas and under-estimation of the water level in other areas will arise in the model. With the immense heterogeneous characteristics of fractured rock aquifers, interpolation of the water level with recognized techniques is preferable. The resulting groundwater level contours thus represent **average water levels** expected among an unknown number of co-existing aquifers.

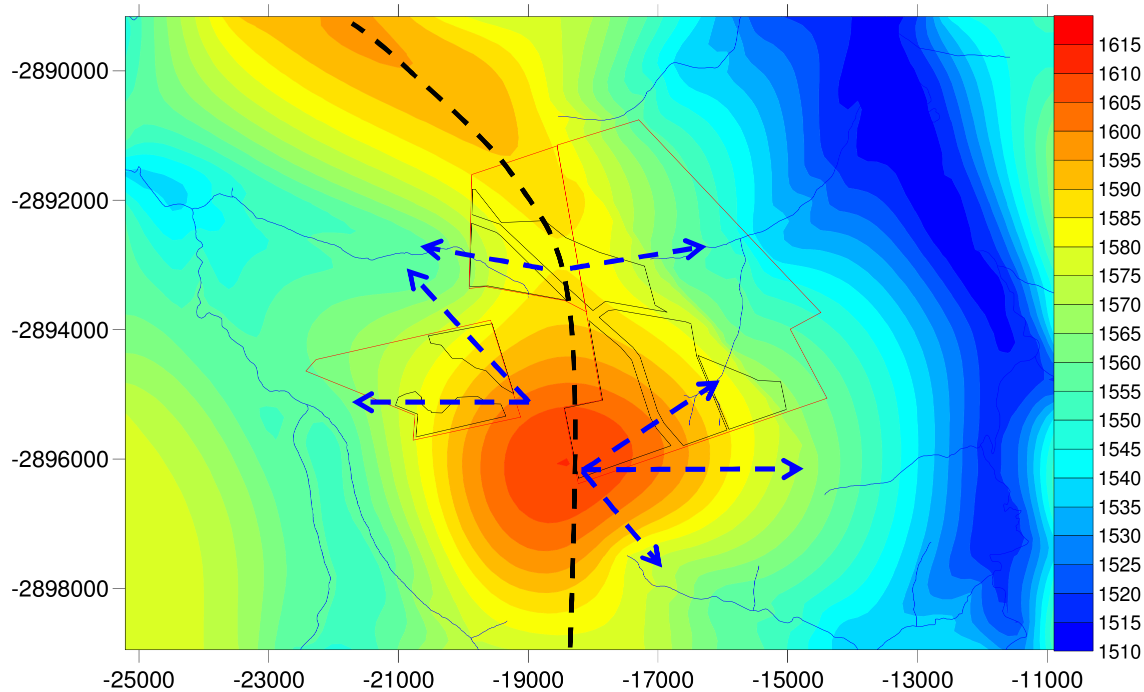


Figure 1.3.1-3: Bayesian interpolated and steady state calibrated water level contour map for the proposed Stuart South Block model area

Main groundwater flow directions as well as the local groundwater divide are indicated in **Figure 1.3.1-3** with the use of dashed blue and black lines respectively. According to **Figure 1.3.1-3** the lowest groundwater level elevation is approximately 1 510 mamsl and occurs to the north-east of the mine lease, while the highest elevation is ± 1 615 mamsl which occurs to the west of the Beta opencast pit.

The groundwater levels in the proposed mining area together with levels measured during the hydrocensus surveys were used as calibration points for the site-specific numerical groundwater model to verify the conceptual model and construction thereof. Seen in the light of water level differences because of the different aquifer systems, filtering and processing of water levels are conducted to remove water levels considered anomalous high or low.

The final interpolated potentiometric surface of the water levels is thus bound to contain local over- or under estimations of the actual water levels but it will be representative of the general regional trend of the static groundwater level.

In Karoo-type sediments like those underlying the proposed mining area, it is generally accepted that the majority of groundwater flow occurs through the bedding plane fractures between the different sedimentary units. In the proposed Stuart South Block lease area the coal-bearing Karoo layers have been preserved as shallow basin-like structures where the bedding mostly dips inwards towards the centre of the basin.

The dip is however often not very significant and usually varies between 0 and 10 degrees. A digital isosurface model of the base of the coal horizon that will be mined at the proposed mining area of Stuart South Block is presented in **Figure 1.3.1-4**. It follows from the contour map that the coal floor in the wider Stuart South Block lease area generally dips towards the south and south-west at gradients of approximately 3.3% and 4.5% respectively.

Coal floor gradients within the wider Stuart South Block lease area are relatively steep, which may lead to the alteration of the natural groundwater flow directions once the coal seams are mined.

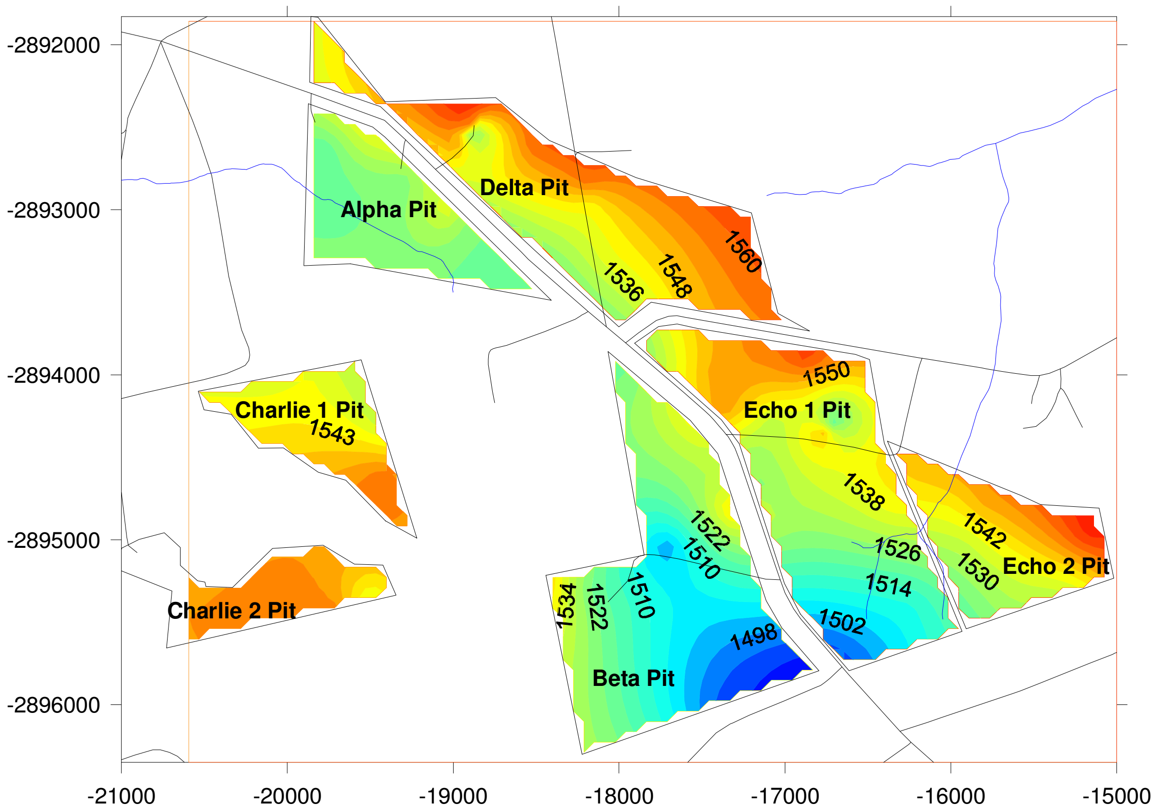


Figure 1.3.1-4: Digital contour model of the base of the 2 Seam

Coal seam elevations were obtained from the consulting geologist at SRK and were used in the numerical flow model simulations and volume/decant calculations.

1.3.2 Flow gradients

Contours of the static water level or piezometric heads in and around the proposed Stuart South Block boundary area is indicated in **Figure 1.3.1-3**. Path lines or flow lines of groundwater particles are lines perpendicular to the contour and is indicated with the use of dashed blue lines.

Flow occurs faster where contours are closer together and gradients are thus steeper. The following groundwater flow directions and gradients were derived from **Figure 1.3.1-3**:

Table 1.3.2: Groundwater flow directions and gradients

Pit area	GW flow direction	GW gradient
Alpha	West	1.2%
Beta	East North-east South-east	1.2% 1.0% 2.1%
Charlie1	North-west	1.5%
Charlie2	West	1.7%
Delta	East West	1.4% 1.2%
Echo1	North-east	2.1%
Echo2	North-east	2.1%

On the relatively steeper sloping hillocks where groundwater gradients are higher (e.g. the NE from Echo 1), groundwater seepage rates are correspondingly higher. Seepage rates on the other hand are much lower in the valley bottoms and flat-lying areas.

1.3.3 Aquifer types and yield

From the drilling results of the new monitoring boreholes as well as numerous other monitoring boreholes and geological exploration boreholes or for domestic and livestock water supply, three possible aquifer types have been found present in the study area. For the purpose of this study an aquifer is defined as a geological formation or group of formations that can yield groundwater in economically useable quantities. According to this definition of an aquifer, only the weathered-fresh interface or fractures in the hard rocks below the weathered zone, as well as dissolution cavities within the dolomites could be defined as aquifers.

The **first** system is a shallow aquifer that occurs in the transitional soil and weathered bedrock zone or sub-outcrop horizon. This aquifer generally has a low yield with phreatic water levels sometimes occurring on un-weathered bedrock or clayey layers. Yields in this aquifer are low (generally less than 0.3 l/s) and the aquifer is not usable as a reliable groundwater supply source on a continuous basis.

Where consideration of the shallow aquifer system becomes important is during seepage estimations into open pit voids and mass transport simulations from mine-induced contamination sources because a lateral seepage component in the shallow water table zone in the weathered zone often occurs. According to the Parsons Classification system, the aquifer is usually regarded as a minor or even a non-aquifer system.

Although groundwater seepage does occur in the weathered zone, the yields are very low and this zone cannot really be defined as an ‘aquifer’ according to the true meaning of the term. The main value and function of the shallow weathered zone ‘aquifer’ lies in the storage and transfer of moisture from rainfall to soil (laterally), vegetation (upwards) and the deeper aquifer (downwards).

The **second** aquifer system is the fractured Karoo rock-type aquifer where groundwater yields, although more heterogeneous, can be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. The aquifer forms in transmissive fractures in the consolidated and mostly impervious bedrock. The fractures may occur in any of the co-existing host rocks due to different tectonic, structural and depositional processes. Aquifer yields in this system vary from zero to approximately 2 l/s in the Karoo rock types that occur in the Stuart South Block mining area.

Yields from this aquifer could be sufficient to supply drinking and sanitation water to mining operations but are too low to use as a source of process water supply. In the boreholes tested as well as surveyed during the hydrocensus, sustainable yields of between 0.1 and 1.5 l/s were determined. According to the Parsons Classification system, the aquifer could be regarded as a minor, but often a sole aquifer system.

The drilling and testing of the monitoring boreholes in the area indicated that the shallow weathered zone aquifer is poorly developed and will mainly manifest during the wetter summer months when significant seepage in the shallow weathered zone occurs. Because of its shallow position and direct interaction with the surface, this aquifer has most characteristics of a primary type aquifer.

The **third** aquifer system is associated with dolomite that forms part of the Malmani Sub-group of the Transvaal Supergroup. Groundwater flow within the aquifer is restricted to open fractures, fissures, and joints. The one feature that distinguishes the dolomitic aquifer from the Karoo aquifer is its ability to form large dissolution cavities that are capable of storing large volumes of groundwater. Irrigation occurs outside of the mine lease area and is made possible by high yielding boreholes which intersect water bearing cavities within the dolomitic aquifer.

In spite of relatively low blow-out yields or being dry altogether, pump tests were performed on all of the new monitoring boreholes, even if they did not show any significant water strikes during drilling. These pump tests were performed using a low yield (± 0.1 l/s) pump with the main aim of determining the transmissivity and storage characteristics of the solid geological formation – the so-called aquifer matrix.

These low rate pump tests are performed instead of the more commonly used slug tests because of the much improved accuracy obtained with the pump tests, resulting in much more reliable aquifer parameters calculated from the tests.

The transmissivity values for boreholes in the proposed open pit mining areas were calculated and averaged **(Table 1.3.3.1)** to use as model input and calibration parameters.

1.3.3.1 Aquifer transmissivity and storativity

Aquifer transmissivity is defined as a measure of the amount of water that could be transmitted horizontally through a unit width of aquifer by the full-saturated thickness of the aquifer under a hydraulic gradient of 1. Transmissivity is the product of the aquifer thickness and the hydraulic conductivity of the aquifer, usually expressed as m^2/day (Length^2/Time).

Storativity (or the storage coefficient) is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in piezometric head. Storativity (a dimensionless quantity) cannot be measured with a high degree of accuracy in slug tests or even in conventional pumping tests. It has been calculated by numerous different methods with the results published widely and a value of 0.002 to 0.01 is taken as representative for the Karoo Supergroup sediments.

As have already been mentioned, aquifer transmissivity and storativity were calculated with the use of low rate pumping tests after the monitoring boreholes were drilled. The results of the analyses are given in **Table 1.3.3.1**.

Fracture transmissivity within the Stuart South Block mine lease vary between 2.9 and 3.4 m^2/d with an average of 3.1 m^2/d, while matrix transmissivity vary between 0.4 and 0.6 m^2/d. Storativity calculated for the mine lease vary between 3.7E-3 and 5.6E-3, which correlates well with the above mentioned values.

Table 1.3.3.1: Calculated aquifer parameters of monitoring boreholes

BH	Te	Tl	Se	Sl
SB01	1.6	0.2	3.9E-03	5.3E-03
SB02	5.5	1.1	1.1E-02	1.4E-02
SB03	3.9	1.5	5.6E-03	7.9E-03
SB04	4.1	0.5	9.3E-03	1.4E-03
SB05	2.1	0.5	6.0E-03	6.4E-03
SB06	2.4	0.3	3.8E-03	7.4E-03
SB07	2.7	0.6	5.9E-03	1.1E-02
SB08	2.1	1.5	4.7E-03	5.1E-03
SB09	19.0	-	5.4E-04	-
SB10	2.7	0.2	5.2E-03	7.5E-03
Har Mean	2.9	0.4	2.9E-03	5.0E-03
Geo Mean	3.4	0.6	4.6E-03	6.3E-03
Average	3.1	0.5	3.7E-03	5.6E-03

Notes:
- *Te* — *Fracture transmissivity,*
- *Tl* — *Matrix transmissivity,*
- *Se* — *Fracture storativity,*
- *Sl* — *Matrix storativity,*
- *Har Mean* — *Harmonic mean,*
- *Geo Mean* — *Geometric mean.*

1.3.3.2 Aquifer recharge and discharge rates

Recharge in the Stuart South Block model area for areas covered by Karoo sediments is estimated as between 1 and 3 % of MAP. Based on this estimate and distribution of rock types, the average natural (steady state) recharge to the modeled area (covered mostly by Karoo sediments) referred to in **Figure 1.2.2.4** is approximately 8 100 m^3/d (2 956 500 m^3/y).

Steady state groundwater discharge to adjacent surface water streams were estimated with the use of the numerical flow model. The results are provided in **Table 1.3.3.2**.

Table 1.3.3.2: Steady state groundwater discharge

Area	GW discharge (m^3/d)	GW discharge (m^3/y)
Tributary of the Bronkhorstspruit – West of Alpha Pit	1	365
Bronkhorstspruit – West of Charlie 1 and Charlie 2 Pits	70	25 550
Tributary of Wilgerivier – East of Delta, Echo 1 and Echo 2 Pits	10	3 650

1.3.3.3 Direction and rate of groundwater movement in potentially impacted areas

The pre-mining groundwater contours and flow directions have been presented in **Figure 1.3.1-3**. These contours represent steady state conditions without impacts from sources or actions other than natural conditions such as rivers, natural spring discharges, pans or wetland recharge areas. Groundwater flow gradients **(Table 1.3.2)** were used to calculate the rate of groundwater movement within the potentially impacted areas:

Table 1.3.3.3: Direction and rate of groundwater movement

Pit	GW flow direction	GW flow velocity (m/d)	Estimated Darcy flux velocity (m/y)
Alpha	West	0.015	5.5
Beta	East	0.015	5.5
	North-east	0.013	4.6
	South-east	0.026	9.6
Charlie1	North-west	0.019	6.8
Charlie2	West	0.021	7.8
Delta	East	0.018	6.4
	West	0.015	5.5
Echo1	North-east	0.026	9.6
Echo2	North-east	0.026	9.6

A large number of manmade actions could impact on the groundwater regime; including the aquifer structure, flow paths and directions, storage, discharges and recharge. Possible impacts relevant to the proposed project will be discussed briefly:

Aquifer structure, flow paths and directions

During active mining and thereafter, the voids created by mining (open cast and underground) will impact on the natural groundwater movement. Mine voids destroy the in situ aquifer structures and could be compared to areas of very high (even infinitely high) transmissivity and also high storativity. Because groundwater will follow the route of least resistance, groundwater will prefer to move through the mined-out areas. Even after the mine has been closed and the mine voids have been backfilled, the transmissivity and storativity remain higher than the pre-mining natural aquifer(s).

Because the Karoo rocks where mining will take place have relatively low transmissivity values, impacts on the natural flow pattern in the Stuart South Block region are expected to be only noticeable in the immediate vicinity of the operations. The extent of the impact depends mostly on the transmissivity of the in situ aquifer material. Karoo type formations in the coal mining environment generally do not have very high in situ transmissivities, as will be confirmed by the pumping tests.

Aquifer discharge
A mining and processing operation may impact significantly on the discharge of an aquifer in different ways. If mining occurs and mine dewatering is required, the natural aquifer discharge will decrease by the volume of groundwater removed by dewatering.

Aquifer recharge may also increase with the use of return water dams, slurry and other dams through leakage of water to the subsurface, especially if water is imported to the project from other sources.

Other factors that may decrease the aquifer recharge are compacted surfaces, haul roads and concrete surfaces that prevent infiltration to the aquifer and decrease groundwater discharge, although increasing surface runoff.

After mine closure, however, recharge is usually higher in the backfilled mine void than in the pre-mining aquifer and after filling up, the discharge is usually higher than before the disruption by mining.

Aquifer recharge
All the aspects mentioned under aquifer discharge apply to aquifer recharge. Opencast mining usually causes an increase in aquifer recharge percentage. Surface water features such as dams (tailings, slurry, process water, storm water, return water etc.) will also usually increase the recharge to the aquifer but compacted or concrete surfaces and roads will decrease the recharge.

1.4 GROUNDWATER QUALITY EVALUATION

Groundwater quality data were evaluated with the aid of diagnostic chemical diagrams and by comparing the inorganic concentrations with the South African Drinking Water Guidelines for Domestic Use **(Table 1.4)**. The groundwater quality data were collected from three sources namely: the analysis of groundwater samples taken from boreholes during the **CSSS hydrocensus survey**, from **previously conducted hydrocensus surveys**, and of newly drilled **monitoring boreholes**.

The four main factors usually influencing groundwater quality are:

- **annual recharge** to the groundwater system,
- **type of bedrock** where ion exchange may impact on the hydrogeochemistry,
- **flow dynamics** within the aquifer(s), determining the water age, and
- **source(s) of pollution** with their associated leachates or contaminant streams.

Where no specific **source of groundwater pollution** is present upstream of the borehole, only the other three factors play a role.

Table 1.4: South African Drinking Water Standards (SANS 241:2005)

Chemical Parameter	Ideal	Recommended	Absolute Maximum
mg/l			
Calcium	0 - 150	150 - 300	300
Chloride	0 - 200	200 - 600	600
Chromium	0 - 0.1	0.1 - 0.5	0.5
Copper	0 - 1	1 - 2	2
EC (mS/m)	0 - 150	150 - 370	370
Fluoride	0 - 1	1 - 1.5	1.5
Iron	0 - 0.2	0.2 - 2	2
Lead	0 - 0.02	0.02 - 0.05	0.05
Magnesium	0 - 70	70 - 100	100
Manganese	0 - 0.1	0.1 - 1	1
Nitrate	0 - 10	10 - 20	20
Potassium	0 - 50	50 - 100	100
Sodium	0 - 200	200 - 400	400
Sulphate	0 - 400	400 - 600	600
TDS	0 - 1000	1000 - 2400	2400

One of the most appropriate ways to interpret the type of water at a sampling point is to assess the plot position of the water quality on different analytical diagrams like a Piper, Expanded Durov and Stiff diagrams. Of these three types, the Expanded Durov Diagram probably gives the most holistic water quality signature.

The characteristics of the different fields will be discussed briefly:

Field 1:

Fresh, very clean recently recharged groundwater with HCO_3 and CO_3 dominated ions.

Field 2:

Field 2 represents fresh, clean, relatively young groundwater that has started to undergo Mg ion exchange, often found in dolomitic terrain.

Field 3:

This field indicates fresh, clean, relatively young groundwater that has undergone Na ion exchange (sometimes in Na - enriched granites or felsic rocks) or because of contamination effects from a source rich in Na.

Field 4:

Fresh, recently recharged groundwater with HCO_3 and CO_3 dominated ions that has been in contact with a source of SO_4 contamination or that has moved through SO_4 enriched bedrock.

Field 5:
Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4 and NaCl mixing / contamination or old stagnant NaCl dominated water that has mixed with clean water.

Field 6:
Groundwater from field 5 that has been in contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock / material.

Field 7:
Water rarely plots in this field that indicates NO_3 or Cl enrichment or dissolution.

Field 8:
Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4, but especially Cl mixing / contamination or old stagnant NaCl dominated water that has mixed with water richer in Mg.

Field 9:
Old or stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans etc) or water that has moved a long time and / or distance through the aquifer or on surface and has undergone significant ion exchange because of the long distance or residence time in the aquifer.

The layout of the fields of the Expanded Durov diagram (EDD) is shown in **Figure 1.4**.

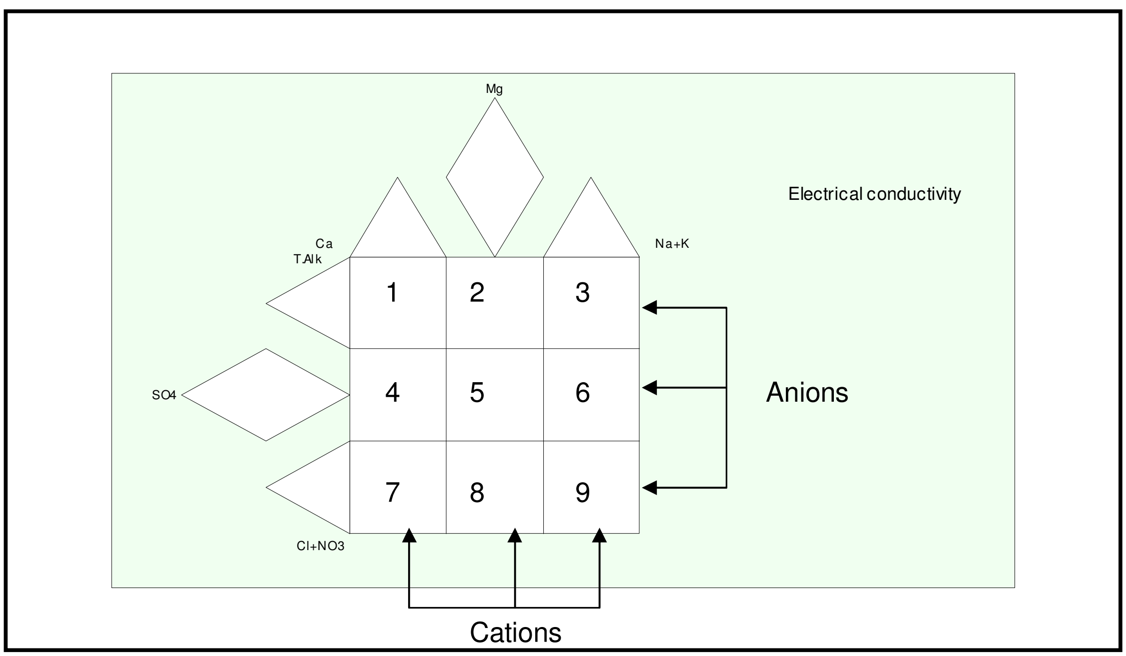


Figure 1.4: Layout of fields of the expanded Durov diagram

Another way of presenting the signature or water type distribution in an area is by means of Stiff diagrams. These diagrams plot the equivalent concentrations of the major cations and anions on a horizontal scale on opposite sides of a vertical axis. The plot point on each parameter is linked to the adjacent one resulting in a polygon around the cation and anion axes.

The result is a small figure / diagram of which the geometry typifies the groundwater composition at the point. Groundwater with similar major ion ratios will show the same geometry. Ambient groundwater qualities in the same aquifer type and water polluted by the same source will for example display similar geometries.

In terms of suitability of the groundwater for agricultural use (irrigation) the SAR diagram (Sodium Adsorption Ratio) is a handy tool to assess the suitability of the water. Sodium enrichment with respect to Ca and Mg in groundwater will present a risk of sodium accumulation in soils (especially when clayey) and cause deterioration in soil structure and increase erodability because of dispersion reactions in the soil. Soils will form surface crusts, compaction rates will increase which will in turn cause poorer infiltration, higher runoff and more erosion.

The typical impacts on groundwater quality caused by coal mining operations include different chemical reactions such as ion exchanges, mobilization and precipitation of ions and / or groups of ions. Sulphate (SO_4) related chemical reaction is one of the most important reactions in this regard and is a fair representation of pollution in coal mines.

SO_4 related reactions take place when it enters the groundwater system through oxidation of pyrite through chemical weathering, mining, washing or percolation through stockpiles of the host material, coal.

An example of a reaction is:

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

Iron sulphate forms, as well as sulphuric acid (H_2SO_4), causing decreases in the pH and mobilization of metal ions (that are usually more soluble at a low pH), the reactions are collectively referred to as "**acid mine drainage**".

As seen from the reaction equation, oxygen is required for the oxidation and consequent acidification to take place. At the pre-mining environment of the proposed Stuart South Block, coal reserves and associated pyrite occur below the static groundwater level and under anaerobic conditions, causing a reducing chemical environment and none of the acid mine drainage reactions to occur.

1.4.1 Regional groundwater quality evaluation

A map showing the distribution of the boreholes where regional groundwater quality information is available is presented in **Figure 1.4.1-1**.

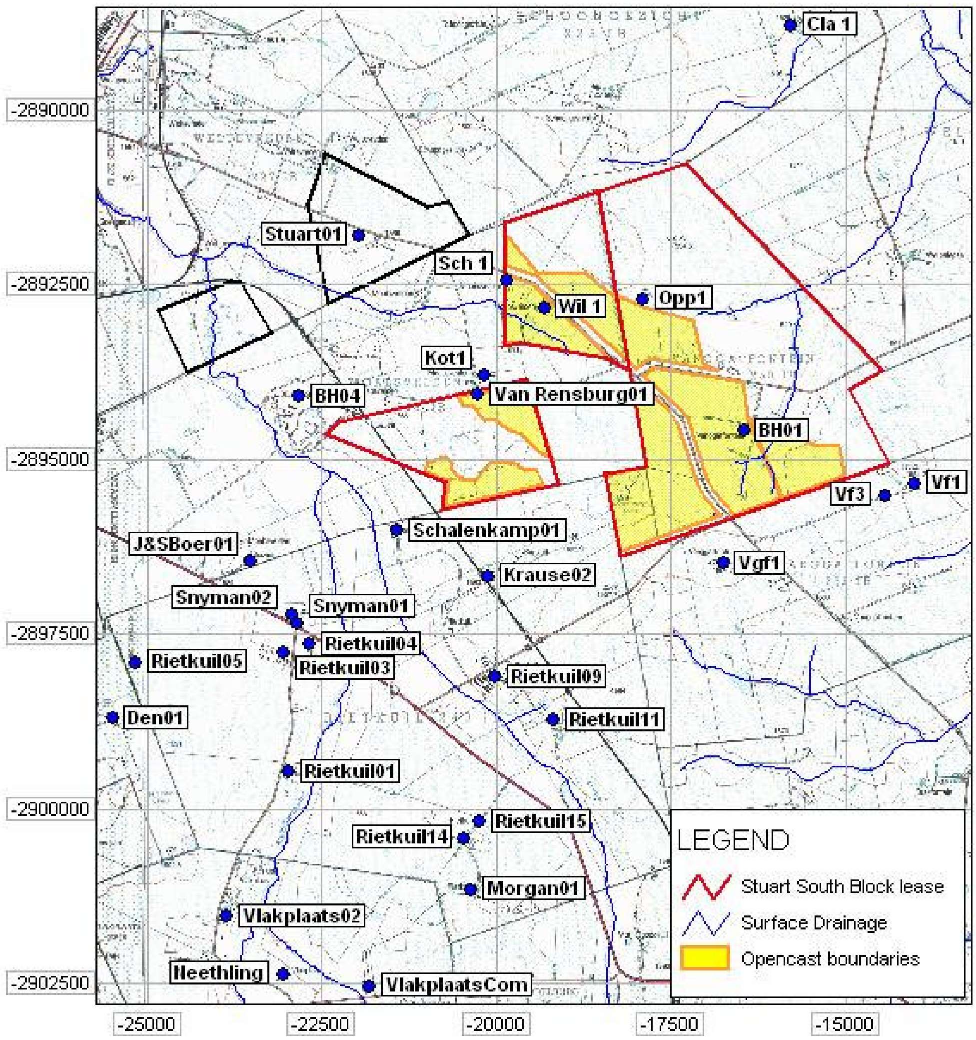


Figure 1.4.1-1: Distribution of regional sampling points

Because only once-off monitoring data exists for many of these points, time-series data, statistical analysis and trend analysis were not possible. The first step in the water quality interpretation was to classify the groundwater quality. The classification was based on the following:

- the spatial distribution of the proposed monitoring points, and
- the proximity of the proposed monitoring points to known pollution sources that are expected to impact on the groundwater and / or surface water in the downstream flow direction area.

Total dissolved solids (TDS) is a good indicator of the overall quality of groundwater. TDS concentrations throughout the study area are all well within the ideal limits for domestic use and vary between 30 and 570 mg/l. The reason for the good ambient quality is the fact that groundwater quality impacts from existing mining areas are limited to within a few hundred meters from the mines due to the overall low aquifer transmissivity.

The average rainfall is in the order of 700 mm per year and even with a low effective **recharge percentage,** a good natural groundwater quality is to be expected since active recharge occurs and stagnation of groundwater in aquifers is very uncommon.

The hydraulic conductivities of the bedrock in the vicinity of the boreholes are usually in the order of 10^{-3} m/d. Such conductivities should facilitate a sufficient flow rate to prevent stagnant groundwater conditions, especially where groundwater gradients are higher such as along sloping topography. As with similar aquifers in the Karoo Supergroup a significant proportion of groundwater seepage does not go down vertically to the solid bedrock zone but drains horizontally in the weathered zone between approximately 0 and 10 m below surface.

Aquifer flow dynamics, in spite of the relatively low matrix transmissivities, does appear to be sufficient to facilitate the existence of fresh groundwater in the Stuart South Block area. A slight deteriorating trend occurs when moving from the topographical higher to the lower lying areas. This slight increase in inorganic ion content is owed to ion exchange reactions occurring from the moment that recharge enters the land surface and continues all the way down the geohydrological cycle. The groundwater infiltrates the subsurface and aquifer, thereby coming into contact with different rock types where different degrees of ion exchange occur. The seepage rate (caused by groundwater gradient, storativity and transmissivity), the type of aquifer host rock and the prevailing redox conditions determine the degree of ion exchange that will take place.

In none of the boreholes does the **type of bedrock** in which the aquifer occurs seem to significantly impact on the chemical composition of the groundwater. If groundwater salinities or indicator parameters are plotted against the backdrop of the regional geology, no clear correlation between groundwater quality and geology is discernible. For this reason the geology of the study area can be described as being inert.

The only slight trend that does seem to apply is the fact that boreholes nearer to the valley bottoms – i.e. the watercourses – seem to have slightly higher overall salinities. The boreholes on the upper slopes of the undulating topography generally have low salinities especially when occurring on Karoo rock types where massive sandstone dominates.

The reason for such distribution is simply the fact that higher recharge usually occurs on the upper slopes and the water quality has the closest resembles to recharging rain water. While seeping through the aquifer under influence of hydraulic gradient, groundwater undergoes ion exchange and becomes progressively more saline. Water that has moved from the upper slopes to the valley bottoms arrive at lower hydraulic gradients, meaning that residence time in the aquifer becomes longer and more time still is available for ion exchange.

Groundwater pH throughout the study area varies between 6.6 and 8.8, which is within the ideal ranges for domestic use. Most metals are insoluble under such neutral conditions, which explain the low iron concentrations throughout the study area. The majority of the inorganic chemical parameters are within the ideal and recommended ranges.

When numerous pollution sources occur within an area the Expanded Durov diagram is expected to show groundwater qualities in nearly all nine fields of the diagram. As no sources of pollution occur within the nearby vicinity of the proposed Stuart South Block lease area one expect the groundwater qualities not to be distributed over all nine fields of the diagram.

According to **Figures 1.4.1-2** and **1.4.1.-3** the following types of groundwater is present within the immediate vicinity of the proposed Stuart South Block:

- The majority of the CSSS hydrocensus boreholes plot within **field two** of the EDD. Field two represents young, recently recharged groundwater of which calcium cations was exchanged with magnesium cations. The groundwater is dominated by magnesium cations and bicarbonate alkalinity,
- The majority of the boreholes surveyed during previous studies plot within **fields two**, **three**, and **five** of the EDD. Field three represents relatively young groundwater that is dominated by sodium/potassium cations and bicarbonate alkalinity. Magnesium cations were exchanged with sodium/potassium cations,
- Field 5 o the EDD represents groundwater dominated by magnesium cations and sulphate anions. The dominance in sulphate might indicate the presence of acid mine drainage reactions.

Summary:

- The regional groundwater is of good quality and is suitable for human consumption,
- Neutral groundwater pH conditions and low iron and sulphate concentrations indicate the absence of acid mine drainage reactions,
- The dominance in sulphate in boreholes J&SBoer01, R222, EX03, and Rietkuil03 **(Figure 1.4.1-3)** seems to be the result of slightly lower bicarbonate alkalinity, rather than sulphate rich contamination as a result of acid mine drainage reactions.

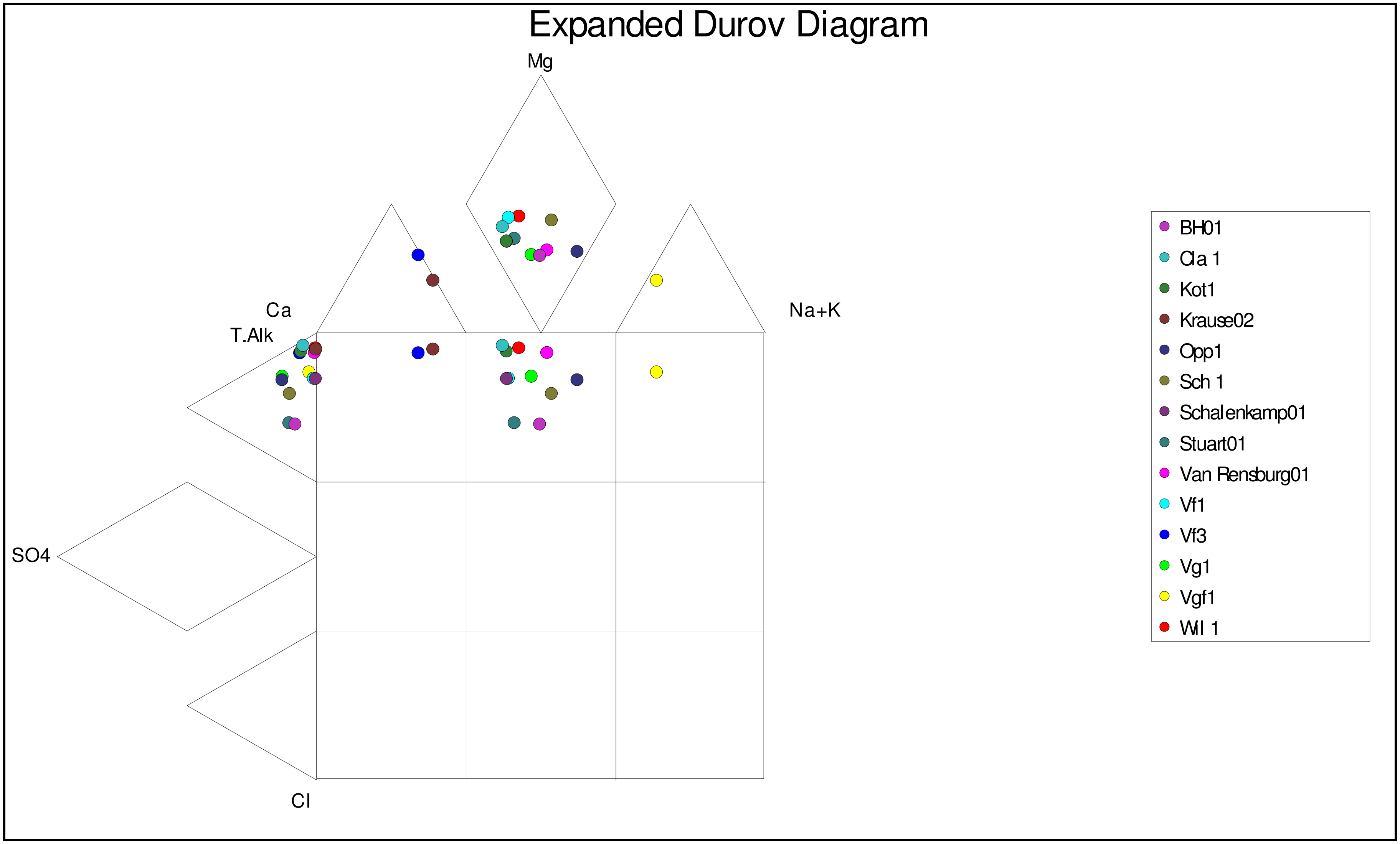


Figure 1.4.1-2: Expanded Durov diagram of CSSS hydrocensus survey

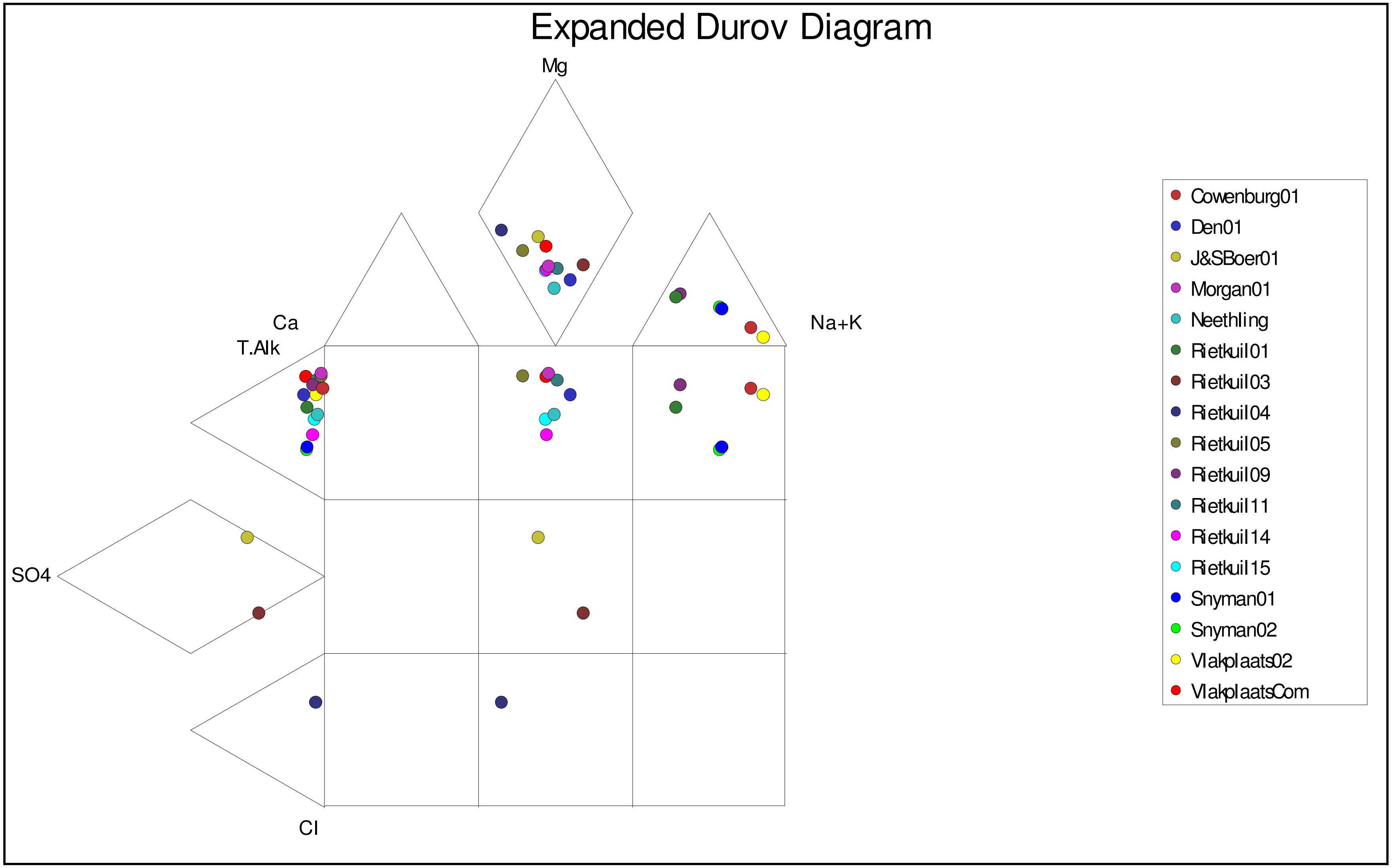


Figure 1.4.1-3: Expanded Durov diagram of previous hydrocensus surveys

1.4.2 Site specific groundwater quality evaluation

As mentioned previously, a total of 10 new boreholes were drilled strategically in order to sufficiently cover the area with monitoring boreholes **(Figure 1.4.2-1)**. The boreholes were sampled after drilling after which all macro inorganic chemical elements were analysed for. Only those elements that are expected to occur within a coal mining environment will be discussed such as total dissolved solids (TDS), sulphate, nitrate, iron, pH, and sodium.

The mine lease area is undisturbed by coal mining activities and groundwater is expected to be of good quality.

Because the newly drilled monitoring boreholes have only been sampled once, concentration trends cannot be identified, neither can conclusive explanations be given for possible anomalies.

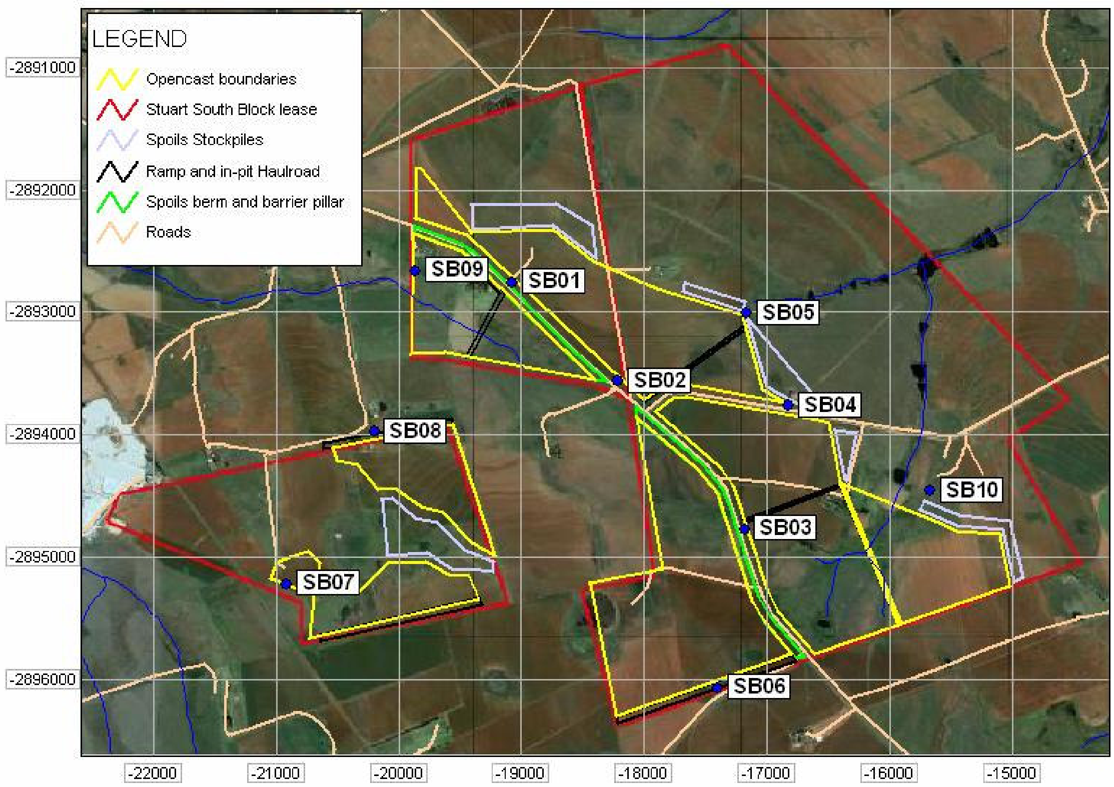


Figure 1.4.2-1: Distribution of monitoring borehole sampling points

All of the above mentioned chemical parameters are well within the ideal limits for domestic use. Basic groundwater pH conditions varying between 6.7 and 8.1, together with low iron and sulphate concentrations are all indicators of the absence of acid mine drainage reactions.

According to **Figures 1.4.2-2** and **1.4.2-3** a single type of groundwater is present within the mine lease area, namely groundwater dominated by magnesium cations and bicarbonate alkalinity. The groundwater chemistry of all 10 monitoring boreholes plot within **field two** of the EDD, which represents fresh, recently recharged groundwater of which the calcium cations were exchanged with magnesium in the geohydrological cycle.

Summary:

- The site specific groundwater is of excellent quality and is suitable for human consumption,
- Basic groundwater pH conditions together with low iron and sulphate concentrations are clear indicators of the absence of acid mine drainage reactions,
- The plotting position of groundwater chemistries within field 2 of the EDD indicates the existence of sufficient groundwater gradients and hydraulic conductivities to prevent groundwater stagnation within the aquifer.

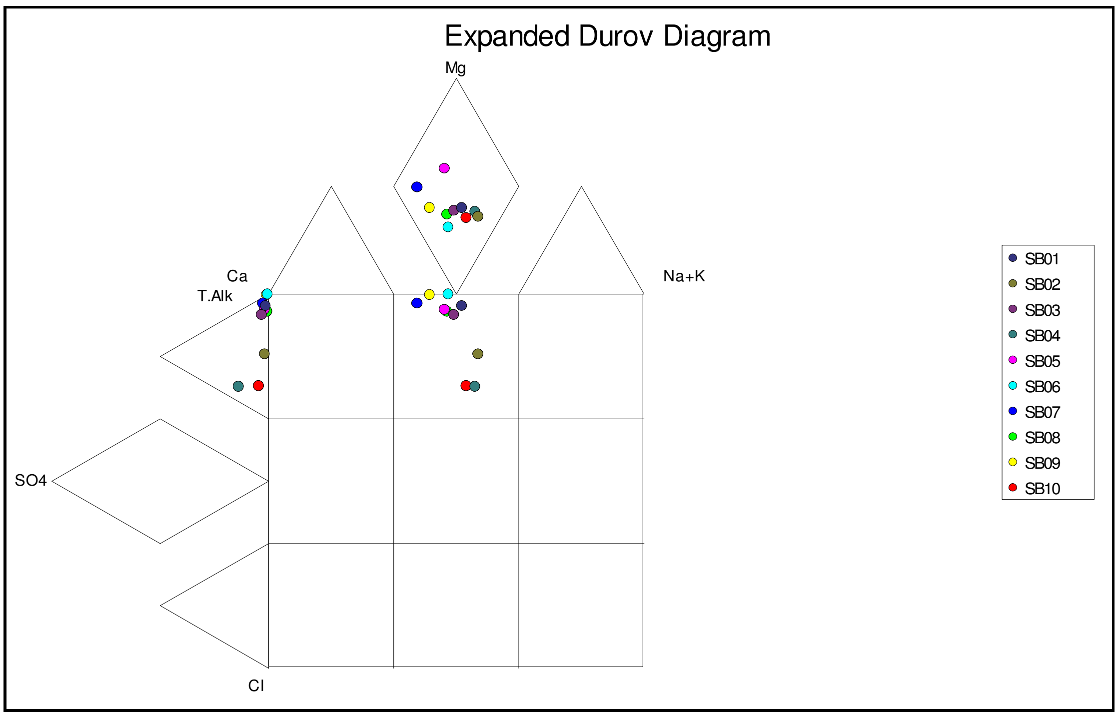


Figure 1.4.2-2: Expanded Durov diagram (EDD) of site specific groundwater qualities

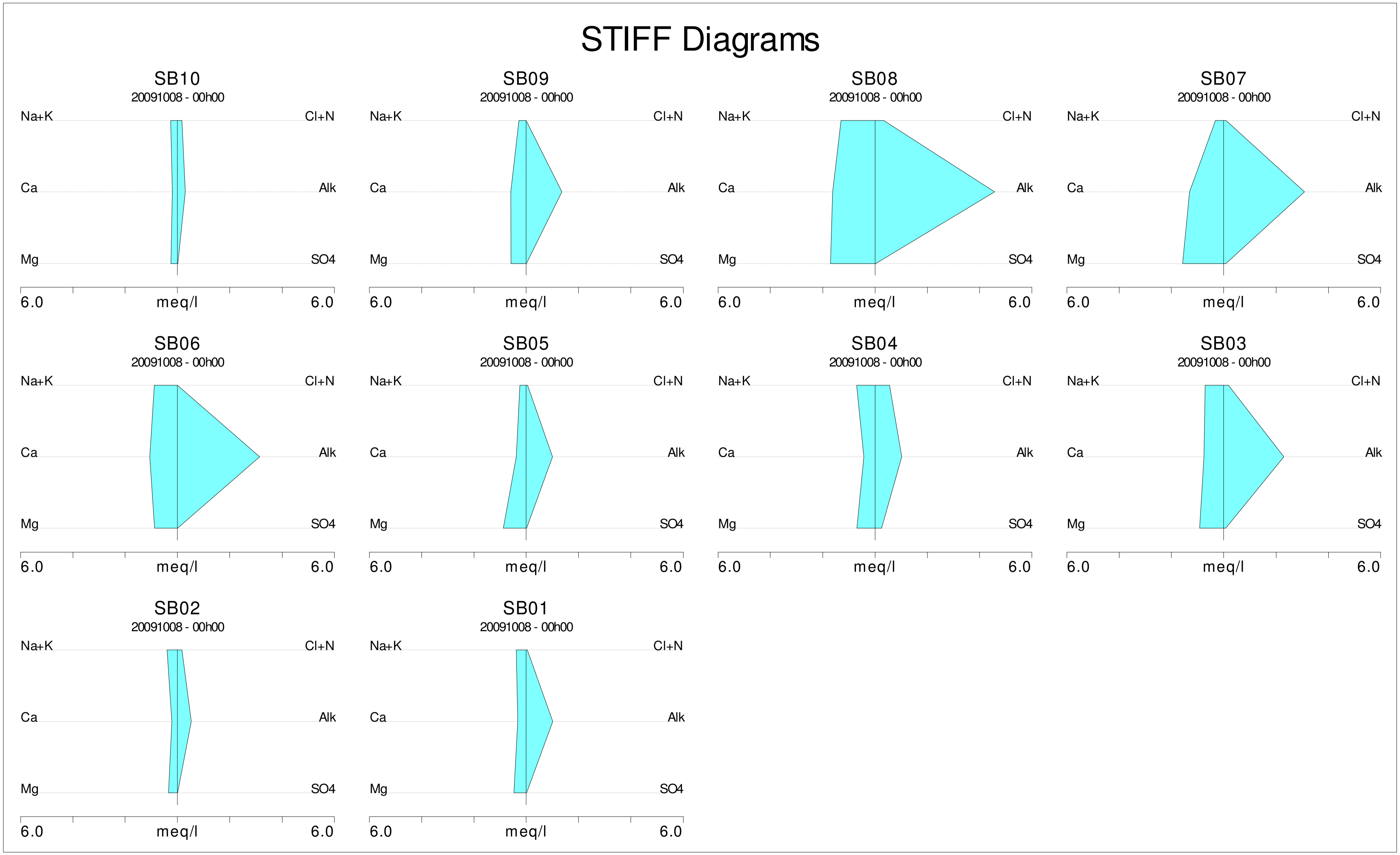


Figure 1.4.2-3: Stiff diagrams of site specific groundwater qualities

2 ENVIRONMENTAL IMPACT ASSESSMENT AND MITIGATION MEASURES FOR THE PROPOSED STUART SOUTH BLOCK COAL MINE

This part of the geohydrological input to the EMP report describes and evaluates the potential impact of the proposed Stuart South Block opencast mining project on the environment. The management program proposed for the proposed new mining areas from a geohydrological perspective will also be discussed in this section. Generic aspects will be discussed together but aspects pertaining to one project specifically will be discussed as such with the specific areas.

Stuart Coal accepts all implications in terms of the legally binding nature of all commitments made and management measures described in this specialist study for the EMP document.

Stuart Coal is further also committed to rehabilitating the proposed new mining areas (Western and Eastern mining blocks) in a responsible manner, with a balanced approach by adequately managing negative environmental impacts to within acceptable limits. Remediation of negative impacts will, as far as possible, be based on the principle of Best Environmental Option (BEO), with the implementation of technically proven and acceptable rehabilitation measures. New techniques will be evaluated when they become available and will be implemented should they prove effective within financial constraints. The evaluation of impacts is conducted in terms of the following criteria:

Extent	
Site	Effect limited to the site and its immediate surroundings.
Local	Effect limited to within 3 – 5 km of the site.
Regional	Effect will have an impact on a regional scale.
Duration of impact	
Short	Effect lasts for a period 0 to 5 years.
Medium	Effect continues for a period between 5 and 10 years.
Long	Effect will cease after the operational life of the activity either because of natural process or by human intervention.
Permanent	Where mitigation either by natural process or by human intervention will not occur in such a way or in such a time span that the impact can be considered transient.
Probability	
Improbable	Less than 33 % chance of occurrence.
Probable	Between 33 and 66 % chance of occurrence.
Highly Probable	Greater than 66 % chance of occurrence.
Definite	Will occur regardless of any prevention measures.

Significance of impact	
Low	Where the impact will have a relatively small effect on the environment and will not have an influence on the decision.
Medium	Where the impact can have an influence on the environment and the decision and should be mitigated.
High	Where the impact definitely has an impact on the environment and the decision regardless of any possible mitigation.
Status	
Positive	Impact will be beneficial to the environment.
Negative	Impact will not be beneficial to the environment.
Neutral	Positive and negative impact.

It must be noted that many of the potential negative consequences can be mitigated successfully. It is however, necessary to make a thorough assessment of all possible impacts in order to ensure that environmental considerations are taken into account, in a balanced way, as far as possible, supporting the aim of creating a healthy and pleasant environment.

2.1 LAND CLEARANCE

The following land clearance activities will take place during the construction and operational phases:

- Vegetation clearance,
- Topsoil and sub-soil stripping and stockpiling.

2.1.1 Construction Phase

2.1.1.1 Potential impacts

The **stripping and stockpiling** of topsoil and subsoil from the pit and infrastructure surface areas is considered negligible since no chemical interaction is envisaged that could have an adverse impact on groundwater quality.

2.1.2 Operational Phase

2.1.2.1 Potential impacts

The **stripping and stockpiling** of topsoil and subsoil from the pit and infrastructure surface areas is considered negligible since no chemical interaction is envisaged that could have an adverse impact on groundwater quality.

Groundwater Impact Rating: Land Clearance
Extent of groundwater impact
Duration of operation impact on groundwater
Probability of impact on groundwater
Significance of impact on groundwater
Status of impact on groundwater

2.2 CONSTRUCTION OF SURFACE INFRASTRUCTURE

The following infrastructure will be constructed during the construction phase:

- Access and haul roads to the opencast voids,
- Storm water control measures (e.g. berms and trenches),
- Water pollution management system (including pollution control dam(s)),
- Attenuation dam to accommodate the river diversions associated with the Leeuwpan Colliery and Alpha Open Pit of the proposed South Block Colliery, and
- Stockpiles (topsoil, subsoil and waste rock stockpile).

2.2.1 Construction Phase

2.2.1.1 Potential impacts

The construction of **access and haul roads** will cause a very small reduction in recharge due to the compaction of the surface of the roads and the foundation layer of the hard rock stockpile area. This impact is countered by the fact that the runoff water will contribute to the catchment yield.

Seepage from carbonaceous material may be acidic, which will mobilise metals and degrade the quality of groundwater when entering the groundwater system. Therefore, any construction undertaken with carbonaceous material can be viewed as a potential source of groundwater pollution.

Seepage from any infrastructure constructed for the purpose of retaining water is inevitable unless properly lined. Seepage from such structures will cause mounding of the groundwater level directly underneath the structure.

2.2.1.2 Management objectives and principles

- To prevent the generation of poor quality leachate,
- To prevent poor quality seepage from entering the groundwater system,
- The size of compacted areas must be minimized as far as practically possible,
- Should it be found that the yield and quality of surrounding users are affected due to the proposed construction phase activities, an alternative water resource will be provided to replace the loss. A number of groundwater users in the vicinity of the proposed Stuart South Block area were identified during the user survey.

2.2.1.3 Management activities or mitigation measures

- No construction of any water management measures, such as the storm water management berms or the haul roads will be undertaken with carbonaceous material,
- All dams will be lined in an effort to prevent poor quality seepage from entering the groundwater system.

Groundwater Impact Rating: Construction of Infrastructure
Extent of groundwater impact
Duration of operation impact on groundwater
Probability of impact on groundwater
Significance of impact on groundwater
Status of impact on groundwater

2.3 UTILISATION OF SURFACE INFRASTRUCTURE

The following activities will take place during the operational phase:
- Utilisation of access and haul roads,
- Utilisation of storm water control measures,
- Utilisation of water pollution management system, which involves the containment and re-use of contaminated water within isolated dirty water management areas, as well as the storage and disposal (or removal) of liquid and solid hazardous and non-hazardous waste,
- Utilisation of attenuation dam,
- Utilisation of stockpiles.

2.3.1 Operational Phase

2.3.1.1 Potential impacts

Poor quality seepage emanating from the pollution control dam/s is inevitable and will have the following consequences on the local groundwater regime:
- groundwater mounding directly underneath the dam,
- downstream movement of a pollution plume within the weathered zone aquifer.

2.3.1.2 Management objectives and principles

- To minimize seepage, prevent contact between clean and dirty areas, and to recycle contaminated water.
- All contaminated water will be contained for re-use and evaporation.
- To minimize the extent of disturbance of the aquifer.
- To prevent degeneration of groundwater quality, and

- To manage the anticipated impacts associated with the inflow of groundwater to the opencast pits.

2.3.1.3 Management activities or mitigation measures

- Wastage of coal-bearing material outside the allocated dirty water management area during the operational phase will be prevented. Haul roads and other compacted surfaces will be kept free of carbonaceous material by cleaning spillages, thereby reducing infiltration of contaminated water,
- Dirty water will be contained in fit-for-purpose designed facilities, which will limit infiltration of contaminated water to the groundwater,
- Water accumulating in the in-pit sump areas will be pumped to the pollution control dam/s to limit the quality related impacts,
- Clean surface water will not come into contact with dirty water or coal bearing material.

Groundwater Impact Rating: Utilisation of Infrastructure
Extent of groundwater impact
Duration of operation impact on groundwater
Probability of impact on groundwater
Significance of impact on groundwater
Status of impact on groundwater

2.4 Development of initial Box-cut and the progression of mining cuts

The following activities will take place during the construction and operational phases:

- Development of the initial box-cut, including blasting, the removal and separate storage of overburden from the initial box-cut opencast area(s) to expose coal layer to be mined,
- Progressive development of mining cuts, including blasting, the removal of overburden, the extraction of coal, and relocation of some of the water management measures, if required, as the box-cut advances.

2.4.1 Construction Phase

2.4.1.1 Potential impacts

With the construction of the **initial box-cut**, dewatering of the aquifer will begin to occur, but only within the immediate vicinity of the box-cut.

The aquifer structure will be destroyed within the immediate vicinity of the box-cut.

2.4.1.2 Management objectives and principles

Not applicable.

2.4.1.3 Management activities or mitigation measures

The dewatering of the aquifer within the immediate vicinity of the pits cannot be prevented, unless the groundwater level elevation is below the base of the mine.

The destruction of the aquifer structure as a result of the construction of the box-cut cannot be prevented.

2.4.2 Operational Phase

2.4.2.1 Potential impacts

The degree of aquifer dewatering depends on the extent and depth of the opencast pits.

During the operational phase the open pit mining will be active which will cause the dewatering of the surrounding aquifer(s). The cone of depression should not exceed a distance of 2 km (confirmed by the numerical groundwater model) from the mining area, thus the impact will be limited. The larger than normal cone of depression is the result of the deep mining activities and the long mining period, which stretches over a time period of 148 years.

Lowering of the groundwater levels will affect availability of groundwater for domestic and stock watering use to all groundwater users within ±2 km radius. No large scale irrigation occurs in the vicinity of the proposed Stuart South Block pits and no significant impact on any such user is expected.

No acid base accounting was conducted on carbonaceous material within the Stuart South Block lease area. Samples submitted for acid-base accounting on Stuart East and also the surrounding coal fields indicate that variable potential for acid generation exists. Experience in the coal mining environments where variable potential for acid generation exists have shown that it is best to assume worst case conditions for after closure, thus to assume that the mine will eventually turn acid and plan accordingly. Even if the mine will not turn significantly acid, the recovering mine water and eventual decant will be saline and would not be permitted to be released into the receiving surface water environment.

The impact on salinity levels of the aquifer is expected to be intermediate during the operational phase, since any groundwater ingress into the pits will be pumped out. Because of the flow towards the pit, groundwater contamination of surrounding users cannot take place while the pits are still operational, unless a significant groundwater sink is generated through large scale groundwater abstraction or mine dewatering to deeper levels nearby.

Affected storm water runoff will be contained in the purpose-built containment facilities. Some quality impacts may still be registered on the weathered zone aquifer. In general, pollution migration will be slow because of low transmissivities.

It is expected that the sulphate concentration of the water in the evaporation pond could be between 500 and 1000 mg/l during the operational phase due to relatively short contact time with carbonaceous material.

2.4.2.2 Management objectives and principles

No management action is available to prevent dewatering.

Drains and cut-off trenches (storm water management system) around the proposed opencast pits will be implemented before commencing with pit development to prevent clean run-off water from entering the pit.

2.4.2.3 Management activities or mitigation measures

The dewatering of the aquifer system cannot be prevented. If the monitoring program indicates that nearby groundwater users are affected by the dewatering, the users need to be compensated for the loss.

Groundwater Impact Rating: Development of the box-cut and progression of mining cuts
Extent of groundwater impact
Duration of operation impact on groundwater
Probability of impact on groundwater
Significance of impact on groundwater
Status of impact on groundwater

2.5 TRANSPORTATION OF COAL

The following activities will take place during the operational phase:

- Hauling of coal via road to the Weltevreden Beneficiation Plant, after which it will be hauled via road to the Grootvlei Power Station.

2.5.1 Operational Phase

2.5.1.1 Potential impacts

A very small reduction in recharge will result due to the compaction of the surface of the roads relating to the hauling of coal. This impact is countered by the fact that the runoff water will contribute to the catchment yield.

Since all contaminated surface water runoff from haul road areas will be collected in the dirty water management system, infiltration of contaminated water will be minimized.

2.5.1.2 Management objectives and principles

To ensure that contaminated surface water runoff from haul roads do not come into contact with clean surface water runoff, or infiltrate into the groundwater system.

2.5.1.3 Management activities or mitigation measures

All contaminated surface water runoff from haul road areas will be collected in the dirty water management system, which means that the infiltration of contaminated water will be minimized.

Groundwater Impact Rating: Transportation of coal
Extent of groundwater impact
Duration of operation impact on groundwater
Probability of impact on groundwater
Significance of impact on groundwater
Status of impact on groundwater

2.6 REHABILITATION

The following activities will take place during the operational and decommissioning phases:

- Concurrent backfilling (including in-pit disposal of mine waste) and rehabilitation of mined-out opencast areas and any other redundant disturbed surface land use areas,
- Backfilling of the final void, depending on the outcome of the long-term groundwater management strategy,
- Levelling of remaining in-pit spoils, shaping and landscaping of rehabilitated areas (the shaping and landscaping of the rehabilitated areas will be specific to conform with the Closure objectives set for the rehabilitated mining surface in terms of both water management aspects and the re-establishment of catchment areas for the pans),
- Removing carbonaceous material from disturbed land use areas for disposal into the final void (below the pre-mining coal level), depending on the long-term groundwater management strategy,
- Demolishing and rehabilitation of redundant surface infrastructure, such as pollution control facilities, depending on the long-term groundwater management strategy and agreed end land use,
- Exotic and invasive plants will be removed, and the re-establishment of such species within the rehabilitated areas will be prevented,
- Final rehabilitation, including the placement of topsoil and establishment of vegetation on rehabilitated areas,
- Aim to establishment a sustainable and agreed end land use through final rehabilitation.

2.6.1 Operational Phase

2.6.1.1 Potential impacts

The rehabilitation of the mine voids will have a positive effect on the groundwater system.

2.6.1.2 Management objectives and principles

- To limit the availability of oxygen in the mine voids, in an effort to minimise the occurrence of acid mine drainage,
- To minimise groundwater recharge that will eventually lead to decant of poor quality mine water.

2.6.1.3 Management activities or mitigation measures

The mine voids are continuously backfilled as the opencast pits progress with time.

2.6.2 Decommissioning Phase

2.6.2.1 Potential impacts

The rehabilitation of the final mine voids and disturbed surface areas will have a positive effect on the groundwater system.

2.6.2.2 Management objectives and principles

To return the post-mining groundwater system to its original pre-mining conditions.

2.6.2.3 Management activities or mitigation measures

As discussed in section 2.6.

Groundwater Impact Rating: Rehabilitation
Extent of groundwater impact
Duration of operation impact on groundwater
Probability of impact on groundwater
Significance of impact on groundwater
Status of impact on groundwater

3 RESIDUAL IMPACTS AFTER CLOSURE

This section is included in the groundwater impact study since the most significant negative impact of the coal mining operation on the groundwater environment occurs after the mine has closed and after it has been rehabilitated. Some of the impacts are described from the operational phase through to after closure to illustrate changes in the water balance and flow conditions.

The following possible impacts are generally associated with closure of coal mining projects:

- Deterioration of groundwater quality within the back-filled opencast mine workings due to acid mine drainage reactions.
- Downstream movement of a deeper groundwater pollution plume.
- Opencast pits will decant into the shallow aquifer or on surface at the lowest surface elevations intersected by the pits.

3.1 GROUNDWATER LEVEL AND RECHARGE RATE

During decommissioning, and for a certain time after closure, the geohydrological environment will dynamically attain a new equilibrium after the dewatering effects of the open pits. The time it will take the pits to decant were calculated with the use of a numerical modeling exercise and volume and recharge calculations and are provided in **Tables 3.1-1** and **3.1-2** respectively.

Due to the irregular sizes and shapes of the backfilling material the effective porosity of the rehabilitated opencast pits may vary between 20 and 30%. The total volume of voids were therefore calculated for the proposed opencast pits with varying degrees of porosity – as indicated in **Table 3.1-1**. An effective recharge varying between 10 and 16% of the mean annual precipitation, which is in the order of 700 mm, were used in the decant calculations and are provided in **Table 3.1-2**. The expected decant positions are indicated in **Figure 3.1**.

In the rehabilitated open cast pits the groundwater level is thus expected to attain a new equilibrium after closure. Although the transmissivity and storativity are higher after rehabilitation, the effective recharge percentage is also expected to be higher in spite of compaction practices and creation of a free runoff surface profile.

The potential decant from the pit areas will be managed to prevent adverse impact on the watercourse and will be included in the WULA.

Stuart Coal will investigate different options of managing any post-closure decant and implement the best option towards closure. Monitoring data during the operational and closure phases will be used to update, calibrate and refine current model simulations to base decisions on verified data.

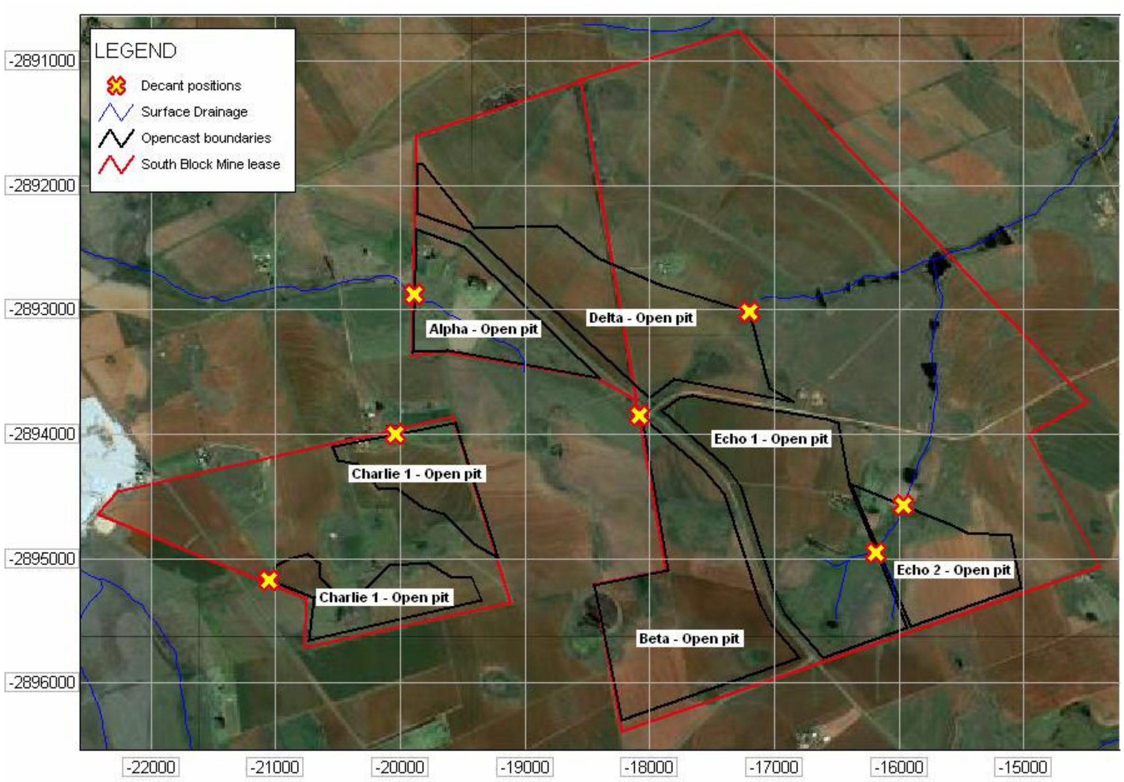


Figure 3.1: Expected decant positions

Void volume, time-to-decant, and decant volume calculations are provided below in **Tables 3.1-1**, **3.1-2**, and **3.1-3**.

Table 3.1-1: Volume calculations (m^3)

Pit	Decant elevation (mamsl)	Surface area (m^2)	Total volume (m^3)	Volume (20% Ø)	Volume (25% Ø)	Volume (30% Ø)
Alpha	1570	828631	36768312	7353662	9192078	11030494
Beta	1582	1852978	122753904	24550781	30688476	36826171
Charlie1	1577	580611	21008512	4201702	5252128	6302554
Charlie2	1570	555430	7617778	1523556	1904445	2285333
Delta	1578	1596590	42892434	8578487	10723109	12867730
Echo1	1579	1864514	85946680	17189336	21486670	25784004
Echo2	1577	777226	23182609	4636522	5795652	6954783

Note: Decant elevation - elevation at which groundwater within backfilled opencast pits will begin to decant,
Total volume - difference in volume between decant elevation and floor of 2Seam,
Ø - porosity.

Table 3.1-2: Time-to-decant calculations

	Worst case	Most probable case	Best case
	Porosity (20%)	Porosity (25%)	Porosity (30%)
	Recharge (16%)	Recharge (13%)	Recharge (10%)
Units	Years to decant	Years to decant	Years to decant
Alpha	79	122	190
Beta	118	182	284
Charlie1	65	99	155
Charlie2	24	38	59
Delta	48	74	115
Echo1	82	127	198
Echo2	53	82	128

Table 3.1-2: Decant volume calculations

Pit	Recharge (10%)	Recharge (13%)	Recharge (16%)
Units	m^3/d	m^3/d	m^3/d
Alpha	159	207	254
Beta	355	462	569
Charlie1	111	145	178
Charlie2	107	138	170
Delta	306	398	490
Echo1	358	465	572
Echo2	149	194	239

In **section 1.3.1** and **1.3.2** of the document the pre-mining groundwater flow directions and gradients have been calculated and discussed. The mining activities, and especially the opencast pits, will without any doubt influence the natural flow directions and gradients of the groundwater.

As already mentioned in the document, the opencast pits will act as groundwater sinks throughout the operational phase until a new groundwater equilibrium has been reached after active mining has ceased.

During the backfilling process material is placed back into the opencast pits in such a manner as to return the pit areas to their original pre-mining hydraulic state. Despite all the measures taken, the backfilled opencast pits will have higher transmissivities than the surrounding environment due to the irregular sizes and shapes of the backfill material. The backfilled pit areas will therefore act as preferred flow paths for groundwater.

3.2 GROUNDWATER QUALITY

The two most common processes by which groundwater are contaminated include **interstitial release** and **ion exchange release**. Argillaceous sediments such as shale and mudstone are known to contain pore water with high saline content. Significant amounts of contaminants may therefore be released as these sediment structures disintegrate because of weathering or when exposed and crushed though the mining process.

The most commonly released ions during this weathering process are sodium and chloride. The process by which ions in solution will exchange for those minerals absorbed onto solid particles is known as **ion exchange**.

Clay minerals are usually negatively charged, which is mostly attributable to broken bonds at the edges of structural clay units. As a result, cations are absorbed onto the clay particles to neutralize the negative charges. The exchangeable cations are held in an aqueous film near the clay particle surface, which is commonly referred to as a diffuse layer. Clays exhibit a selective preference for some ions over others according to the ion size, charge etc. The order of preference for the more common ions is:

$Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$

As groundwater moves through the spoil in rehabilitated areas or through underground workings where it is exposed to coal in abundance, calcium and magnesium in the groundwater will be absorbed onto clay particles in exchange for sodium and potassium. Both interstitial and ion exchange release therefore result in groundwater with high sodium content.

Operational and post-mining geohydrological impacts are described below based on collating information from the previous groundwater sections and adding geohydrological experience from previous coal mine projects in similar geological environments.

The secondary, water-bearing characteristics of the geological formations (Karoo Supergroup) or aquifers where mining will take place in the Stuart South Block mining areas are relatively low. The secondary porosity of this material can vary between 10 and 30 percent.

The hydraulic conductivities of spoils used to backfill the open pit void are significantly higher than the *in situ* material and can be as high as 10 to 100 m/d with boreholes in spoils yielding up to 15 l/s (Hodgson et al., 1985). Weathering and fracturing of sedimentary formations will enhance their water bearing capacity. Blasting operations and excavation of subsoil will increase the fracturing of the rock material within only few meters (< 20 m) from the pits or coal seam.

During the operational phase and for a time after closure the open pits act as a groundwater sink. Groundwater will thus flow radially inwards towards the open pit areas and the natural groundwater flow direction will be increased, decreased, altered or reversed, depending on the position in the depression cone.

No preferential pathways or zones of high seepage velocity such as major faults or fractured contact zones of intrusive dykes have been mapped in the opencast areas that are to be disturbed. After filling up of the mine voids the groundwater flow directions will tend to return to the normal flow directions that existed before mining commenced. Because of the higher conductivity of the backfill areas, flow on a regional scale will be through the voids as preferred flow regions due to high transmissivity.

Long-term pollution effects depend on the amount and type of pyrite in the coal and other sediments, as well as the amount of air (specifically oxygen) available for chemical reaction.

Rehabilitation of the opencast pit areas should aim at duplicating the pre-existing *in situ* soil profile and entails tipping of coal spoils and other carbonaceous material in the bottom of mined-out cuts. This will be followed by placement of clayey overburden in a dry state, compacted by frequent traversing of the surface after flattening by graders, and a final cover of topsoil.

The low permeability clay layer encapsulates the carbonaceous material placed at the bottom of the mined out cuts. These materials should be placed below the regional groundwater level in order to create a reducing redox environment and eliminate contact with oxygen, thus reducing acid mine drainage to a minimum. Although the carbonaceous materials will be submerged, horizontal groundwater seepage of clean water as well as limited infiltration of surface water will occur and some contamination will occur over the medium and long-term.

The effective recharge percentage to the aquifer is a function of the amount of rainfall, the permeability of the strata and evapotranspiration from surface. Depending on the shaping and compaction of the capping layers (especially the clay), the effective recharge to the groundwater system at the opencast pits will vary between 3 and 20 % of the mean annual precipitation (MAP).

Long-term groundwater pollution on coal mines and associated processing and disposal operations is synonymous with acid-mine-drainage (AMD) reactions. The root of the problem lies in **chemical and bacteriological oxidation of pyrite** occurring in the coal and other carbonaceous material. The pyrite oxidation model of Stumm and Morgan (1981) is one of the ways to present the reaction group:

$$FeS_2(s) + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (1)$$

$$Fe + 0.25O_2 + H^+ \rightarrow Fe^{3+} + 0.5H_2O \quad (2)$$

$3FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$ (3)

$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 (s) + 3H^+$ (4)

Of importance is the fact that reactions 1 and 2 are chemical reactions whereas the reaction 3 is also the result of bacteriological action. This bacteriological reaction flourishes in a pH environment of between 2 and 6, which is often reached by water leaching through coal mine operations.

Another distinction is that reactions 1 and 2 are oxidation reactions while reaction 3 is anaerobic. Exclusion of oxygen or elimination of the bacteria will thus greatly limit acid formation. Exclusion of oxygen will occur automatically when water levels in the mined pit start to recover after closure through seepage and aquifer recharge.

Decant after filling up is often a problem because large volumes of contaminated water could be generated that cannot be released into the environment. A relatively small portion of the opencast pits will often be flooded with water when decant starts to occur and poor quality leachate will continue to form since a large portion of the carbonaceous material in the pit remains under aerobic conditions.

No acid base accounting was conducted on carbonaceous material within the Stuart South Block mine lease area. Experience in similar coal mining environments has however shown that both the coal reserves and carbonaceous material have the ability to generate acid. Furthermore, the overall low buffer capacity of the groundwater and the surrounding aquifer will provide no resistance to the acidification of the aquifer system.

All coal and carbonaceous material must therefore be treated as acid generating, to ensure that all reasonable measures are taken to minimize pollution and prevent pollution spread.

For the purpose of constructing an environmental management and mine closure plan, all such material is thus treated as if it will have an adverse impact if in contact with water with the potential for acid mine drainage reactions to occur.

In the operational phase the overall inorganic salinity of the water will increase over time as will be evident in the total dissolved solids (TDS) content of the water. Indicator parameters like sulphate and magnesium can also be expected to increase significantly from the ambient concentrations.

With AMD reactions becoming active the pH and bicarbonate alkalinity values of the water can be expected to decrease. The majority of metals have very low solubility in water at the normal (pH 6 to 8) pH range but will go into solution as a result of the lower pH environment (see reactions 2 and 3 above).

As the water leaves the coal-containing areas, it will mix with better quality water and the pH and bicarbonate values will be buffered back to more acceptable levels. Metals should also precipitate and the sulphate and TDS concentrations should decrease through dilution. Outside the boundaries of the mineable coal reserves (pit boundaries) the Karoo rock types usually become thinner or they are absent altogether.

Over the long-term, the groundwater quality will improve because of dilution effects with high quality recharging water. Such recharge will result in a stratified water quality distribution in the backfilled opencast pits with the best quality water on top and the more saline (and with slightly higher specific gravity) water in the bottom of the pit.

3.3 NUMERICAL GROUNDWATER MODEL

3.3.1 Flow model

Numerical flow and mass transport groundwater models were constructed to simulate current aquifer conditions and impacts and to provide a tool for evaluation of different management options for the future. A risk analysis could also be performed where affects of different flow and concentration parameters as well as the impacts of nearby existing operations and management options could be evaluated.

The modeling package PMWIN Pro (Processing Modflow Professional for Windows) was used for the simulation. The regional Stuart South Block model covers an area of ± 140 km^2 (14 by 10 km). The model was run in steady state conditions until representative transmissivity and recharge distributions were obtained with a simulated hydraulic head distribution closely mimicking the average measured conditions. Two model layers were constructed in the model. Layer 1 simulates the upper weathered zone aquifer conditions, which has both the characteristics of a primary and secondary aquifer. Layer 2 represents the fractured rock, or secondary aquifer. The aquifer parameters that were assigned to the model are given in **Table 3.3.1-1**.

Table 3.3.1-1: Numerical flow model parameters

	Layer 1	Layer 2
Layer properties	Confined/Unconfined	Confined
Thickness (m)	20	100
Recharge (m/d):	0.5 to 3%	N/A
Transmissivity (m^2/d)	1.4	0.45
Specific yield	0.06	N/A
Storage Coefficient	N/A	0.005

A significant dolerite dyke occurs towards the north-east of the Delta and Echo 1 and Echo 2 opencast pits and was simulated in both the numerical flow and mass transport models.

Dolerite dykes act as groundwater flow barriers due to an overall lower transmissivity when compared to the surrounding geology. The sides of dykes are however prone to fracture formation, which leads to zones of high transmissivity that will act as preferred flow paths for groundwater and mass.

After the model was run and the steady state solution was used to calibrate simulated water levels with the available measured water level information, a groundwater mass transport model was constructed. Calibration of the flow model was aided largely by existing flow and water level information gathered from various hydrocensus and monitoring boreholes, which are situated within the same geological environment. Data obtained from previous investigations was also compared with calibrated flow parameters. The calibration results are indicated in **Figure 3.3.1-1**. A correlation of 94% was achieved with the steady state calibration of the flow model.

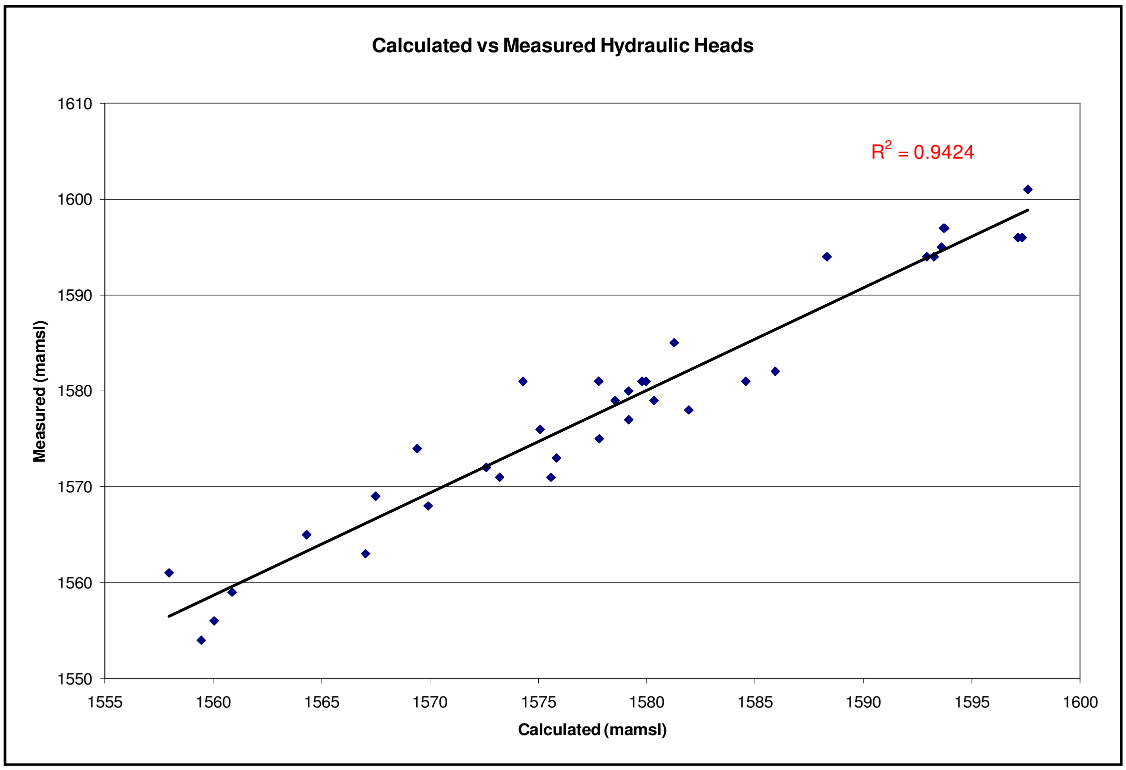


Figure 3.3.1-1: Calculated vs. observed hydraulic heads

The model simulation was subdivided into a total of 11 different stress periods. A stress period in the model is a period where groundwater flow and mass transport conditions are constant. All time dependent parameters in the model, like drains, rivers, aquifer recharge, contaminant sources, sinks and contaminant concentrations remain constant during the course of a stress period. For the proposed new mining areas at Stuart South Block, the following conditions were used to divide the simulation into stress periods in the transient state model run after steady state was simulated:

Table 3.3.1-2: Stress periods in the numerical model

Stress Period	Duration (years)	Conditions and impacts
1	20	Active opencast mining of Alpha Pit.
2	38	Active opencast mining of Beta Pit.
3	9	Active opencast mining of Charlie 1 Pit.
4	6	Active opencast mining of Charlie 2 Pit.
5	33	Active opencast mining of Delta Pit.
6	35	Active opencast mining of Echo 1 Pit.
7	13	Active opencast mining of Echo 2 Pit.
8-11	100	Simulates post-closure recovery of groundwater levels.

In order to fully comprehend the impact of opencast mining on the surrounding groundwater levels, groundwater contours were exported from the flow model at the end of active mining when maximum groundwater level impacts are expected to occur. The contours were used to construct the simulated cone of depression, which is provided in **Figure 3.3.1-2**.

During numerical flow model simulations, a maximum drawdown of approximately 100 meters was simulated to occur (at mine closure) in the most southern corner of the Echo 1 Pit. At this specific position the floor of the 2 Seam is approximately 100 m below the static water level, which is the reason for the deep drawdown of the water level. According to the model simulations, the cone of depression is not expected to exceed a maximum distance of approximately 2 km from the opencast pits at mine closure **(Figure 3.3.1-2)**. The larger than normal extent of the cone of depression is the result of the deep mining activities and long mining period which stretches over a time period of 148 years.

The dyke that was simulated to the north-east of the Delta and Echo 1 and Echo 2 opencast pits significantly reduces the expansion of the cone of depression in this downgradient direction. Further tests are however necessary to confirm its resistance to groundwater flow, as the existence of fractures might allow water to flow through the structure, thus causing the cone of depression to expand beyond it.

Figure 3.3.1-3 further confirms the fact that greater groundwater level impacts are expected to occur in the region of the Beta and Echo 1 opencast pit, as this is where the deepest drawdown of the groundwater level was simulated to occur at the time of mine closure. Groundwater levels within the backfilled opencast pits are expected to rise above their original, pre-mining levels (given that the decant elevations are situated above their pre-mining water levels) which is the direct result of increased recharge to the disturbed aquifer.

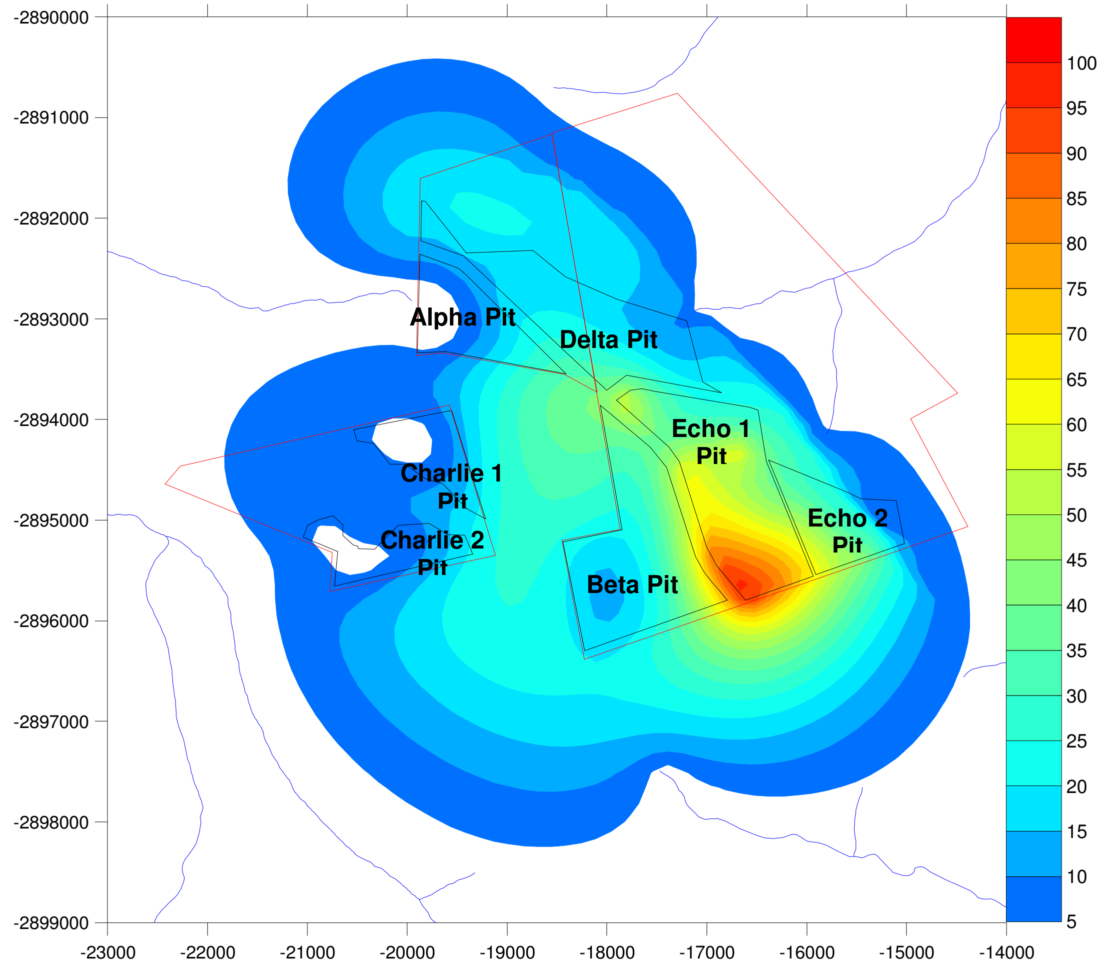


Figure 3.3.1-2: Maximum water level impacts at mine closure

Groundwater budget calculations were conducted during which the average groundwater discharge to the opencast pits was estimated. The results are provided below in **Table 3.3.1-3**. **Table 3.3.1-3** only further confirms the greater groundwater level impacts expected in the region of the Beta and Echo 1 opencast pits, where overall higher groundwater discharge was simulated to occur. The depth of the coal seam relative to the local groundwater level is the reason for the high groundwater discharge to both the Beta and Echo 1 opencast pits.

Table 3.3.1-3: Average groundwater discharge to opencast pits (m^3/d)

Pit	Groundwater discharge
Alpha	600
Beta	1 260
Charlie 1	330
Charlie 2	310
Delta	700
Echo 1	1 080
Echo 2	170

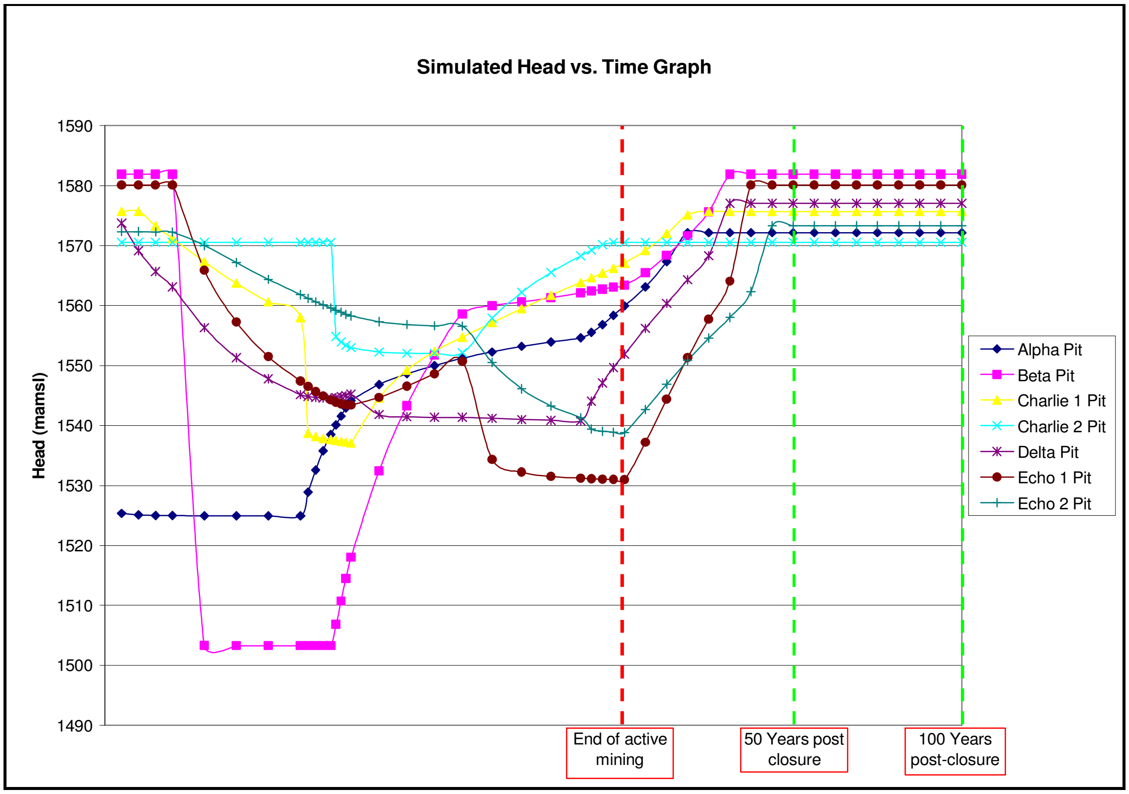


Figure 3.3.1-3: Simulated head vs. time curves

Summary:

- Groundwater level impacts are expected to be more severe in the region of the Beta and Echo 1 opencast pits, as is confirmed by **Figures 3.3.1-2** and **3.3.1-3**, and **Table 3.3.1-3**,
- The natural, pre-mining groundwater flow directions wil undoubtedly be affected by the cone of depression caused by mine dewatering,
- Until a new groundwater level equilibrium has been reached, groundwater will move radially inwards towards the cone of depression **(Figure 3.3.1-2)**,
- Due to the increased transmissivity of the backfilled opencast pits, water will always tend to move through the pit areas as preferred flow paths,
- A maximum drawdown of approximately 110 meters was simulated to occur along the southern boundary of the Beta opencast pit and southern corner of the Echo 1 opencast,
- The cone of depression is not expected to exceed a distance of ±2 km from the opencast pits.

The long-term impacts on groundwater quantity have been estimated through numerical modeling but have to be confirmed through groundwater monitoring during the operational and decommissioning phases.

3.3.2 Mass transport model – Simulated pollution plumes and movement

In the case of a perched water table or an unconfined / semi-confined aquifer, the hydraulic gradient is equal to the slope of the water table, measured at different points in the aquifer. The hydraulic gradients in the Stuart South Block mining area were calculated from the difference in elevation of groundwater levels in each area. The averaged hydraulic conductivities of the saturated zone, as calculated from the low rate pumping tests, were used as approximations of the saturated hydraulic conductivity of the Stuart South Block mining area. The average groundwater flow velocities (Darcy flux) in the Stuart South Block mining area were calculated, using the following equation (after Fetter, 1994):

$$v = \frac{KI}{\phi}$$

where: *v = flow velocity (m/day)*

K = hydraulic conductivity (m/day) = 0. 1

I = average hydraulic gradient

ϕ = probable average porosity = 0.1

The hydraulic conductivity and average porosity were chosen so as to provide a very liberal estimation of seepage velocity. The actual seepage through the aquifer matrix should be lower than the products calculated below but highly transmissive fracture zones or areas of steeper gradient might cause higher transport rates.

The hydraulic conductivity and the average hydraulic gradient are known parameters. By making use of these values, the average steady state flow velocity in the proposed mining areas is estimated as follows:

Table 3.3.2-1: Groundwater gradients and seepage rates

Pit	GW flow direction	Gradient	GW flow velocity (m/d)	GW flow velocity (m/y)
Alpha	West	1.2%	0.015	5.5
Beta	East	1.2%	0.015	5.5
	North-east	1.0%	0.013	4.6
	South-east	2.1%	0.026	9.6
Charlie1	North-west	1.5%	0.019	6.8
Charlie2	West	1.7%	0.021	7.8
Delta	East	1.4%	0.018	6.4
	West	1.2%	0.015	5.5
Echo1	North-east	2.1%	0.026	9.6
Echo2	North-east	2.1%	0.026	9.6

These estimates do however not take into account all known or suspected zones in the aquifer like preferential flow paths formed by igneous contact zones like the intrusive dykes that have higher than average flow velocities. In fractured aquifer media, the transport velocity is usually significantly higher than the average velocities calculated with this formula and may increase several meters or even tens of meters per year under steady state conditions. Under stressed conditions such as at groundwater abstraction areas the seepage velocities could increase another order of magnitude.

During active opencast mining and until a new groundwater equilibrium (when water levels within the pits reach the decant elevations) has been reached, the opencast pits act as groundwater sinks and groundwater will move radially inwards towards the pits. This means that during this period poor quality leachate generated by acid mine drainage will move towards the mine voids and cannot drain towards the immediate surroundings. For this reason the migration of pollution will only be simulated for 50 and 100 years post-closure.

The mass transport model was constructed by assigning high transmissivity, storativity, and recharge values to the backfilled opencast pits. Infrastructure that was identified as potential sources of groundwater pollution includes the opencast pits as well as the spoils stockpiles. Groundwater contamination was simulated by assigning contaminated recharge to the potential sources. A theoretical concentration of 5 000 mg/l was assigned to the opencast pits and spoils stockpiles.

At Stuart South Block, the carbonaceous material placed in the pit bottom will largely remain under oxidation conditions since the largest area will not be covered by water due to the dip of the coal floor and sloping surface topography. Water quality deterioration in the rehabilitated pits as a result of acid mine drainage will thus be significant and decant qualities are expected to be poor with TDS in the range of 2500 to 3 000 mg/l and pH from 2.5 to 4.

Even with dilution from recharge and aquifer storage the plumes are expected to reach the receiving watercourses downgradient from the pits. The source concentration into the receiving watercourse will however have diluted to approximately 20% and impacts will be softened. The only way to effectively prevent seepage from the pit areas into the stream is to prevent the level of the recovering water level in the pits from increasing above the elevation of the watercourses. The plume movement can also be minimized by keeping the water level as low as possible at the decant points so the driving head is minimized.

Plume movement is slow as a result of the overall low transmissivity of the surrounding aquifer. At 100 years post closure **(Figure 3.3.2-2)** the contamination plumes would have moved a maximum distance of approximately 500 m away from the sources according to the model simulations. Model simulations indicated a dilution of approximately 4 % of the original source concentration at 100 years post closure and at a distance of 500 m from the source/s.

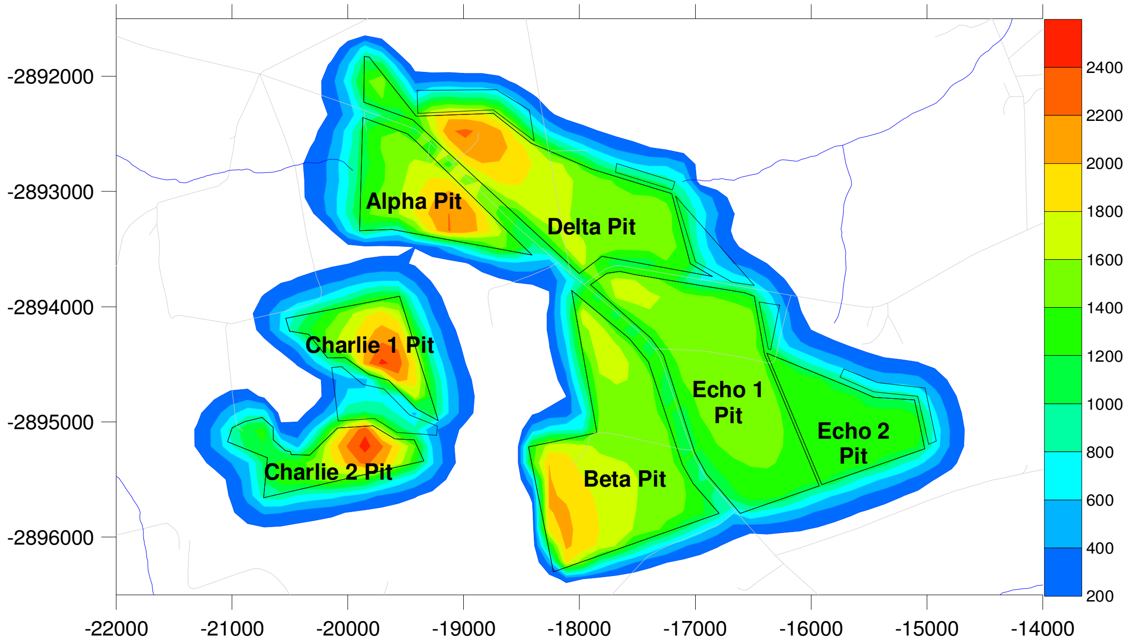


Figure 3.3.2-1: Simulated TDS source concentration contours 50 years post closure

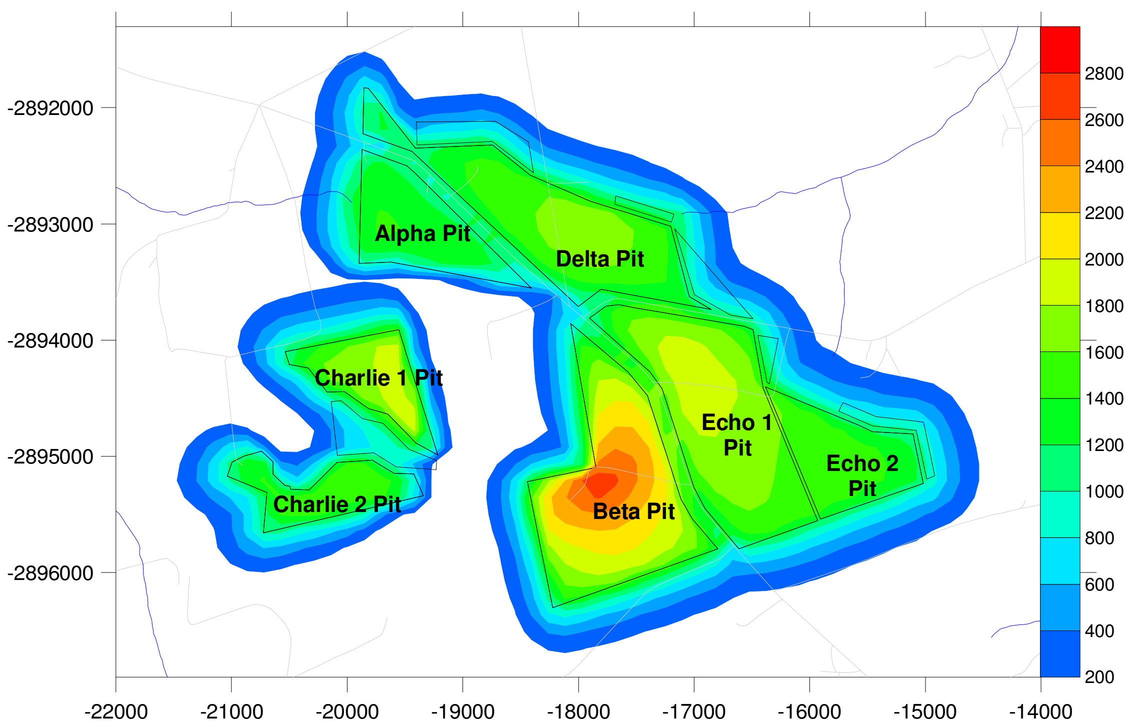


Figure 3.3.2-2: Simulated TDS source concentration contours 100 years post closure

Summary:

- Poor quality seepage emanating from the potential sources of groundwater contamination will remain restricted to the mine voids during active mining and until a new groundwater equilibrium has been reached after closure,
- Decant qualities are expected to be poor with TDS in the range of 2 500 to 3 000 mg/l and pH from 2.5 to 4,
- Plume movement is slow and is not expected to exceed a distance of 500 m from potential sources.

The long-term impacts on groundwater quality have been estimated through numerical modeling but have to be confirmed through groundwater monitoring during the operational and decommissioning phases.

4 GROUNDWATER MONITORING PROTOCOL

4.1 MONITORING PLAN/PROTOCOL – WHERE, WHAT, HOW

Water samples will be taken around the mining areas as well as in the dams constructed for the purpose of dirty water management on a quarterly basis. Samples will also be taken in the monitoring boreholes on a quarterly basis. Water levels of these boreholes will also be determined on a quarterly basis when the sampling is done. Samples will be analyzed for chemical and physical constituents normally associated with coal mining. These constituents are listed in **Table 4.1-1**.

It must be mentioned that this monitoring schedule will be re-assessed by a qualified geohydrologist at a later stage in terms of stability of water levels and quality. Should the sampling program be changed, it would be done in consultation with the DWA&F.

Table 4.1-1: Groundwater constituents for routine analysis

Monitoring	Variable
Quarterly*	EC, pH, TDS, total hardness, total alkalinity, calcium, magnesium, sodium, potassium, chloride, sulphate, fluoride, nitrate, iron, manganese, aluminium and turbidity

Note:
** = Once trends are established, some of these constituents may be sampled less frequent, while others found to be problematic may be added as determined on consultation with the relevant role players, such as the DWAF: Regional Office.*

Reporting on groundwater quality conditions will be included in the annual report.

The quarterly report will be an update of the database with time-series graphs, statistical analysis (average, maximum, minimum, 5 -, 50 –and 95 percentile values as well as linear performance). Data will also be presented in a map format to present a clear picture of the water quality situation. Laboratory results will be analyzed against the target water quality guidelines for domestic use, the aquatic environment, livestock watering and irrigation (according to the South African Water Quality Guidelines, 1996: DWAF). The strictest value between the target water quality objectives or objectives through a reserve determination will be used.

In terms of flow, all water uses and discharges will be measured on an ongoing basis. The flows include:

- Make-up water,
- Volumes of groundwater seepage into the pit and pumped from the in-pit sump,
- Volumes of contaminated water used for dust suppression,
- An annual detailed evaluation report on the surface and groundwater quality will be prepared that will analyze the water quality situation in detail to investigate trends and non-compliance.

Data Management

Monitoring results will be entered into an electronic database as soon as results are available, and at no less than one quarterly interval, allowing:

- Data presentation in tabular format,
- Time-series graphs with comparison abilities,
- Statistical analysis (minimum, maximum, average, percentile values) in tabular format,
- Graphical presentation of statistics,
- Linear trend determination,
- Performance analysis in tabular format,
- Presentation of data, statistics and performance on diagrams and maps, and
- Comparison and compliance to South African Water Quality Guidelines and any other given objectives.

As far as possible, the same monitoring points will be used from the construction phase through the operational and decommissioning phases to after mine closure to develop a long data record and enable trend analysis and recognition of progressive impacts with time.

4.2 SURFACE REHABILITATION INSOFAR IT AFFECTS GROUNDWATER

It was indicated that it is the purpose of the surface rehabilitation to re-establish surface drainage to the pre-mining conditions as far as practical.

The rehabilitation will aim to:

a. Restore normal infiltration rates to areas where recharge were reduced due to surface compaction such as the access roads, and
b. Restore normal infiltration rates where recharge was increased such as the exposed surfaces prior to rehabilitation of the opencast mining area.

The rehabilitation, including the placement of soils and re-vegetating of the opencast mining areas will form part of the roll-over mining method used. These previously disturbed areas will thus be rehabilitated to be free draining thereby maximizing the clean surface water runoff and minimizing the percentage infiltration of water, which may become polluted.

The dams constructed for the purpose of dirty water management will also be rehabilitated and the disturbed area sloped to be free draining and vegetated with the purpose of maximizing clean runoff.

4.3 LEGITIMATE REQUIREMENTS OF GROUNDWATER USERS

The proposed new project is in short expected to have the following impacts on the legitimate requirements of the surface or surrounding groundwater users in terms of quantity or quality:

a. No adverse impact is expected on the nearby groundwater users in terms of groundwater availability since the cone-of-depression is not expected to extend more than 2 km from the pits,
b. Simulated pollution movement is also not further than 500 m from the pits at 100 years post closure,
c. The receiving surface water environment will however be affected adversely through base flow reduction and base flow of polluted water.

All of the above predictions and estimated will however be verified during monitoring through the production, closure and post-closure phases according to the proposed monitoring program.

Management actions will be evaluated to deal with any potential decant predicted by this investigation at the proposed Stuart South Block opencast areas. **The mine remains committed to a zero effluent operating principle and contaminated water will be prevented from entering the receiving surface water environment through actions like evaporation, reuse or treatment.**

Should it be indicated through monitoring and investigation by a suitably qualified person that any legitimate groundwater users are impacted upon in terms of quantity or quality of borehole water, alternative water sources will be made available to such users by the mine.

Stuart South Block Colliery will comply with the target objectives set for the surface- and groundwater resources in terms of a reserve determination under the National Water Act, 1998.

4.4 PERFORMANCE ASSESSMENT AND MONITORING OF THE ENVIRONMENTAL MANAGEMENT PROGRAM

In order to ensure compliance with the environmental management program and to assess the continued appropriateness and adequacy of the environmental management program, Stuart South Block commits to:

- Conduct the monitoring of the environmental management program on an ongoing basis,
- Conduct the performance assessments of the environmental management program,
- Compile and submit to the Director: Mineral Development a report on the performance assessment of the environmental management program,

- The performance assessments of the environmental management program and the compilation and submission of the reports will occur every year from the date of approval of the environmental management program,
- The first performance assessment of the environmental management program will be scheduled to take place within 1 year of the approval of this EMP amendment report,
- Stuart South Block will appoint a responsible person(s), in writing, who will monitor all environmental aspects of the site on a regular basis. A copy of this letter of appointment including the relevant emergency numbers will be supplied to the Director: Mineral Development of the DME,
- The appointed person will communicate, on a regular basis, with the local interested and affected parties identified with regards to the project and will report on the progress made with regards to implementation of the mitigation measures. Any complaint, with regards to the mining activity, will be reported to the appointed person and be recorded in the complaint register.

A report with regards to the following issues will be submitted to the DME on a yearly basis:

a. Quantities processed to be recorded on a monthly basis,
b. Percentage of disturbed area rehabilitated (rehabilitation figures) – recorded on a three monthly basis. A six monthly report to be compiled,
c. Water quality results,
d. Water levels of identified boreholes, and
e. A copy of the complaints register.

A quarterly water quality (surface and groundwater) report will be compiled and submitted to the Regional Director: Department of Water Affairs and Forestry; Mpumalanga. The contents of the report will include the monthly water monitoring results at surface points and quarterly results at groundwater monitoring positions.

A register of environmental monitoring and auditing results will be available for inspection. This will also include compliance with environmental legislation, e.g. Environment Conservation Act, 1989 (Act 73 of 1989), National Environmental Management Act, 1998 (Act 107 of 1998), National Water Act, 1998 (Act 36 of 1998), etc.

4.5 SUBMISSION OF INFORMATION

The following environmental aspects will be monitored during the closure phase:

Groundwater quality and levels on a quarterly basis of all monitoring boreholes for the specified variables (refer to Part 4.1). The schedule will be based on the variance of the groundwater quality database during LOM. Accessibility of boreholes for monitoring purposes will also be assessed to determine maintenance requirements.

Surface water quality on a quarterly basis based on variance of surface water quality database (refer to Part 4.1 for localities and analyses).

4.6 ANNUAL MONITORING OF REHABILITATION SUCCESS

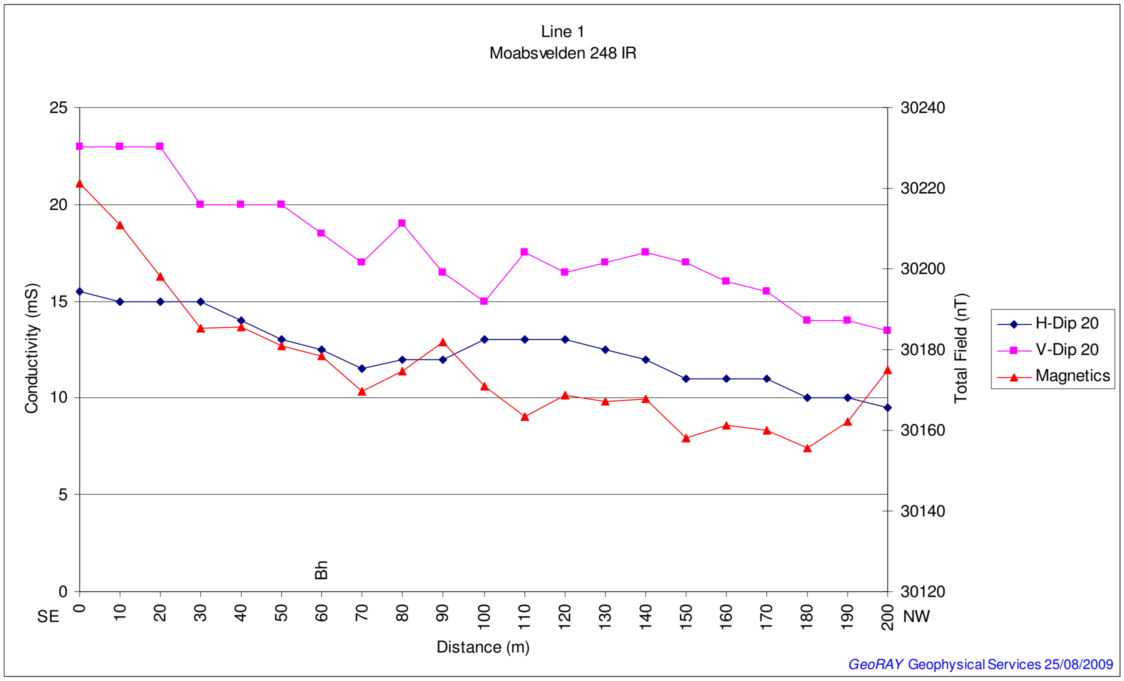
An annual monitoring report will be submitted to the Director: Mineral Development until official closure has been obtained. Once the database shows stability of the various environmental aspects, application for official closure will be made. This will be accompanied by a geohydrologist report with an updated and calibrated model to indicate long-term groundwater conditions and management measures, if required.

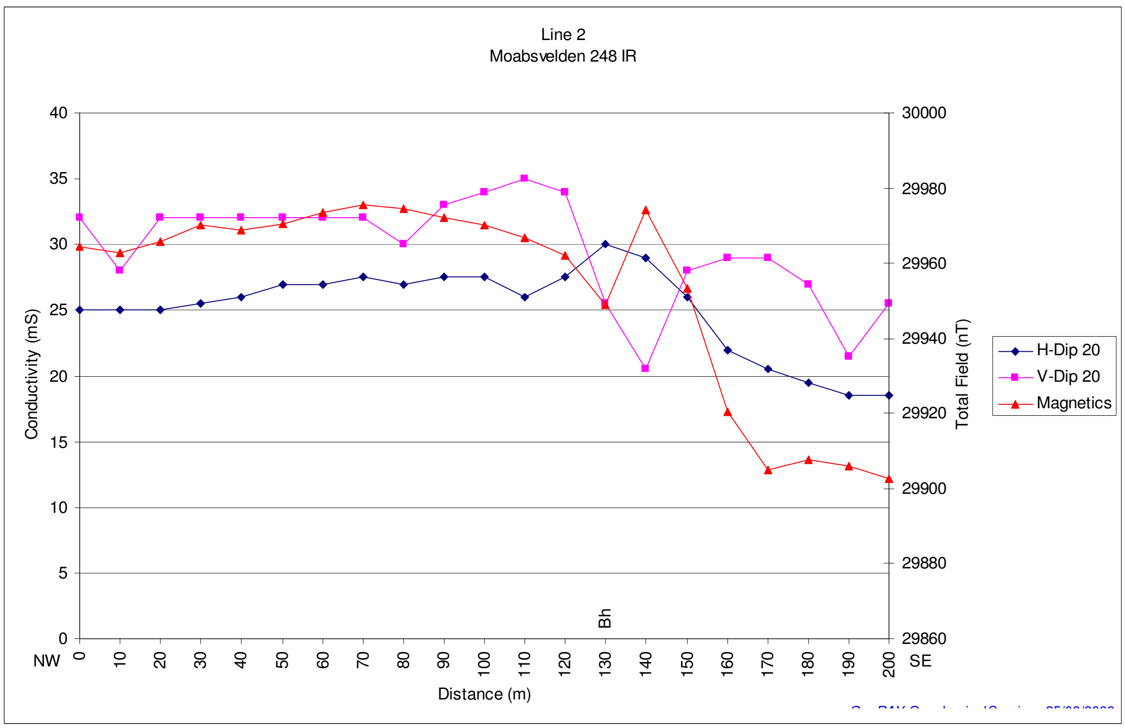
Boreholes

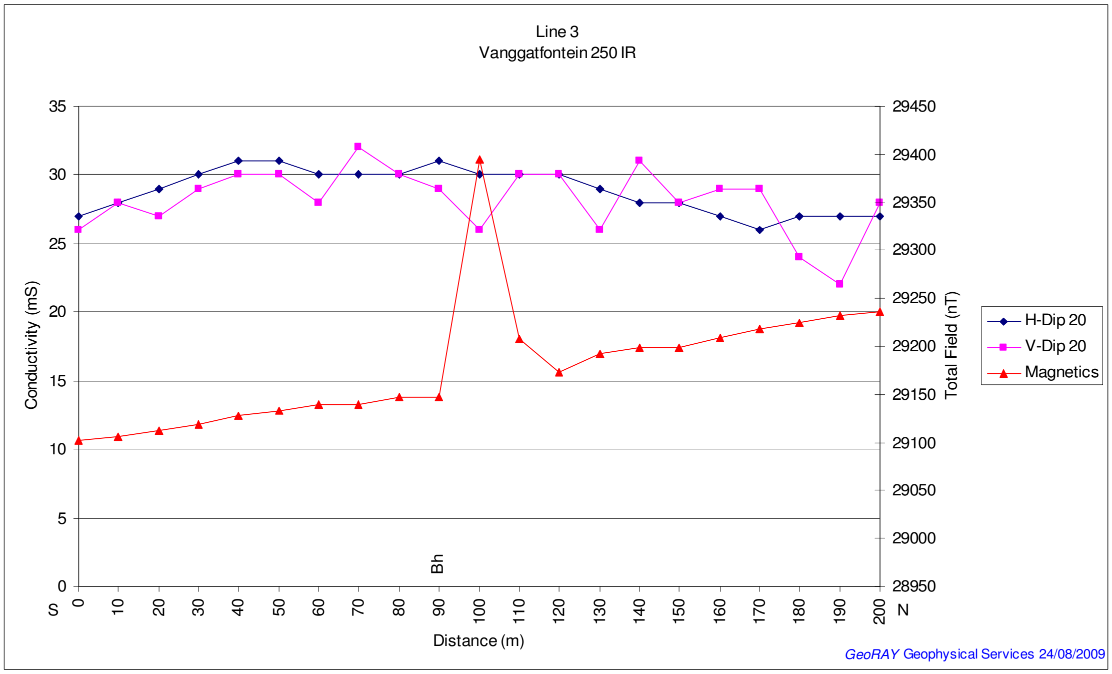
The following maintenance activities will be adhered to:

- Monitoring boreholes will be capped and locked at all times,
- Borehole depths will be measured quarterly and the boreholes will be blown out with compressed air, if required and
- Vegetation around the boreholes will be removed on a regular basis and the borehole casings painted, when necessary, to prevent excessive rust and degradation.

5 APPENDIX A: GEOPHYSICAL GRAPHS



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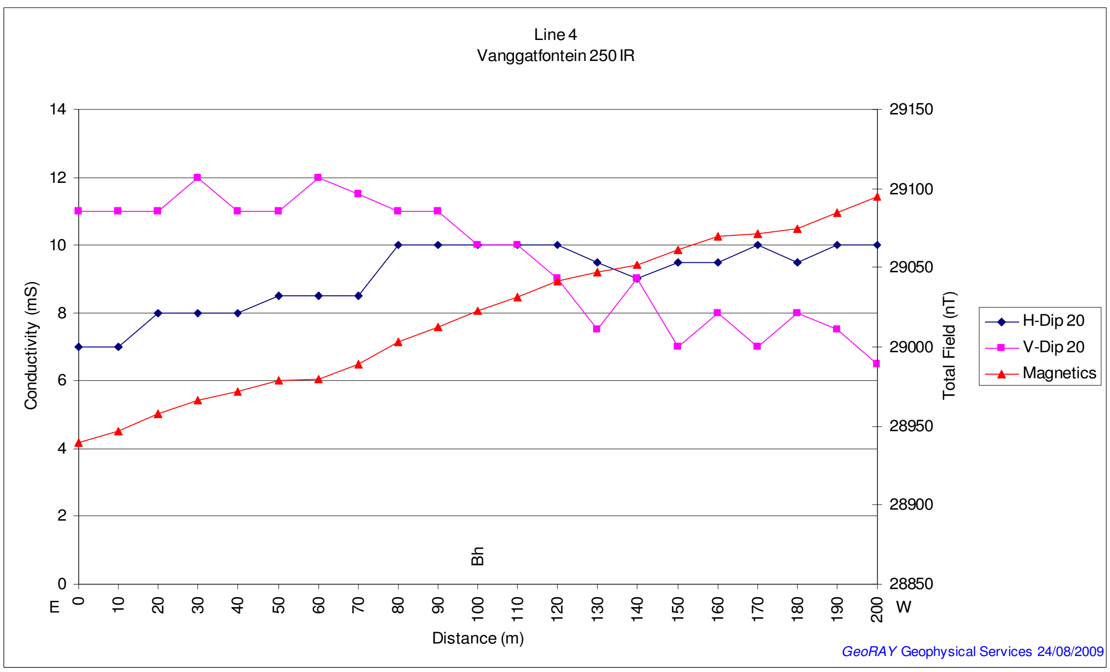
GeoRAY Geophysical Services 24/08/2009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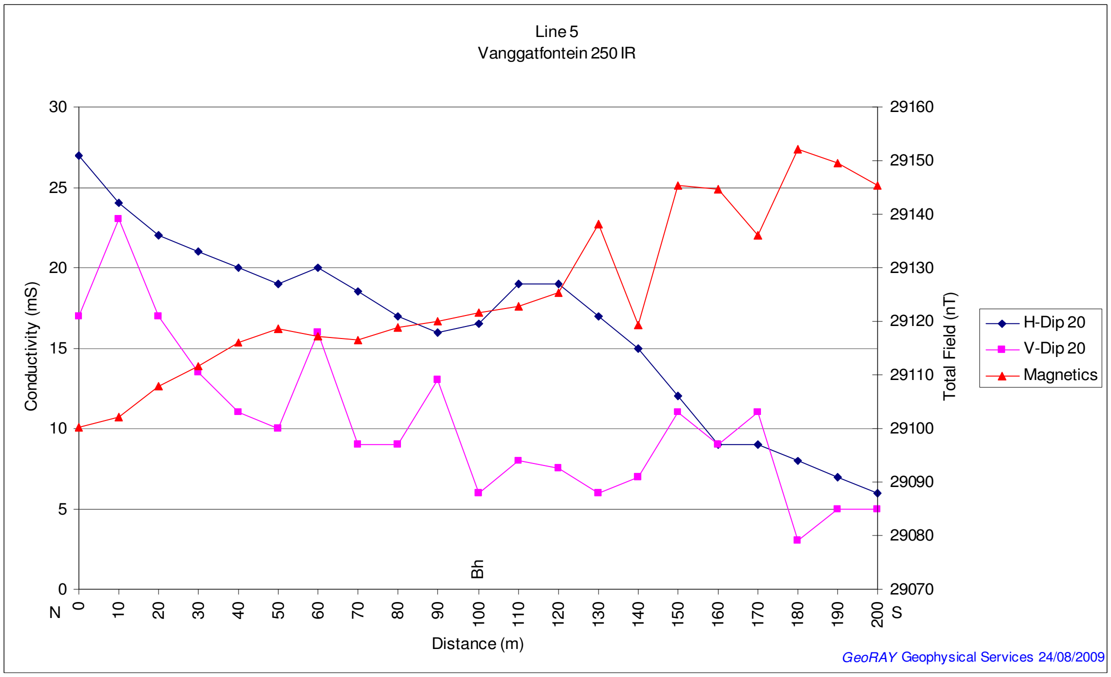
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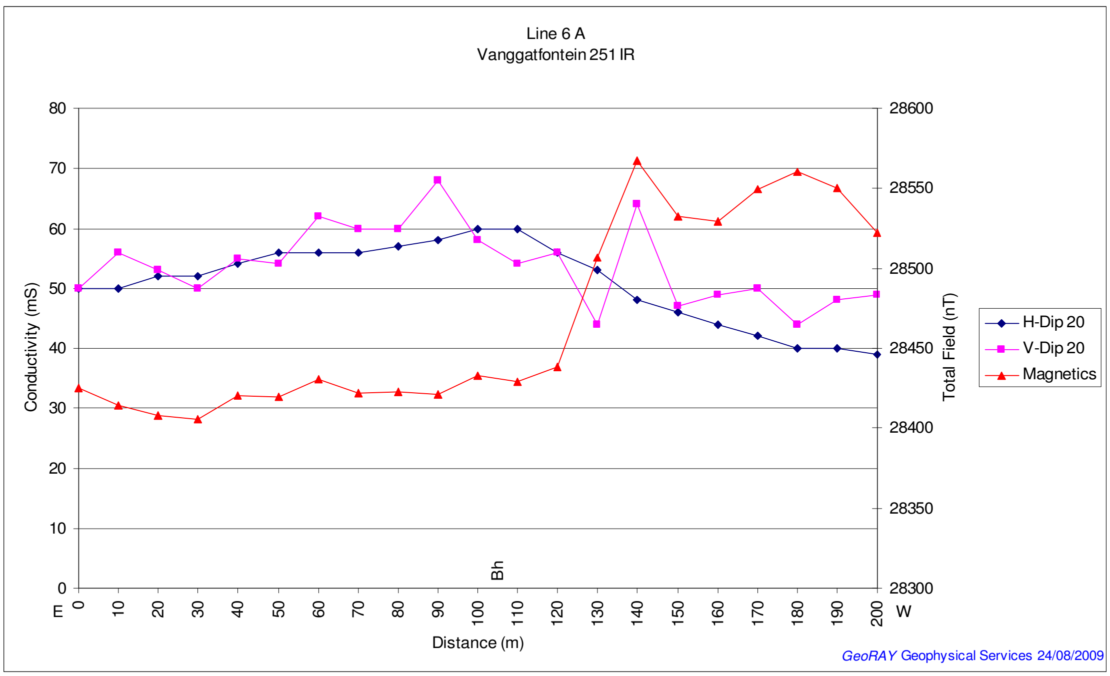
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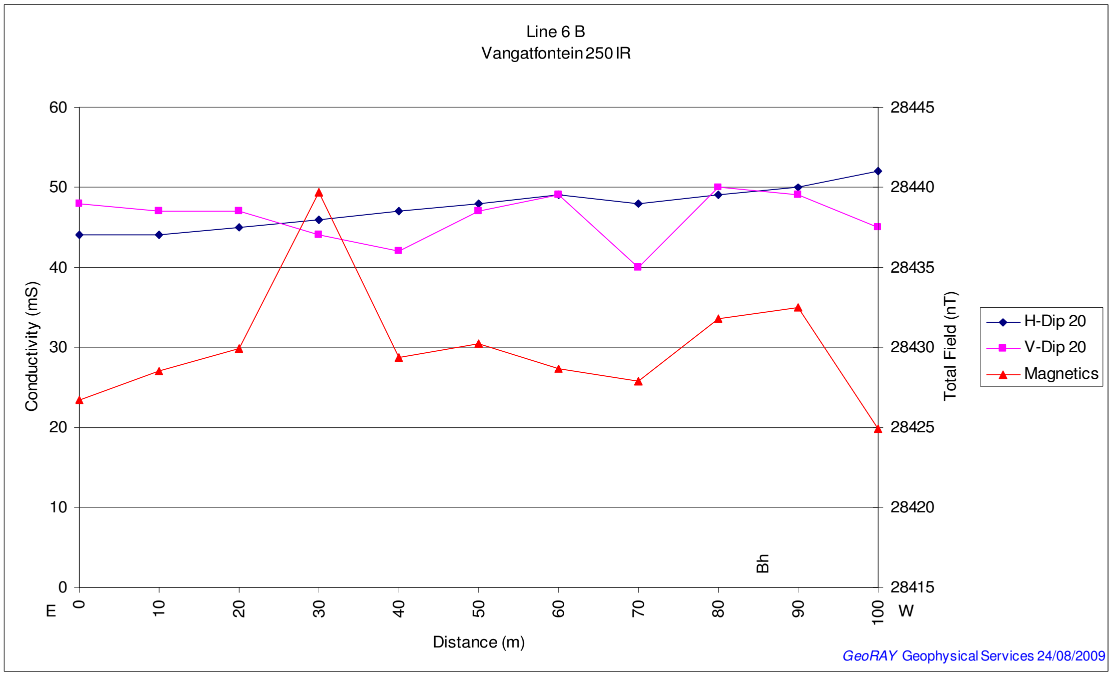
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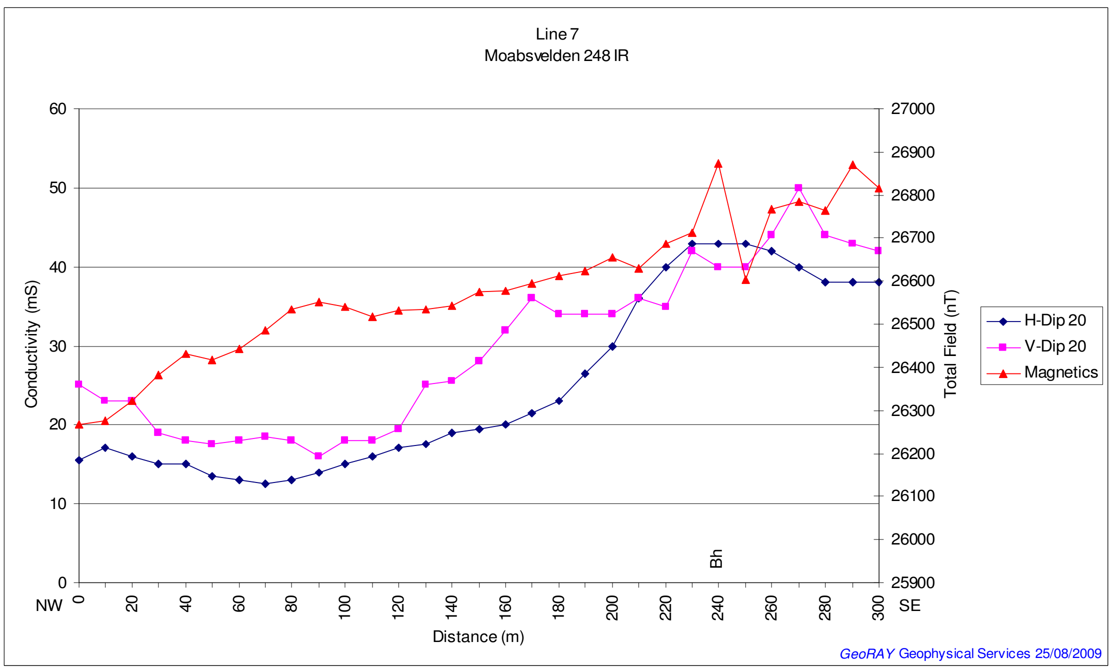
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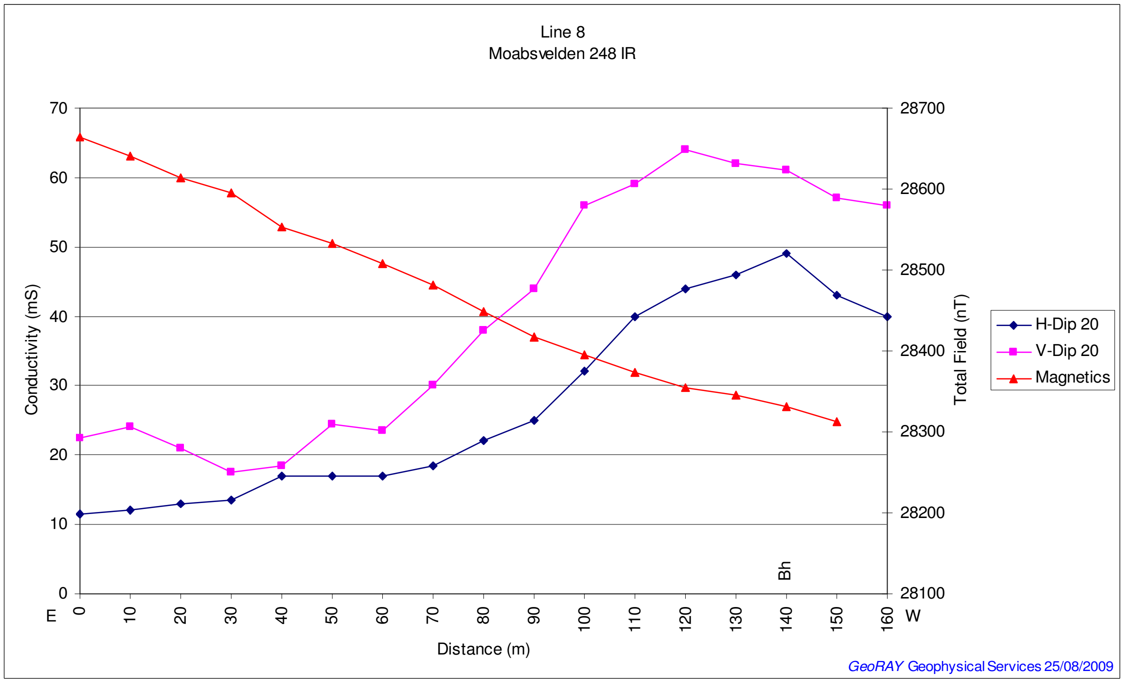

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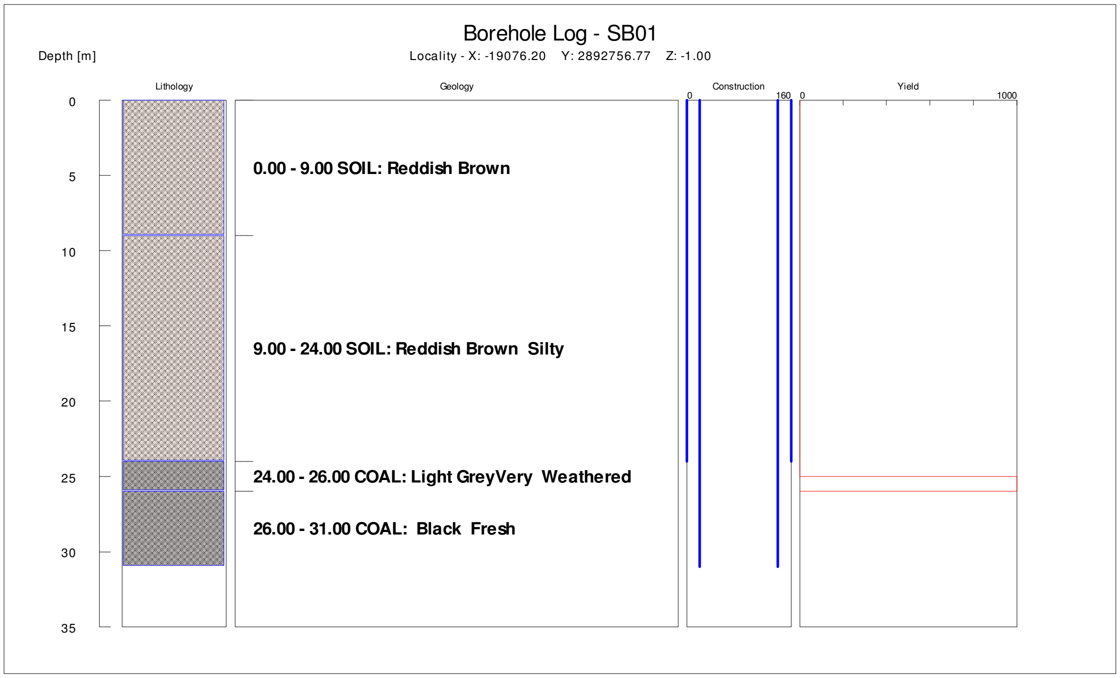
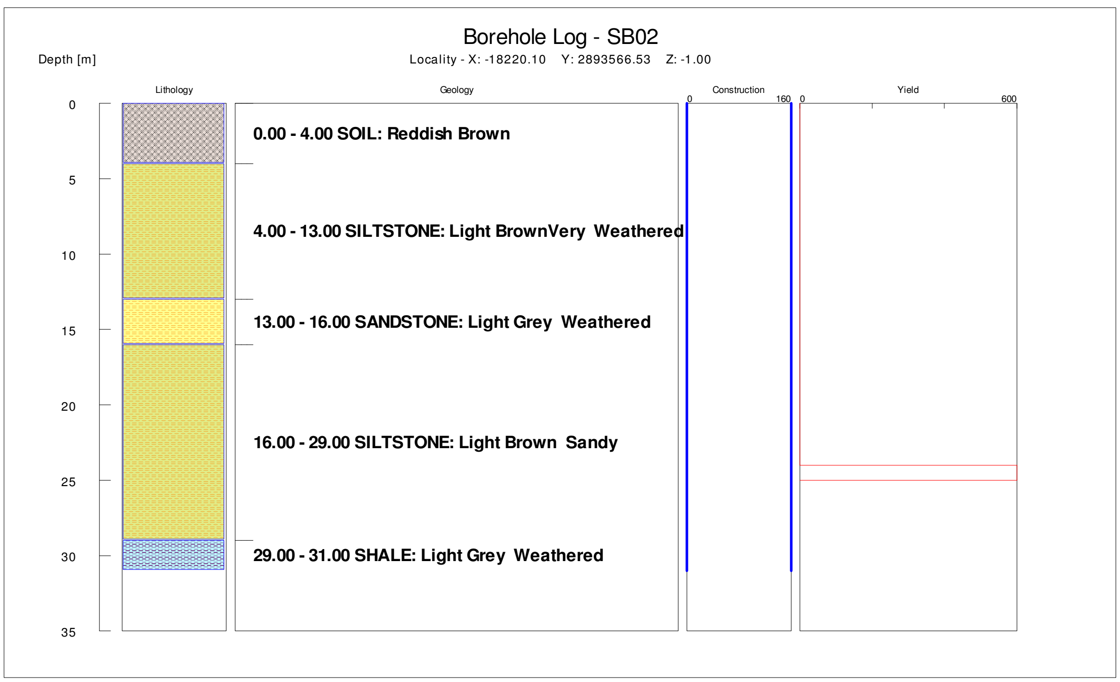
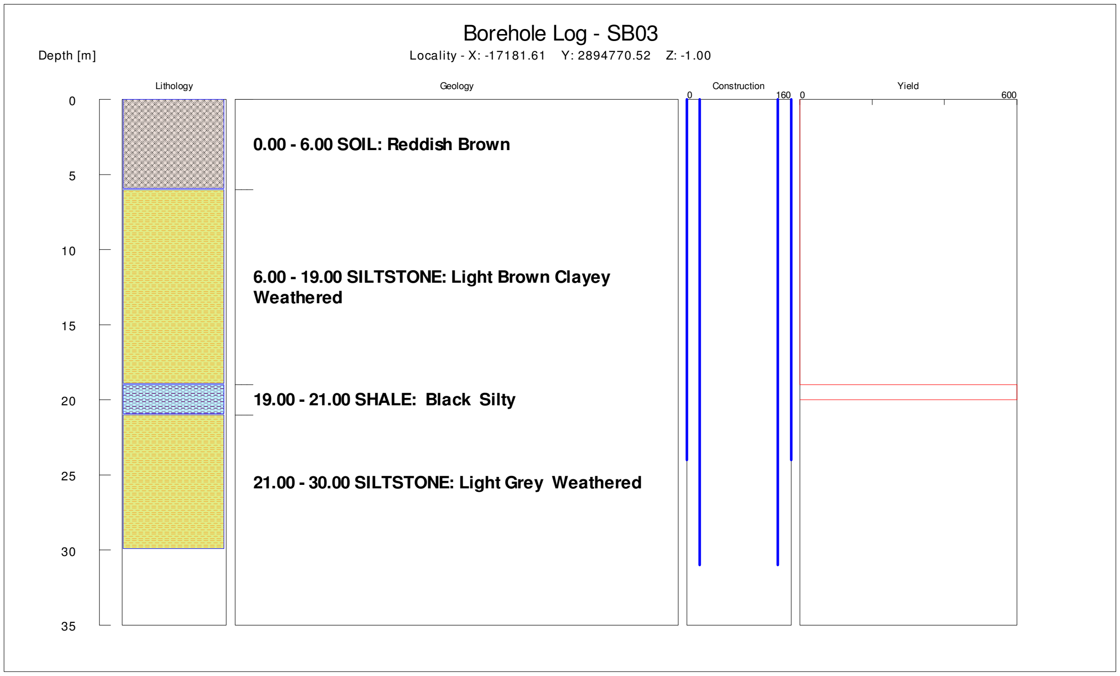
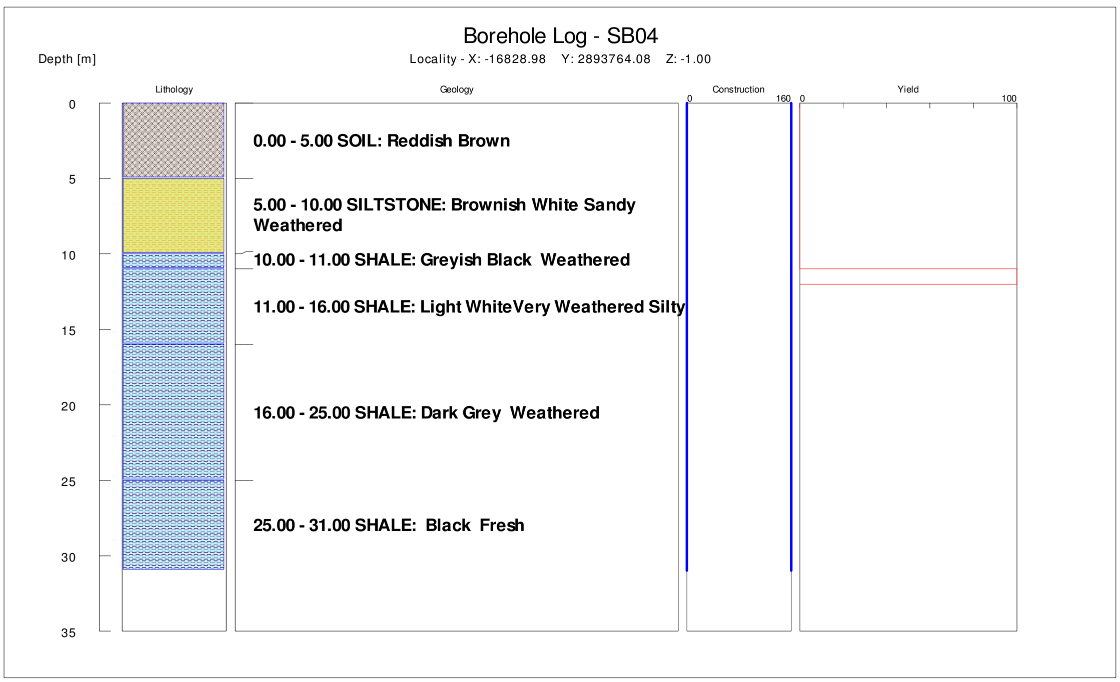
6 APPENDIX B: MONITORING BOREHOLES LOGS



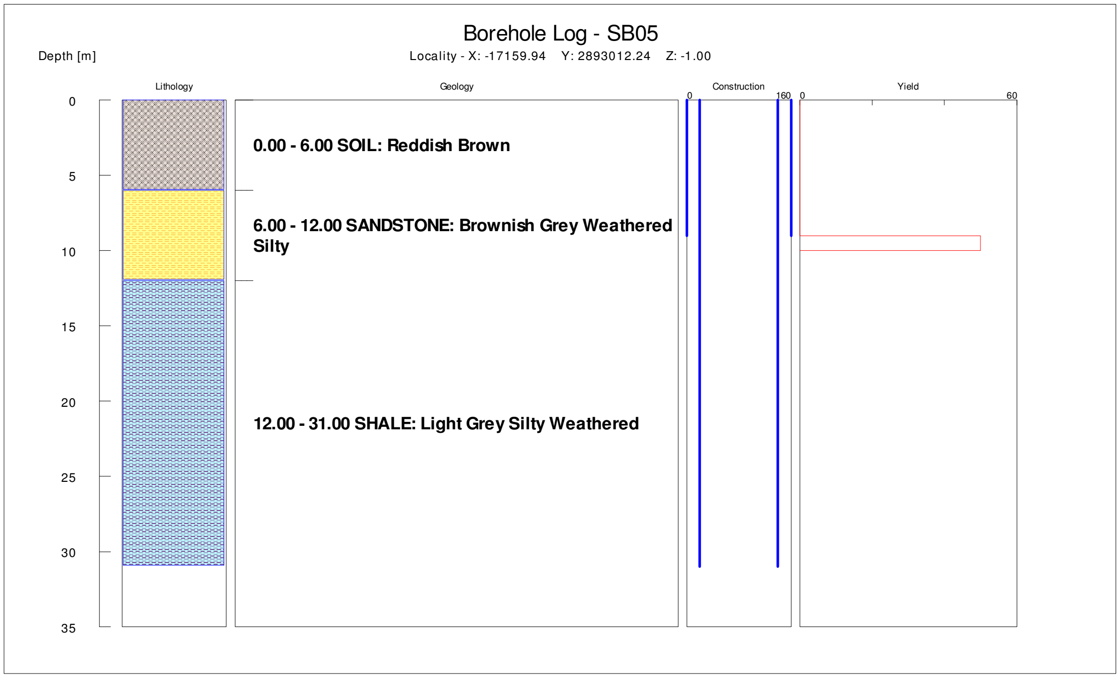


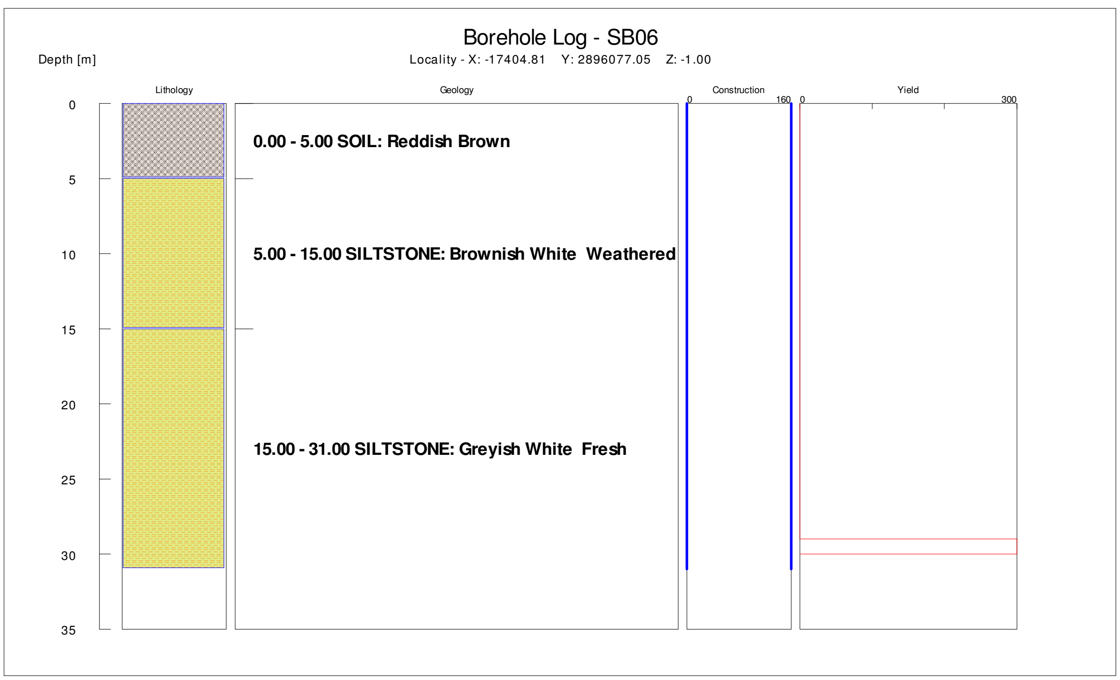


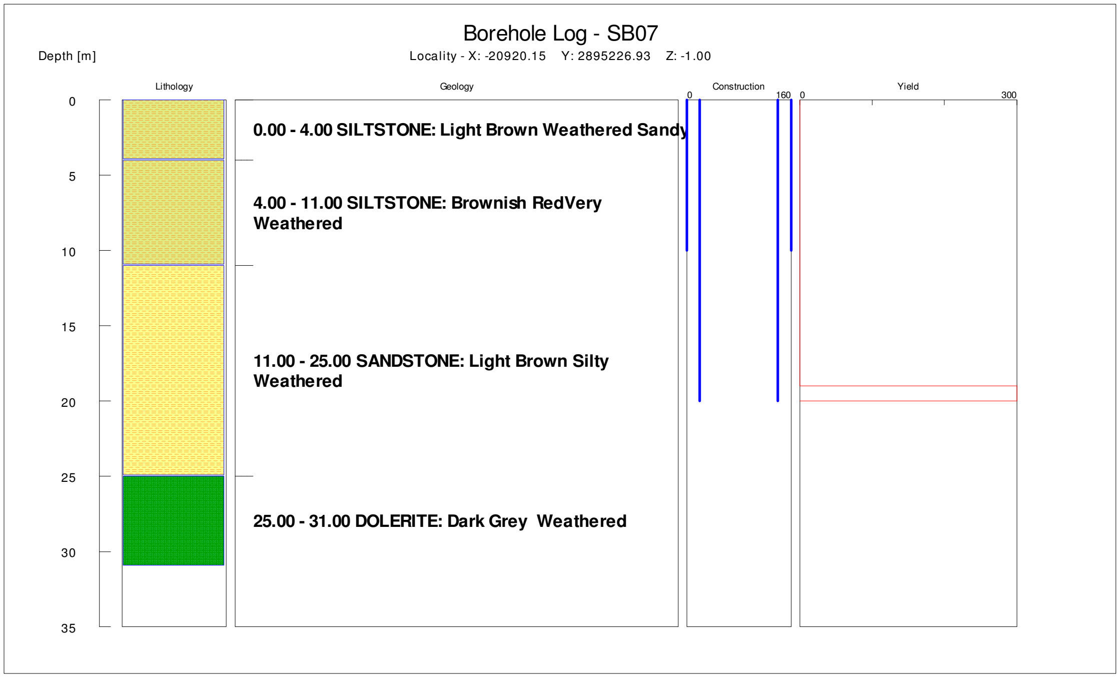
Borehole Log - SB03
Depth [m]
Locality - X: -17181.61 Y: 2894770.52 Z: -1.00
Lithology
Geology
Construction
Yield
0.00 - 6.00 SOIL: Reddish Brown
6.00 - 19.00 SILTSTONE: Light Brown Clayey Weathered
19.00 - 21.00 SHALE: Black Silty
21.00 - 30.00 SILTSTONE: Light Grey Weathered

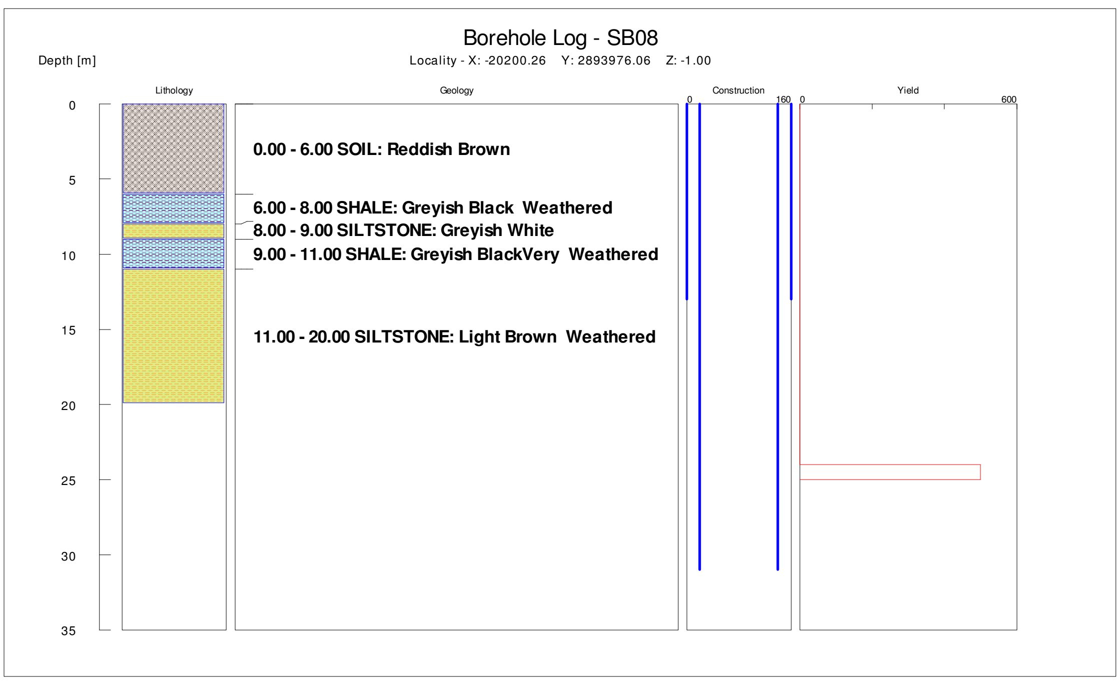


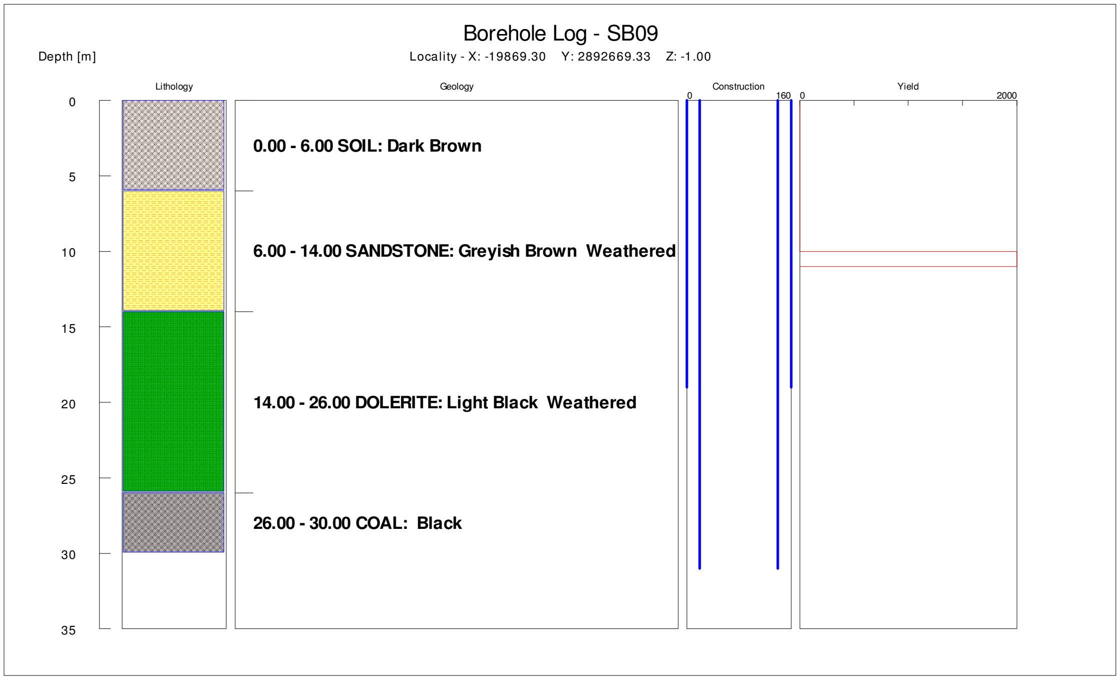
Borehole Log - SB04
Depth [m]
Locality - X: -16828.98 Y: 2893764.08 Z: -1.00
Lithology
Geology
Construction
Yield
0.00 - 5.00 SOIL: Reddish Brown
5.00 - 10.00 SILTSTONE: Brownish White Sandy Weathered
10.00 - 11.00 SHALE: Greyish Black Weathered
11.00 - 16.00 SHALE: Light WhiteVery Weathered Silty
16.00 - 25.00 SHALE: Dark Grey Weathered
25.00 - 31.00 SHALE: Black Fresh

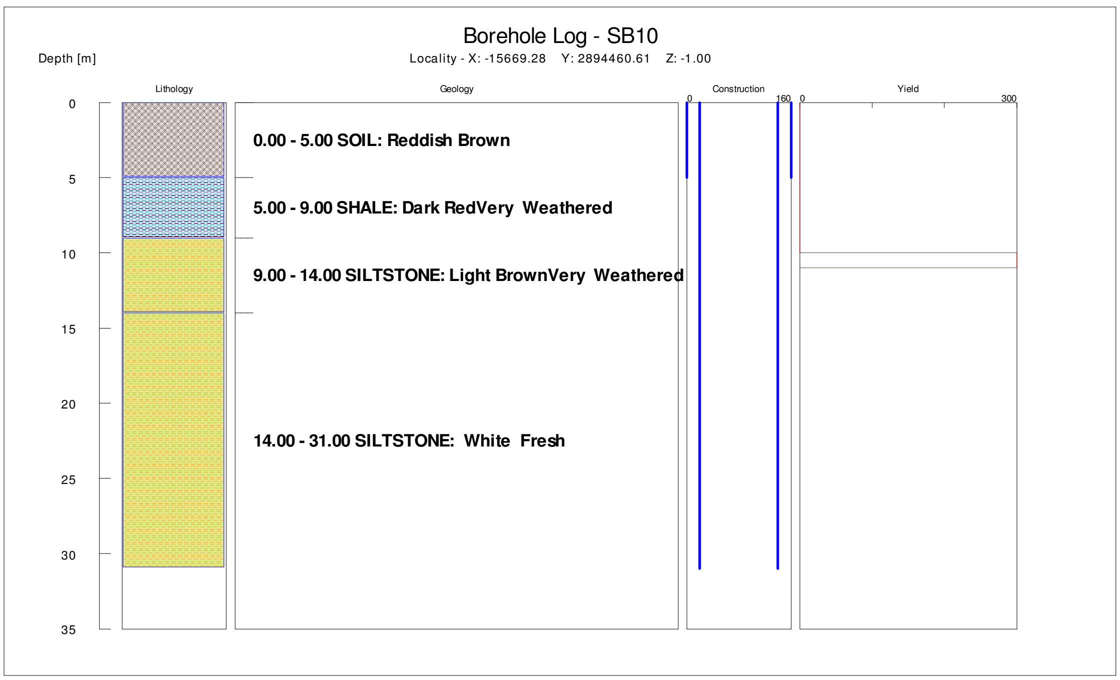

Borehole Log - SB05
Depth [m]
Locality - X: -17159.94 Y: 2893012.24 Z: -1.00
Lithology
Geology
Construction
Yield
0
5
10
15
20
25
30
35
0.00 - 6.00 SOIL: Reddish Brown
6.00 - 12.00 SANDSTONE: Brownish Grey Weathered Silty
12.00 - 31.00 SHALE: Light Grey Silty Weathered
0
160
0
60


Borehole Log - SB06
Depth [m]
Locality - X: -17404.81 Y: 2896077.05 Z: -1.00
Lithology
Geology
Construction
Yield
0
5
10
15
20
25
30
35
0.00 - 5.00 SOIL: Reddish Brown
5.00 - 15.00 SILTSTONE: Brownish White Weathered
15.00 - 31.00 SILTSTONE: Greyish White Fresh
0
160
0
300


Borehole Log - SB07
Depth [m]
Locality - X: -20920.15 Y: 2895226.93 Z: -1.00
Lithology
Geology
Construction
Yield
0.00 - 4.00 SILTSTONE: Light Brown Weathered Sandy
4.00 - 11.00 SILTSTONE: Brownish RedVery Weathered
11.00 - 25.00 SANDSTONE: Light Brown Silty Weathered
25.00 - 31.00 DOLERITE: Dark Grey Weathered


Borehole Log - SB08
Depth [m]
Locality - X: -20200.26 Y: 2893976.06 Z: -1.00
Lithology
Geology
Construction
Yield
0.00 - 6.00 SOIL: Reddish Brown
6.00 - 8.00 SHALE: Greyish Black Weathered
8.00 - 9.00 SILTSTONE: Greyish White
9.00 - 11.00 SHALE: Greyish BlackVery Weathered
11.00 - 20.00 SILTSTONE: Light Brown Weathered


Borehole Log - SB09
Depth [m]
Locality - X: -19869.30 Y: 2892669.33 Z: -1.00
Lithology
Geology
Construction
Yield
0
5
10
15
20
25
30
35
0.00 - 6.00 SOIL: Dark Brown
6.00 - 14.00 SANDSTONE: Greyish Brown Weathered
14.00 - 26.00 DOLERITE: Light Black Weathered
26.00 - 30.00 COAL: Black
0
160
0
2000


Borehole Log - SB10
Depth [m]
Locality - X: -15669.28 Y: 2894460.61 Z: -1.00
Lithology
Geology
Construction
Yield
0
5
10
15
20
25
30
35
0.00 - 5.00 SOIL: Reddish Brown
5.00 - 9.00 SHALE: Dark RedVery Weathered
9.00 - 14.00 SILTSTONE: Light BrownVery Weathered
14.00 - 31.00 SILTSTONE: White Fresh
0
160
0
300

7 APPENDIX C: CSSS HYDROCENSUS REPORT

STUART COAL
South Block Mine
Hydrocensus Report
February 2010

1. INTRODUCTION

Clean Stream Scientific Services was commissioned to do a hydrocensus on the surrounding area of the proposed Stuart Coal South Block Mine. A concentrical radius of two (2) kilometers around the mining section was included for the hydrocensus study. Various water levels and water samples were taken on the site visits during April and May 2009.

The proposed mining area as well as a buffer zone was surveyed. The potential surface and groundwater users in the area were identified. Although more than one borehole often exists for a user like a farmstead, all boreholes will be surveyed and water level (if access is obtainable to the water level), use and related info recorded but only the main used borehole will be sampled and analysed for groundwater quality.

2. SCOPE OF WORK

The goal of a hydrocensus field survey is as follows:

- Locating and informing all I&AP of the proposed development
- Gathering of personal information from the I&AP (Name, Telephone number, Address, etc.)
- Accurately logging representative boreholes on the I&AP properties
- Gathering of information of the logged boreholes (Water level, pump type, use, etc.)
- Analysing a representative groundwater sample from the I&AP property
- Establishing baseline groundwater quality before mining commences in the area
- Presenting all the surveyed localities on a GIS based map

3. INTERESTED AND AFFECTED PARTIES

Contact was made with 13 interested and affected parties, as shown in Table 3-1 below. Figure 3-1 indicates the position of all the surveyed localities in the area. Various borehole localities were logged (34 localities were surveyed), and water levels were taken. Water quality data for 19 localities and water level data for 11 localities were gathered. Table 3-1 is only a summarised version of the I&AP information gathered during the hydrocensus, for complete information, the hydrocensus forms in Appendix A can be viewed. As indicated by Table 3-1, the proposed Stuart Coal - South Block Mine project is surrounded by various landowners farming with cattle, sheep, and maize.

4. FIELD RESULTS & FINDINGS

Table 4-1 indicates the summarised geohydrological information gathered for the boreholes surveyed on the various farms. As indicated by Table 4.1, all landowner affiliated boreholes, are ether used for domestic, irrigation, or livestock watering purposes. Table 4-2 indicates the percentage break-up of the total localities surveyed, in terms of water use.

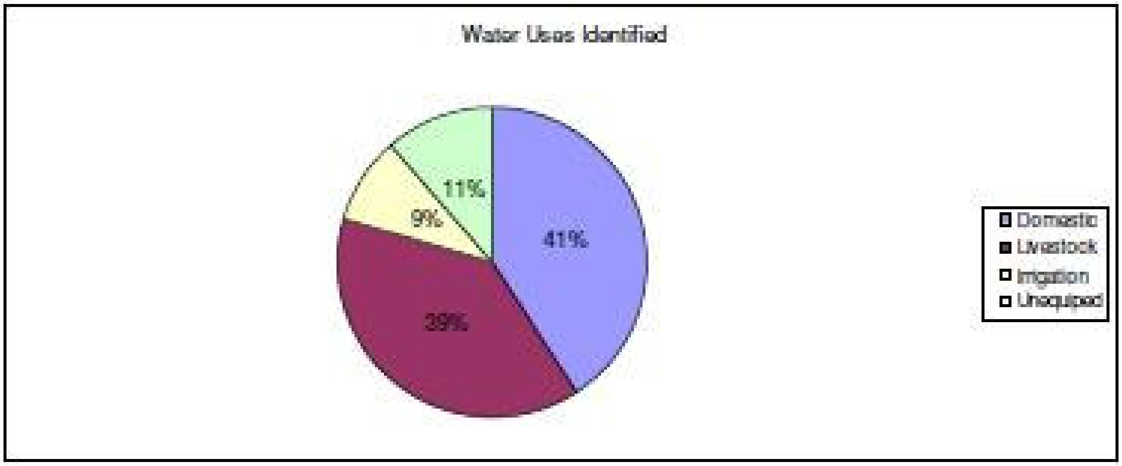


Table 4-2: Percentage break-up of the total localities surveyed, in terms of water use, for the Stuart Coal - South Block Mine hydrocensus.

As is evident from Table 4-2, the majority (80%) of the groundwater localities are utilised for domestic (potable) water (41%) and / or livestock watering purposes (39%). A small portion of the groundwater localities are used for irrigation (11%) purposes. Water usage per surveyed locality is summarised in Table 4-1.

Contact Details of Land Owners surveyed					
Contact Person	Owner (If not Contact Person)	Postal Address	Physical Address	Tel Number	Other
DJ Opperman		PO Box 1224, Delmas, 2210	Vangatfontein 250 IR ptn 02	013 665 5760	082 902 0217
K Claasen					
E Krause	MA Schalenkamp		Rietkuil 249 Portions 8/ 12/ 14 and Rietkuil 278 IR and Brakfontein		083 560 1637
P Schutte			Moabsvelden 246 IR	082 524 8328	083 524 8327
MA Schalenkamp			Rietkuil 249 Portions 8/ 12/ 14 and Rietkuil 278 IR and Brakfontein		082 944 0701
J van Rensburg	JR Terhaar	Box 389 Delmas 2210	Moabsvelden 246 IR Portion 10 - J&S Boerderye	082 524 8288	santietehaar@gmail.com
JC Williams			Moabsvelden 246 IR	082 900 9139	
S Kotze		PO Box 350, Delmas, 2210	Moabsvelden 246 IR	083 501 1898	
K Peach		PO Box 581, Delmas, 2210	Vangatfontein 251 IR ptn04	083 271 0184	
J Claasens		PO Box 37, Delmas, 2210	Schoongezicht 225 IR and Vangatfontein 251 IR	082 944 4591	
J Snyman		PO Box 405, Delams, 2210	Rietkuil 249 IR	013 665 1462	082 456 5576
P Bezuidenhout			Welgelegen 221 IR	082 524 8365	
L Gouws		PO Box 346, Delmas, 2210	Weltevrededn 227 IR		

Table 4-1: Summarised geohydrological information gathered for the boreholes on the Stuart Coal - South Block Mine survey.

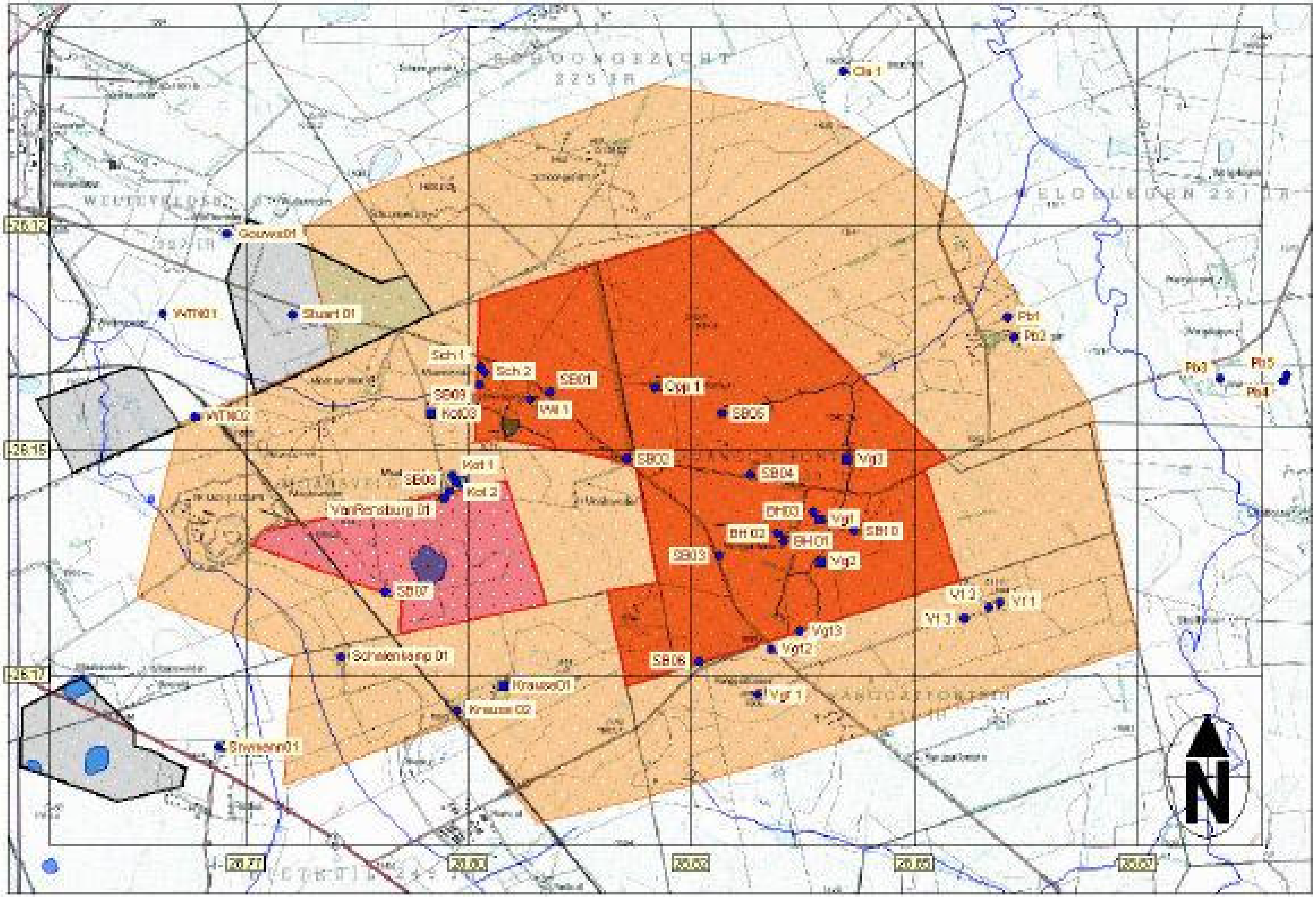


Figure 3-1: All localities surveyed during the Stuart Coal – South Block Mine hydrocensus

Summarised geohydrological information for the localities surveyed								
Locality	X coords	Y Coords	Elevation	Owner	Site Type	Usage	Analysed	Level (m)
BH 01	28.83544	-28.18011	1591	DJ Opperman	Borehole	Domestic	Yes	30.00
BH 02	28.83468	-28.15932	1593	DJ Opperman	Borehole	Domestic and Irrigation	Yes	30.00
BH 03	28.83871	-28.15869	1583	DJ Opperman	Borehole	Livestock	No	
Cla 1	28.84209	-28.10793	1540	K Claasen	Borehole	Domestic	Yes	
Gouws01	28.77300	-28.12800	-	L Gouws	Borehole	Domestic and Livestock	No	
Kot 1	28.79822	-28.15293	1588	S Kotze	Borehole	Domestic and Livestock	Yes	
Kot 2	28.79861	-28.15359	1588	S Kotze	Borehole	Domestic and Livestock	Yes	
Kot 3	28.79585	-28.14594	1587	S Kotze	Marsh	Livestock	No	
Krause02	28.79870	-28.17900	1585	E Krause	Borehole	Domestic	Yes	
Krause01	28.80395	-28.17824	1604	E Krause	Marsh	Livestock	No	
Opp 1	28.82102	-28.14311	1618	DJ Opperman	Borehole	Domestic and Irrigation	Yes	48.55
Sch 1	28.80143	-28.14077	1584	P Schutte	Borehole	Domestic and Livestock	Yes	10.50
Sch 2	28.80175	-28.14144	1583	P Schutte	Borehole	Open Hole - Not in Use	No	6.45
Schalenkamp 01	28.78575	-28.17298	1588	M Schalenkamp	Borehole	Domestic	Yes	
Snymann01	28.77200	-28.18300	1577	J Snymann	Borehole	Domestic	No	
Stuart 01	28.78035	-28.13493	1580	Communities	Borehole	Domestic	Yes	
VanRensburg 01	28.79731	-28.15537	1583	Van Rensburg	Borehole	Domestic	Yes	
Vl 1	28.85972	-28.16897	1594	K Peach	Borehole	Domestic and Livestock	Yes	15.00
Vl 2	28.85845	-28.16752	1598	K Peach	Borehole	Not in Use	No	13.60
Vl 3	28.85588	-28.16865	1593	K Peach	Borehole	Domestic and Livestock	Yes	
Vg1	28.83938	-28.15788	1580	DJ Opperman	Fountain	Livestock	Yes	
Vg2	28.83948	-28.16251	1580	DJ Opperman	Dam	Livestock	Yes	
Vg3	28.84245	-28.15111	1580	DJ Opperman	Fountain	Livestock	No	
Vgf 1	28.83241	-28.17721	1621	J Claasens	Borehole	Domestic	Yes	
Vgf2	28.83404	-28.17214	1605	J Claasens	Borehole	Irrigation	No	
Vgf3	28.83715	-28.17008	1598	J Claasens	Borehole	Irrigation	No	
Wil 1	28.80897	-28.14438	1585	JC Williams	Borehole	Livestock and Irrigation	Yes	
WTN01	28.78571	-28.13489	1555	Leeuwpan Monitoring	Borehole	Monitoring	Yes	2.32
WTN02	28.78929	-28.14839	1558	Leeuwpan Monitoring	Borehole	Monitoring	No	Dry
PB01	28.88053	-28.13534	1532	P Bezuidenhout	Borehole	Domestic and Livestock	Yes	72.86
PB02	28.88119	-28.13744	1538	P Bezuidenhout	Borehole	Domestic and Livestock	No	
PB03	28.88441	-28.14207	1549	P Bezuidenhout	Borehole	Livestock	No	25.45
PB04	28.89142	-28.14233	1572	P Bezuidenhout	Borehole	Livestock	No	
PB05	28.89184	-28.14184	1574	P Bezuidenhout	Borehole	Livestock	No	

Table 4-2: Summarised geohydrological information gathered for the boreholes on the Stuart Coal – South Block Mine survey

5. WATER QUALITY RESULTS

Water quality data for 19 localities was available for the study area. Clean Stream Scientific Services were responsible for the hydrochemical analysis and the water quality results (Analysis Certificate) are presented in Appendix B. Water qualities are discussed for selected pollution indicator parameters i.e. pH, EC (salinity), SO4, and NO3 concentration. Water qualities are compared against the proposed SANS241:2006 drinking water standards.

Four main factors usually influence groundwater quality in the aquifer, namely:

- **annual recharge** to the groundwater system,
- **type of bedrock** where ion exchange may impact on the hydrogeochemistry,
- **flow dynamics** within the aquifer(s), determining the water age and
- **source(s) of pollution** with their associated leachates or contaminant streams.

Where no specific **source of groundwater pollution** is present upstream of the borehole, only the other three factors play a role.

For the selected parameters, maps are included indicating the recorded parameter concentrations at each surveyed locality. In evaluating the data presented on the maps, it must be noted that the size of the circle indicating the concentration or value at a monitoring locality is in relation to the values of the other monitoring localities on the map. A large circle therefore does not necessarily imply water of a poor quality or very high concentration for the specified variable. Compliance to the SANS 241 drinking water guideline is coloured according to compliance (green=compliant/good water quality, yellow=Non-compliant/marginal water quality, red=Non-compliant/poor water quality).

5.1 pH

pH is the logarithmic expression of the hydrogen ion concentration in water which reflects the degree of acidity (pH < 7.0) or alkalinity (pH > 7) of the water. The pH levels of most unpolluted waters are between 6.5 – 8.5. pH levels below 6.5 may be found in areas were acidification processes have occurred, the most dramatic being that of acid mine drainage where pH levels may drop to 3.5. Health effects associated with pH can be direct or indirect. Direct causes include the irritation or burning of the mucous membranes with extreme acidic waters, and indirect causes are consequences of corrosion to cooking appliances and distribution pipes. Figure 5.1-1 indicated the various recorded pH concentrations for the Stuart Coal South Block Project surveyed localities. As indicated by the Figure, all water qualities comply with the SANS241:2006 drinking water standards, and can be described as neutral to slightly alkaline.

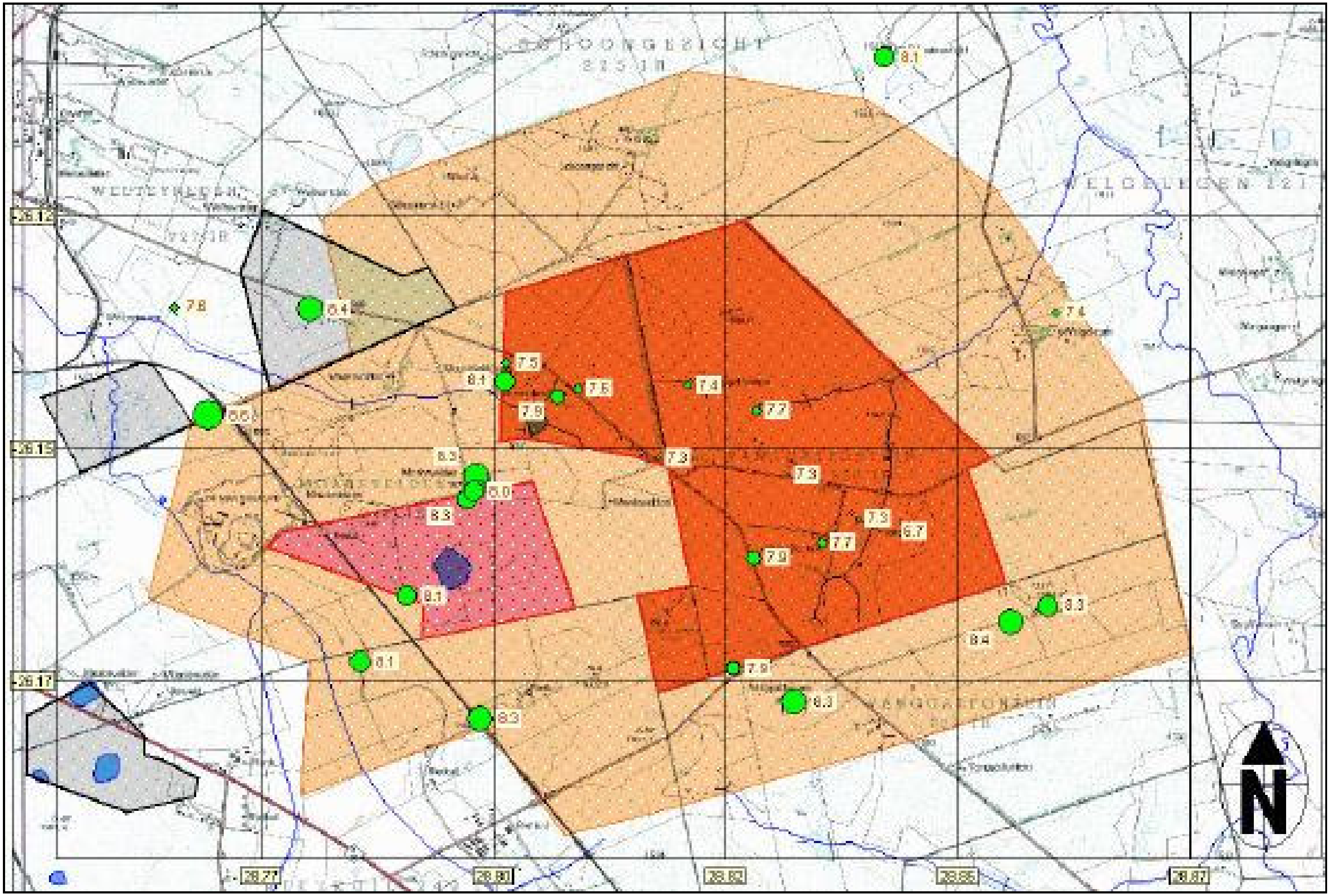


Figure 5.1-1: Recorded pH concentrations for the Stuart Coal South Block surveyed localities, October 2009.

5.2 Salinity (EC)

Salinity (EC) is the measurement of ease with which water conducts electricity, or the sum of dissolved salts (Cl, SO4, etc) in the water. Distilled water (no salinity) conducts electricity poorly, whilst sea water (high salinity) is a good conductor of electricity. Health effects associated with high salinity (>370 mS/m) values are:

- Disturbance in the salt balance of infants,
- Adverse effects on sensitive users such as individuals with high blood pressure and heart diseases,
- Adverse effects on individuals with renal/kidney disease.

Figure 5.2-1 indicates the spatial variation of the EC concentration across the hydrocensus area. Low salinity concentrations are recorded throughout the hydrocensus area. Salinity concentrations range between 5.3 mS/m to 72 mS/m indicating non-saline water quality conditions.

5.3 Sulphate (SO4)

Sulphate is the oxy-anion of sulphur and forms salts with various cations such as magnesium (Epsom Salt). Consumption of excessive amounts of sulphate, typically results in diarrhea. However, adaptation to high sulphate tends to occur with prolonged use. Sulphate imparts a bitter or salty taste to water. Corrosion of the distribution system is also likely in cases of high sulphate concentrations. Figure 5.3-1 indicates the spatial variation of the SO4 concentration across the hydrocensus area. As with the EC concentrations, very low SO4 concentrations are recorded for the hydrocensus area. The bulk of the sampling localities recorded SO4 concentration of below 10 mg/l, with only three localities, VG01 (14 mg/l), Stuart 01 (20 mg/l), and WTN02 (66 mg/l) recording higher sulphate concentrations. All localities are compliant with the SANS potable water standards.

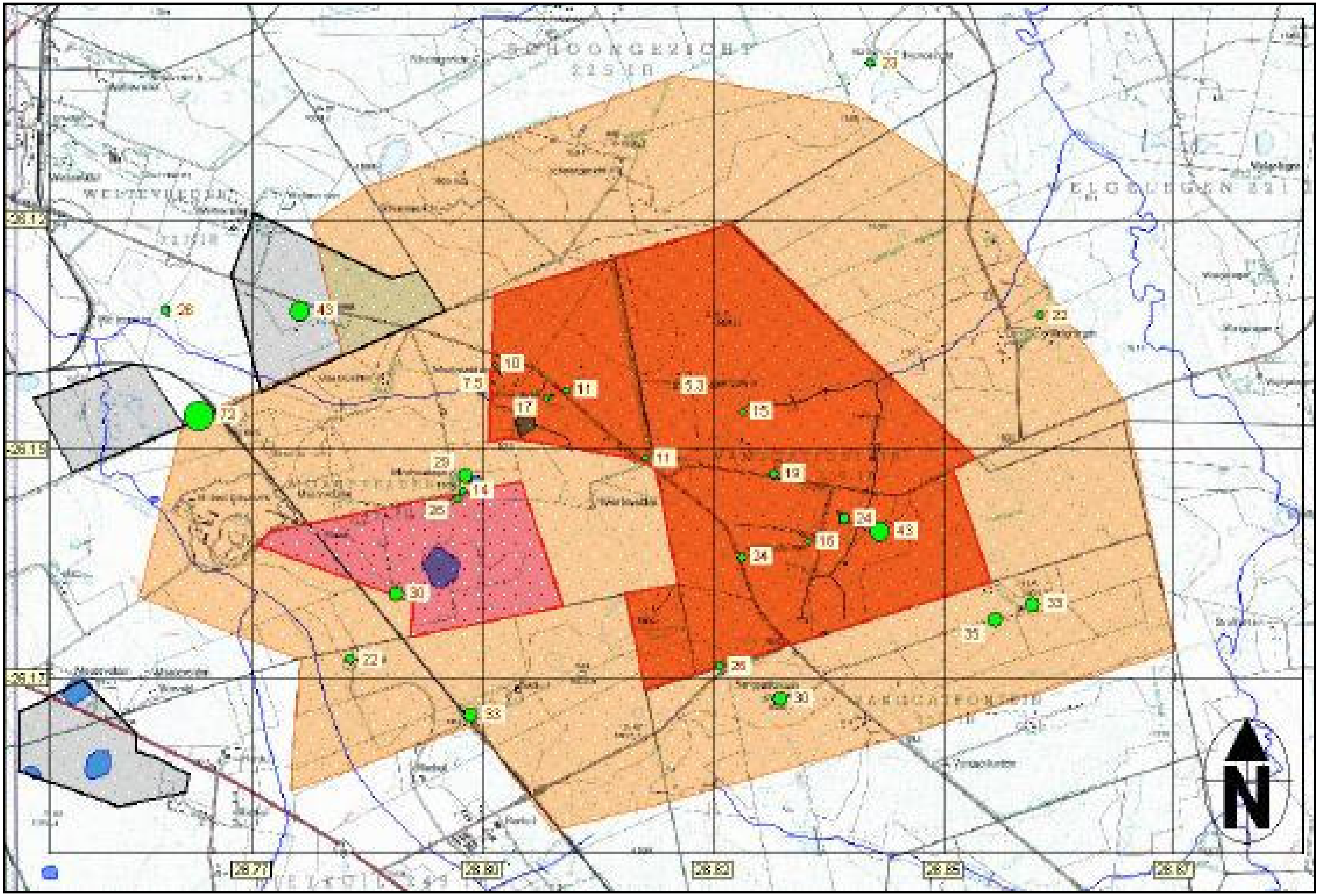


Figure 5.2-1: Recorded EC (Salinity) concentrations for the Stuart Coal South Block surveyed localities, October 2009.

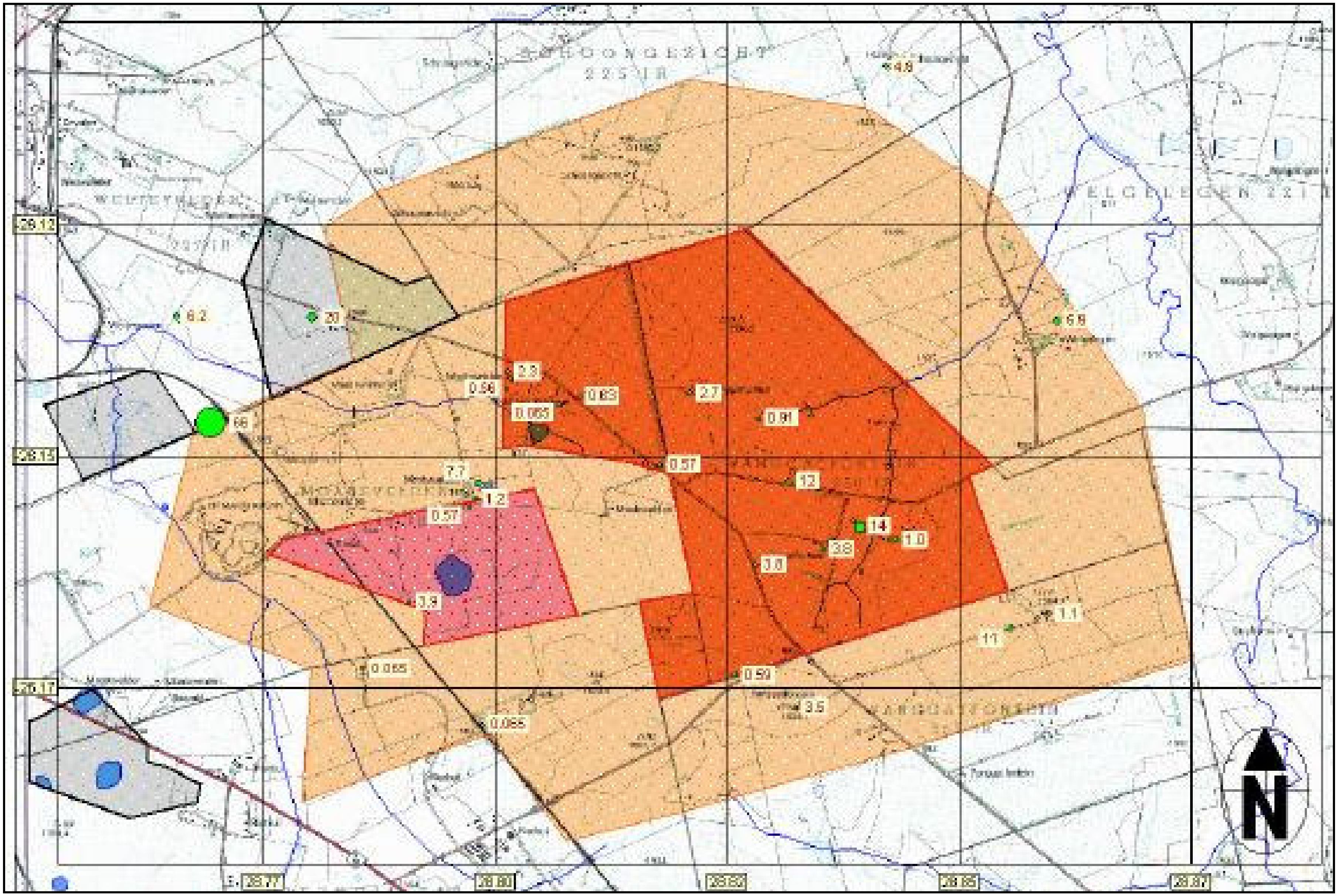


Figure 5.3-1: Recorded SO4 (sulphate) concentrations for the Stuart Coal South Block surveyed localities, October 2009

5.4 Nitrate (NO3)

In fresh unpolluted water, the NO3 concentration is often below 2mg/l (as N). Nitrate concentrations are produced by the decay of plant, animal, and human waste, and nitrate pollution is often found wherever intensive land use activities take place. Nitrate concentrations exceeding 20mg/l are common in groundwater where extensive land use takes place. Health effects associated with high NO3 (>20mg/l) concentrations are impaired concentration, lack of energy, and the formation methaemoglobin in blood cells. Individuals at risk are specifically infants under the age of 1 year. From Figure 5.4-1 it is evident that all localities comply with the SANS drinking water guidelines. The recorded NO3 concentration range between 0.03 mg/l to 5.8mg/l.

6. RECORDED WATER LEVELS

Recorded water levels for the hydrocensus localities are illustrated in Figure 6.1-1. Table 4.1 indicates the measured water levels, for the hydrocensus localities where access to the water level were possible. All water levels are given as meters below ground (surface) level. The static groundwater levels varied between 2.32m and 72.86m indicated by both Table 4.1 and Figure 6.1-1, lower groundwater levels (<15m) were recorded for most of the hydrocensus area.

The deeper groundwater levels were recorded towards at BH01, BH02 (30m), and Opp01 (48.55m) on the farm of Mr DJ Opperman. These boreholes are all recorded as being equipped with pumps. The other deep water level was recorded on the farm of Mr P Bezuidenhout (Pb01 – 72,86m) also equipped with a pump.

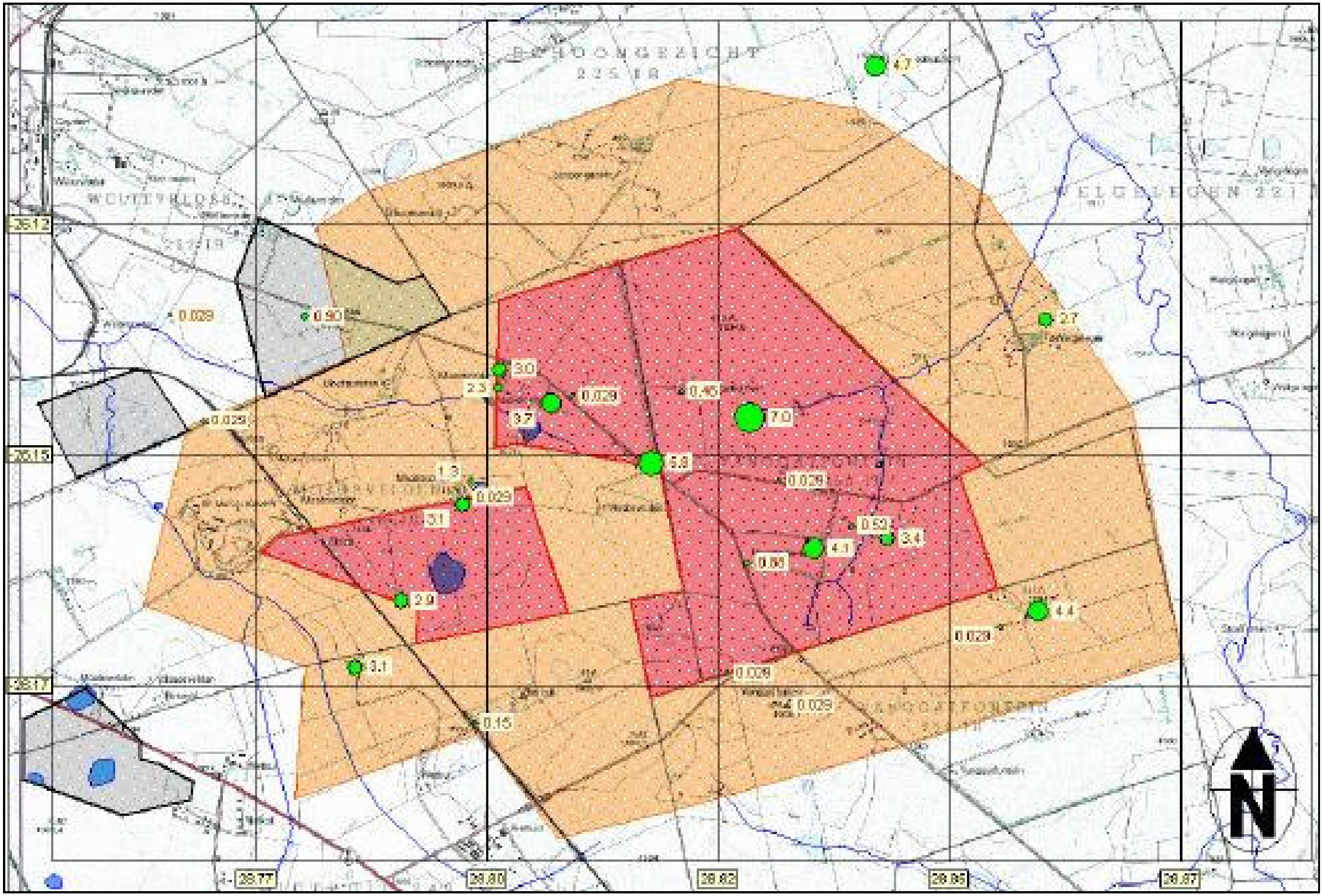


Figure 5.4-1: Recorded nitrate (NO3-N) concentrations for the Stuart Coal South Block surveyed localities, October 2009.

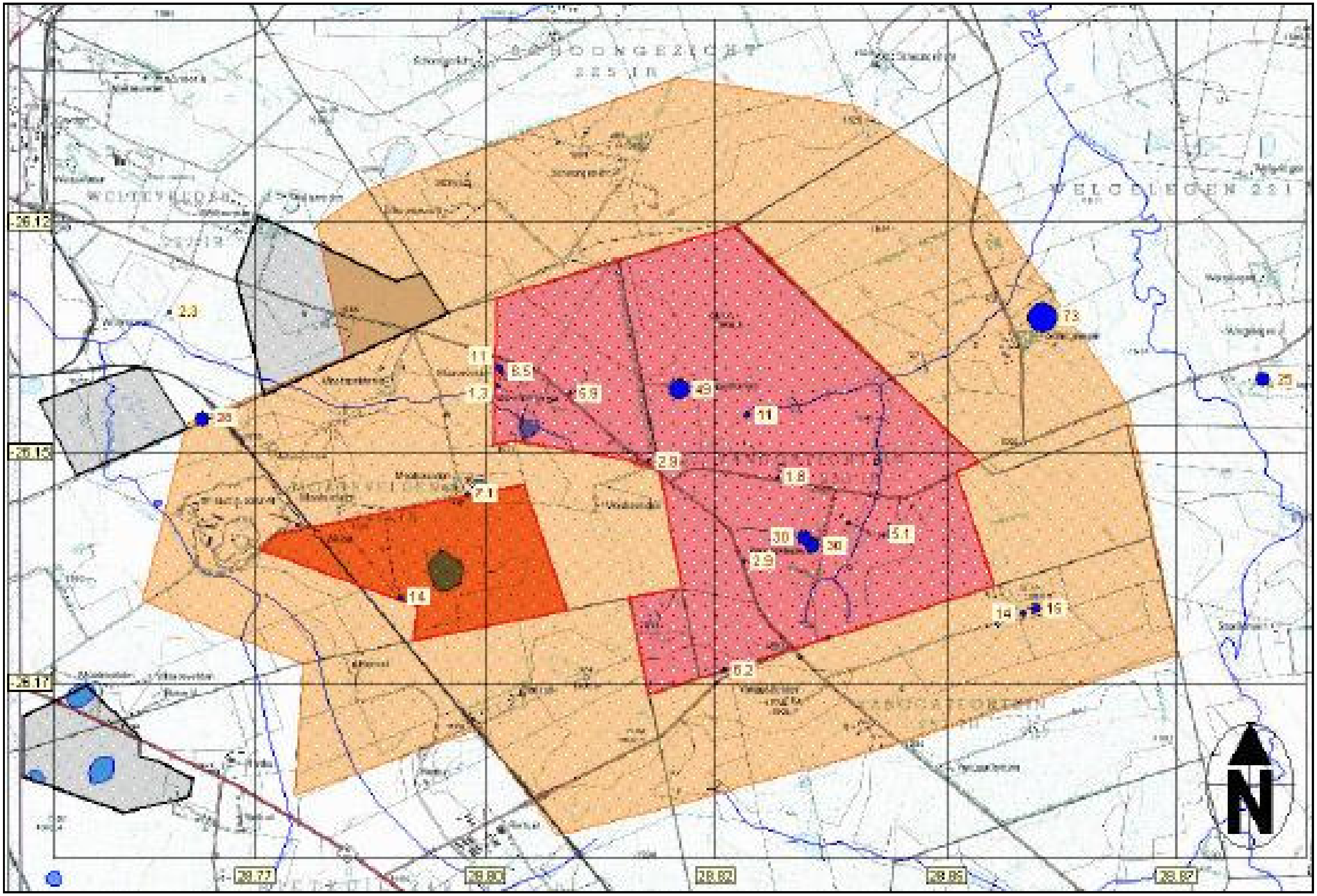


Figure 6.1-1: Recorded water levels for the Stuart Coal South Block surveyed localities, October 2009.

7. CONCLUSION

Clean Stream Scientific Services conducted a hydrocensus in October 2009 on the properties of landowners adjacent to the proposed Stuart Coal South Block mining area. The aim of the hydrocensus was to establish baseline water quality and water level data for the area for any future reference. Contact was made with 13 interested and affected parties. Various borehole localities were
logged (34 localities were surveyed), and water levels were taken. Water quality data for 19 localities and water level data for 11 localities were gathered. The proposed Stuart Coal – South Block Mine project is surrounded by various landowners farming with cattle, sheep, and maize.

The water quality can be summarised as follow:

- Regional pH, EC, SO4 and NO3 concentrations were recorded as compliant with the SANS241 drinking water standards.
- The general water quality of the area can be described as good for domestic, irrigation and livestock watering purposes.

Groundwater levels can be summarised as follow:

- Static groundwater levels varied between 2.32m and 72.86m.
- Lower groundwater levels (<15m) were recorded for most of the hydrocensus area.
- The deeper groundwater levels were recorded towards at BH01, BH02 (30m), and Opp01 (48.55m) on the farm of Mr DJ Opperman, all equipped with pumps.
- The other deep water level was recorded on the farm of Mr P Bezuidenhout (Pb01 – 72,86m) also equipped with a pump.

8. REFERENCES

Department of Water Affairs and Forestry (DWAF). Act N. 36 of 1998: National Water Act, 1998

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