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Exxaro Leeuwpan Coal Mine Hydrogeological Investigation Update

Report

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EXECUTIVE SUMMARY

GCS Water and Environmental Consultants (Pty) Ltd ("GCS") was appointed by Exxaro Resources Ltd ("Exxaro") to undertake an update of the hydrogeological study conducted by GCS in 2014 at the Exxaro Leeuwpan Colliery ("Leeuwpan"), located south-east of Delmas in Mpumalanga, South Africa.

Leeuwpan is a conventional opencast-pit mine with a coal reserve base of approximately 52.9 million, which utilises dense medium separation to process coal from Seam 4 and Seam 2 for supply to metals and power-generating industries.

The planned expansion of OI Block towards the west and the revised mining schedules necessitated an update of the GCS (2014) study. New time-series groundwater level and quality data obtained during the 5-year monitoring period were incorporated, and the most recent infrastructure plans were included. The numerical flow and contaminant transport model was updated with the latest mining plans, schedules and groundwater levels. The hydrogeological impact assessment and Groundwater Management Plan (GMP) were revised based on the changes to the mining OI and OL areas.

Physiographic Setting

Leeuwpan coal mine falls under a summer rainfall region, receiving the highest rainfall reading in January and lowest in July with average mid-day temperatures of 26^{o}C in January and 17^{o}C in July. Based on rainfall measurements taken at the South African Weather Service (SAWS) Delmas rain station (477309) between 1907 and 1999, the station recorded a Mean Annual Precipitation (MAP) of 681 mm. Based on the Leeuwpan Monitoring Station database (2017 to 2019) available on the Africa Weather Website, a total of 602 mm of rainfall was recorded in this region during 2018.

The topography in the study area is relatively flat with a topographic high in the southern section of the mining right area. The mine is located within quaternary catchment B20A of the Olifants Water Management Area. Drainage across the study area predominantly occurs in a northerly direction and locally towards the Bronkhorstpruit River, which is flowing through the eastern to western sections of the mining right. Tributaries flow towards the Bronkhorstspruit River. Anthropogenic water bodies within the mining right include pans, farm dams, ponded water on backfilled areas, pollution control dams (PCD's), trenches, seepage at the base of opencast pits and river diversion channels.

Sedimentary sequences of the Karoo and Transvaal Supergroups outcrop in the regional study area. Jurassic dolerite dykes and sills have intruded the sedimentary rocks of the Karoo Supergroup. Localised dolerite outcrops are observed across the study area.

Surface weathering processes, the undulating tillite floor of the Dwyka Group and devolatilization and weathering due to the intrusion of dolerite dykes and sills, influence the geological and grade continuity within the study area.

The coal measures are up to 16 m thick within the mining right are divided into a Bottom Coal Seam and Top Coal Zone. The Number 2 Seam of the Witbank Coalfield is synonymous with the Bottom Coal Seam of the mining right, and the Top Coal Zone can be correlated with the Number 4 Lower Seam, Number 4 Upper Seam and Number 5 Seam of the Witbank Coalfield. An interburden layer of sandstone, approximately 2 m thick and named the O-sandstone, separates the Bottom Coal Seam and Top Coal Zone.

Opencast mining activities at Leeuwpan Colliery of the OF (Kenbar) pit, located to the south of the current plant area, commenced in 1992 and concluded in 2004. Thereafter mining of the OA (Witklip) pit located on the western extent of the mine commenced in 1996 and was decommissioned in March 2005. Mining at Block OE (Midklip) commenced in 1998 and was decommissioned in June 1999. The mining blocks OG, OH, OD and OM were commissioned between 1999 to 2008, and decommissioned between 2010 and 2016. Mining at Block OJ commenced in 2008 and concluded in 2018. The Wolvenfontein (UB) reserve is a westward extension of the OD, OF (Kenbar) opencast pits and mining is planned to commence in 2024 and conclude in 2029. The Weltevreden (OWM_WTN) and Moabsvelden (OWM_MN) reserves is situated approximately 4.5 km north-east of the OJ opencast pit. Opencast mining at these reserves commenced in 2011 and 2008, respectively. Block OWM_WTN was decommissioned in 2017, however, mining is currently underway in Block OWM_MN and is planned to continue until 2020.

The Block OI opencast is situated directly south-east of the OH and OM opencast mining blocks. The Block OL is located east of Block OH and south of Block OJ. The expansion of the mining activities to blocks OL and OI commenced in 2018 and is planned to continue until 2024 and 2030, respectively. Block OI is planned to extend further towards the west and has prompted an update of numerical hydrogeological model. A new PCD has also been constructed west of Block OI, and a new bypass area has been constructed at the plant area. Stuart Coal is mining immediately north of the OWM_MN pit and north east of the OWM_WTN pit. Stuart Coal is also mining to the north of the OJ reserve. Stuart Coal and Leeuwpan share a haul road toward the OWM_MN and OWM_WTN pits. The Samquarz Silica mine is also currently in operation and located north east of the OJ opencast pit.

The mine residue consists of overburden and plant residue. The slurry fraction recovered from the slime's dams is compacted and backfilled into to the mined-out pits. The coarser discard material is also backfilled in selective opencast areas. It is then covered with a clay layer and topsoil. Thus, no permanent mine residue disposal sites are constructed for the mining operations. The decommissioned mining blocks have been partially to completely backfilled. Backfilling at Block OJ is currently underway.

Drainage from the opencast backfill will become acidic over the long-term as the ABA results from the 2014 geochemical assessment show that the material has the potential to generate acid-mine drainage. The sandstone and soft overburden have limited potential for acidic generation. The shale samples show a great variance in net acidic generation but may have a potential for acidic generation. Elevation of TDS and SO_4 will occur as a result of pyrite oxidation. In the opencast the SO_4 will increase roughly to about 2 500 mg/l over the long term;

It is not foreseen that significant elevation in metals will occur at near-neutral conditions. After acidification non-compliance for Al, Fe and Mn may occur. Cr, Ni and to a lesser degree As and V are some of the other trace elements that may be slightly elevated and may reach occasional marginal to non-compliance.

Three distinct aquifer types or hydrogeological units are present with the study area. These units vary by aquifer characteristics; however, the aquifers are generally interconnected by fractures and faults:

- Shallow weathered aquifer: a shallow aquifer formed within the residual and weathered zone of the Karoo Supergroup, locally perched on fresh bedrock;
- Deeper fractured aquifer: a deeper aquifer formed by fracturing of the Karoo Supergroup and dolerite intrusions; and
- Fractured karst aquifer: a fractured aquifer hosted within the dolomite- and chert-rich Malmani Subgroup.

GCS conducted a hydrocensus in the project area during April and July 2012 within a 2 km radius of the proposed mining activities. A total of 59 boreholes were visited of which eleven (11) boreholes formed part of the existing Leeuwpan monitoring network. A total of 48 privately owned boreholes were identified of which eleven (11) boreholes were not in use. The boreholes are used for mainly domestic supply, small-scale irrigation (gardens), livestock watering as well as large scale pivot irrigation of crops.

Leeuwpan Colliery has an active groundwater monitoring programme, which originally consisted of eighteen (18) boreholes. Of the original eighteen (18) boreholes, six (6) were non-operational during the GCS (2014) study. Percussion drilling of seventeen (17) additional monitoring boreholes commenced on 21 November 2013 and was completed on 30 November

2013, including five (5) pairs of shallow and deep borehole combinations. A total of 26 boreholes were monitored during the 2015 to 2019 monitoring period.

Groundwater levels were measured in accessible monitoring boreholes between 2015 to 2019. Seasonal fluctuations are evident in most boreholes, with several boreholes exhibiting impacted water levels by either mining activities or abstraction activities. The groundwater levels for the area generally follow topography in the absence of anthropogenic activities in the identified aquifers. The water levels of mine monitoring boreholes drilled into the shallow weathered Karoo aquifer are relative shallow and ranged from 1.9 to 9.8 mbgl with an average groundwater level of 7 mbgl. The static water levels of the borehole's representative of the deeper fractured Karoo aquifer ranged between 2.1 and 53 mbgl with the average calculated as 16.6 mbgl.

Groundwater flows predominantly towards the northwest and northeast, following the topography towards drainage lines. Local groundwater divides are evident around RKL01 and RKL02, as well as MOAMB4 and WOLMB15D/S. Slightly lowered groundwater levels are observed within the Kenbar area. Groundwater depressions, deeper than expected for the natural groundwater table, are evident at boreholes MOAMB7 and MOAMB9, likely attributed to cumulative dewatering impacts from an adjacent mine and Block OJ at MOAMB7, and surrounding abstraction activities at MOAMB9. However, continued monitoring is required to assess the activities potentially impacting the groundwater in these areas.

Groundwater quality sampling was conducted in 2012 during a hydrocensus, in 2013 and 2014 after additional monitoring boreholes were drilled for the GCS (2014) study and during the 2015 to 2019 monitoring network. The dominant water type was determined as calcium/magnesium-bicarbonate and it was concluded that water was mostly un-impacted from mining activity. The secondary water type was found to be calcium/magnesium-sulphate-chloride, which is indicative of the impact of mining activities on groundwater.

The groundwater quality results of the 2015 to 2019 monitoring network were made available by Leeuwpan Coal Mine and interpreted during this investigation. The results were compared to the Department of Water Affairs' South African Water Quality Guidelines for Domestic Use Target Values (DWA SAWQTV) and South Africa National Standard (SANS 241-1:2015) Drinking Water Standard in order to evaluate the water quality. The dominant water type across the study area is calcium/magnesium-bicarbonate, however, within close vicinity of mining activities the water type is predominantly calcium/magnesium-sulphate type, which is indicative of the impact of mining activities on groundwater. Mixed and sodium-bicarbonate type was also present in the mine area. Sulphate concentrations are predominantly elevated in the plant area, north of the Kenbar (OF) Block, and south of the mining block at the PCD and raw water dams. Slightly elevated sulphate concentrations are also observed down gradient of the OWM_MN Block (Moabsvelden) opencast.

During the GCS (2014) study, pumping tests, consisting of constant discharge and recovery tests, were conducted on selected newly drilled monitoring boreholes at Leeuwpan. The hydraulic conductivity ranges from 0.01-0.60 m/day with a harmonic mean of ~0.05 m/day. The transmissivity ranges from 0.20 to 20 m^2/day with a harmonic mean of ~0.7 m^2/day. These values are typical of the Karoo type aquifers and correspond with the values identified in previous studies.

Conceptual Hydrogeological Model Update

The conceptual model describes the hydrogeological environment and is used to design and construct the numerical model to represent simplified, but relevant conditions of the groundwater system.

Leeuwpan Colliery is an existing operation and as a result there are numerous contaminant sources present within the mining rights area, including the plant area, pollution and return water dams, overburden and discard dumps, rehabilitated opencast and operational opencast areas.

During the operational phase of the opencast mining, the mined-out areas are backfilled with waste rock material as well as coal discard and slurry cake. After closure the water level in the pits will rise as a result of groundwater inflow, pit wall runoff, and natural ingress of rainwater. Concurrent and partial backfilling or complete backfilling could be considered for the voids. The groundwater levels in the rehabilitated backfilled areas will rebound upon the cessation of dewatering and recover to a new equilibrium level, which could be the decant elevation. Above the equilibrated groundwater level, the backfilled material will be unsaturated, and the potential oxidation of sulphur minerals within the pit backfill or exposed along the pit walls could likely impact the overall mine water quality.

Leeuwpan Coal Mine is situated within the larger Karoo Supergroup weathered and fractured rock aquifer, a typical unconfined to semi-confined aquifer. Groundwater flow occurs mainly within joints, fault zones and bedding plane contacts. The three aquifer/hydrogeological units present within the Leeuwpan area include:

- Shallow weathered aquifer: a shallow aquifer formed within the residual and weathered zone of the Karoo Supergroup, locally perched on fresh bedrock;
- Deeper fractured aquifer: a deeper aquifer formed by fracturing of the Karoo Supergroup and dolerite intrusions; and
- Fractured karst aquifer: a fractured aquifer hosted within the dolomite- and chert-rich Malmani Subgroup.

The recharge in the area within which rocks of the Karoo Supergroup outcrop, is estimated between 1 and 3% (7 mm to 20 mm/annum) of mean annual precipitation (MAP). Where dolomite outcrops occur, the effective recharge percentage is likely to be higher and is estimated to be between 2 and 6% (14 mm to 41 mm/annum) of the MAP.

Groundwater flows predominantly towards the northwest and northeast, following the topography towards drainage lines. The hydraulic conductivity of the shallow and deep Karoo aquifers range between 0.01 to 0.6 m/day, based on aquifer tests conducted previously (GCS, 2014).

The unsaturated zone (~5 - 26 mbgl) in the study area consists of colluvial material and clay (residual dolerite and shale) underlain by weathered sandstone / siltstone / mudstone / shale and coal of the Ecca Group, which become less weathered with depth. The Dwyka tillite is highly weathered at shallow depths and is found to be more competent at depth. A dolerite sill likely covers the areas near Block ODN, ODS, OI, OL, and eastern portions of OWN_MN. The shallow weathered Karoo aquifer can generally be considered a minor aquifer as substantiated by previous drilling results.

The surrounding river systems also act as potential pathways for contamination, particularly when decant or contaminated seepage is intercepted.

Contamination from the mining areas is contained within the mining right. It is furthermore evident that several monitoring boreholes have been impacted by contaminants, particularly at the plant and PCD areas. The dominant water type across the study area is calcium/magnesium-bicarbonate, however, within close vicinity of mining activities the water type is predominantly calcium/magnesium-sulphate type, which is indicative of the impact of mining activities on groundwater. The majority of privately-owned boreholes are associated with the underlying dolomitic aquifer which is unlikely to be impacted by any mining related dewatering activities. The impact of abstraction for irrigation and industrial users should however be assessed. Some of the streams could be impacted by contaminated seepage and decant in the future. It must be noted that a number of mines are located in the area which may also impact on these drainage networks.

Numerical Hydrogeological Model Update

The objective of the model is to simulate groundwater ingress into the mine and the migration of potential contaminant plumes. The potential scenarios simulated using the model include the following: groundwater inflows and the extent of potential dewatering at the mine blocks, particularly, OI and OL; potential impacts on surrounding groundwater users; and potential contaminant plumes that may originate from the mining areas.

An Australian Guideline Class 1 model classification was pursued and was evaluated from a semi-quantitative assessment of the available data on which the model was based, the manner in which the model was calibrated and how the predictions were formulated.

Groundwater flow models are inherently simplified mathematical representations of complex aquifer systems. The simplification limits the accuracy with which groundwater systems can be simulated in general. The complexities of fractured rock aquifers imply that the model can only be used as a guide to determine the order of magnitude of dewatering and contaminant transport.

The numerical model used in this modelling study was based on the conceptual model developed from the findings of the desktop and baseline investigations. The simulation model simulates transient three-dimensional ground-water flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions. The model was updated using GMS 10.3.8, a pre- and post-processing package. GMS uses the well-established MODFLOW-2005 and MT3DMS numerical codes. MODFLOW uses 3D finite difference discretisation and flow codes to solve the governing equations of groundwater flow. MODFLOW NWT (Niswonger et al., 2011) was used in the simulation of the groundwater flow model. MT3DMS is a 3D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems.

The groundwater model was formulated in three-dimensions (3D) in order to simulate groundwater movement in both the horizontal and vertical planes. The conceptual model contains more than one overlying hydrogeological unit with depth with both horizontal flow in individual units and vertical flow between adjoining units that are important.

A relatively large model domain was selected in order to ensure that boundary conditions did not unduly influence modelling outcomes. The flow of groundwater in nature is impacted by boundary conditions. Where practical, natural topographical and groundwater water divides were used as flow boundaries in the top layer, assuming that the groundwater elevation follows the topography. The modelling area was discretised by a 300 x 250 grid in the x and y direction. A refined cell size of 50 m x 50 was used in the mining area with gradual increase to about 400m on a regional scale.

The subsurface was modelled in three dimensions (three-layer model). The upper 40 m thick layer represents the weathered and fractured Karoo aquifer system within which the coal resides, as well as the much older dolomite and Timball Hill formation ferruginous quartzite/shale inliers. Where the coal seams are at a deeper level, the bottom of this layer was lowered to reflect the actual coal floor. In the two deeper layers, the Dwyka tillite underlies the Karoo sediments as a thin 10 m layer, while the dolomite underlies this as a third layer of 50m. The quartzite was represented from the first to the third layer.

Steady state conditions were first set in order to simulate the natural pre-mining environment. This was followed by transient simulations whereby mining commenced in 1993 and is likely to be completed at the end of 2030. The mining period from 1993 to 2019 was used for the transient model calibration. Mining of OI and OL was simulated to conclude in 2030 and 2024, respectively, as indicated on the latest mine plans received from Leeuwpan Coal Mine in May 2019. Mine closure was thus assumed after 2030. A total of 45 stress periods were used.

The opencast schedules, particularly OI and OL and as provided by the client, were used as input for the model for the purpose of scenario modelling. The mining operations were simulated by means of drain cells. The following fixed assumptions and input parameters were used for the numerical model of this area: initial heads, hydraulic conductivity and storativity, recharge and other parameters including longitudinal dispersion and effective porosity.

Steady state calibration of the model area was accomplished by refining the horizontal hydraulic conductivity relative to average fixed recharge values until a reasonable resemblance between the measured piezometric levels and the simulated piezometric levels were obtained. The previous GCS (2014) groundwater model calibration was reassessed.

Model parameter values and hydrologic stresses determined during the steady-state calibration were used to simulate a transient response. The groundwater level data used for transient calibration was available from 2015 to 2019 whilst mining was active. No groundwater level data was available for the period prior to mining.

The following performance measurements were evaluated during the calibration of the baseline model:

- Model convergence: Model convergence was obtained during calibration and a maximum change in heads between iterations was set to 1.0 x 10^{-5} m.
- Water Balance: The model demonstrated an accurate water balance at all times during steady state calibration. A water balance error (all flows into the model minus all flows out of the model) of less than 0.5% is regarded as an accurate balance calculation.
- Quantitative measures: The difference in measured compared to calculated head was less than 5 m for 15 target points and less than 10 m for 6 target points of the 2017 measured groundwater levels. The transient calibration was regarded as sufficient at ME= 1.5m, MAE = 4.93 m and RMS = 6.46 m, which takes into account the variations on simulated versus observed water levels for the entire modelled period. If only 2017 groundwater levels are considered, the calibration error is ME= 1.15m, MAE = 4.00.m and RMS = 5.47 m.

- Qualitative measures: The steady state water level contours are consistent with the regional drainage features.

Model error and uncertainty are not uniformly distributed. The groundwater levels measured were generally confined to the mining area, however time series data was available for the monitoring boreholes around the mine. Limited hydrogeological data (transmissivity, storativity at depth and in different lithologies/intrusions) was available to characterise the aquifer system (especially the Dwyka tillite and dolomite). Therefore, a level of uncertainty exists regarding the representativeness of the calibrated hydraulic parameters. Nevertheless, models are a simplified approximation of reality. Efforts have been made to base the model on sound assumptions and the model was calibrated to observed data. The interpretation of modelled results should be based on the assumptions the model was built on and actual results will vary as unknown aquifer conditions and parameters vary in the natural system.

A number of operating and defunct mines border the Leeuwpan Colliery. A few mines located adjacent to it may contribute to the impacts posed by Leeuwpan.

The calibrated groundwater flow model was used as a basis for developing a contaminant transport model. Sulphate concentration was used to determine the impact of mining on the aquifer. Sulphate is considered to be a water-soluble oxidation product of acid rock drainage (ARD) and is considered to be a representative indicator of the impact of coal mining on groundwater quality. The results from the contaminant transport model are considered to represent a first approximation of the impact on groundwater quality. The sulphate source concentrations in the various opencasts were taken as 2500 mg/l $SO_{4,}$ as determined during the GCS (2014) geochemical assessment.

The impacts of dewatering and contamination were quantified using the 3D numerical groundwater flow and contaminant transport model. The significance of the potential impacts were asseses using a standard methodology and discussed.

During construction of the new mining blocks (Block OI and OL) minimal additional impacts to the groundwater system are expected. The main activities that could impact on groundwater in this phase include the construction and clearing of footprint areas for construction.

At the time of this investigation, three opencasts were in operation. However, the major purpose of this study is to assess how OI, including OI West Expansion, and OL will impact on the groundwater environment during the operational phase. The environmental impact significance is expected to be moderate to low.

The mine floor elevation is below the general groundwater level thus causing groundwater inflows into the opencast mining areas from the surrounding aquifers during operations. The 3D numerical groundwater flow model was used to simulate the development of the drawdown cone over time in the study area. The latest mine schedules received in May 2019 (at the time of investigation) were incorporated into the existing predictive model scenario. During the operational phase, it is expected that the main impact on the groundwater environment will be dewatering of the surrounding aquifer. At the time of the investigation boreholes LWG02, KENMB02D, WWN02D, MOAMB7, WTN02D, MOAMB4, MOAMB10, WELMB13D, WELMB13S, LEEMB18D, KENM3D could be affected to varying degrees by dewatering activities. Boreholes LEEMB18D and KENMB03D indicate recovering groundwater levels. Dewatering activities at an adjacent mine may be affecting WTN02D. Cumulative dewatering impacts from an adjacent mine and dewatering of Block OJ may have impacted borehole MOAMB7, and dewatering at Block OJ in conjunction with dewatering at an adjacent mine may have impacted borehole MOAMB10.

In order to interpret the changing cone of groundwater depression as mining progresses at the different opencasts, a scenario in 2025 (completion of mining at OL) and 2031 (completion of mining at OI) have been analysed. According to the mine schedule provided to GCS by the client in May 2019, the OI and OL mining areas are scheduled to cease mining in 2030 and 2024, respectively. By the year 2025, these opencast areas will also likely result in a lowering of the groundwater level surrounding the opencasts. It is also observed from model predictions that the extent of groundwater cone of depression around the OD, OH, OM, OJ, OWM_MN (Moabsvelden) and Block OF (Kenbar) is decreasing as the groundwater level rises in the aquifer surrounding these mined-out opencasts.

The OL Block opencast was scheduled to be mined up to the end of 2024 and therefore still has a negative impact on the groundwater levels. More than half of OI will be mined out by 2025. Mining at UB will commence in 2025 based on the schedule. The simulated extent of drawdown extends 100 m to 300 m from the active mining area.

Only the OI and UB are scheduled to be mined between 2025 and 2030. The extent of drawdown around these opencast areas range from 100 to 500m. As the mined-out opencasts start filling with water the groundwater levels around the opencast will also rebound.

The following deductions were made: the water levels could be lowered over a relatively large area around the opencasts but recover once dewatering in the pits ceases; there are several monitoring boreholes in the potential affected area that might experience a decline in water levels of 5 m or more; and the following boreholes identified during the GCS (2014) hydrocensus and older monitoring boreholes that do not form part of the current (2015 to 2019) monitoring network, will likely be impacted by dewatering (their existence should be verified):

- CBH7B – however, this borehole may no longer exist.
- Moa1, Moa2 and Moa3 – however these boreholes will likely be mined out during mining of blocks OL and OI.
- Borehole Moa4 may be exhibit groundwater level drawdown by 25 to 30 mbgl, as it is located between the OI and OL mining blocks.
- Boreholes Rie5, Rie6 and Rie7 could be impacted by dewatering, however, these boreholes are likely to be mined out in the OI block.
- Borehole ILB6 may be mined out in Block UB.
- Dewatering at Block UB may impact original monitoring boreholes WWN01 and WWN02S.

It was possible to calculate the inflow into the opencasts for each mining cut, from the numerical model. The inflows into OI Block during the first cut is (~360 m^3/day) in the OI west area. The inflow increases at the end of 2030 (~900 m^3/day) as the mining depth increases to 65-78 mbgl. The proposed Block opencast OL mining depth is shallower than OI. As a result, the expected groundwater inflows are likely to be less than Block OI. The inflows in 2019 may approach ~270 m^3/day which then increases to ~600 m^3/day at the end of 2022 (as the mining depth increases), and then decreases to ~350 m^3/day at the end of 2024. Evaporation will take place over the whole area of the opencasts, and will remove large amounts of water, particularly in the dry season.

The life of mine for the existing and proposed mining at Leeuwpan is planned until 2030. This allows sufficient time for chemical reactions to take place in the mined-out areas, overburden dumps and other potential pollution sources to produce ARD conditions. Due to mine dewatering activities, groundwater flow directions will be directed towards the mining areas. Therefore, contamination will be contained within the mining area, and limited contamination will be able to migrate away from the mining area. Effective lining of the water balancing dam and pollution control dams should be ensured, thereby preventing contamination of the underlying aquifers.

Backfilling efforts at Blocks OJ and OWM_MN are currently underway. Contamination from the mining areas is generally contained within the mining right. It is furthermore evident that several monitoring boreholes have been impacted by contaminants at the plant and dam areas.

In the post closure phase, all the opencasts are deemed to be backfilled and vegetated. Water and oxygen will likely react with the backfilled material and as a result ARD could peak during this phase. The environmental impact significance is expected to be moderate to high if not mitigated.

Groundwater contaminant plumes are likely to migrate from the mining areas once the water level in the rehabilitated pits have reached long term steady state conditions (i.e. each pit water level has reached the equilibrium level, which could also be the decant elevation). The contaminant plume emanating from the rehabilitated opencasts will have a cumulative impact on the groundwater quality as seen in the post mining simulations. The migration of contaminated water from the opencasts has been simulated for 50 and 95 years after colliery closure. The contaminant plume emanating from the Blocks OA, UB, OWM_MN and OWM_WTN opencasts will move in a north westerly direction towards the dolomitic area and the Bronkhorstspruit. The contaminant plume migrating from Blocks ODN, OD, OF, OM, OH, OG and OJ will move in a northerly direction, while the plume from OI and OL will moved in an easterly direction towards the Bronkhorstspruit. The contaminant concentration is likely to increase over time as the plume develops.

Several monitoring boreholes could be located within the long-term sulphate contaminant plume. The following boreholes identified during the GCS (2014) hydrocensus and older monitoring boreholes that do not form part of the current (2015 to 2019) monitoring network, will likely be impacted by the potential sulphate contaminant plume post-closure (their existence should be verified):

- 2628BA22008; WTN01S; CBH7B; WTN02S; 2628BA21001; Moa4; WWN01; WWN02S and EMPR02/E2.

Shallow contaminated seepage may impact on the Bronkhorstspruit. Without mitigation, the impact is likely to be moderate. Given the significance of the underlying dolomite aquifer, the interaction between the dolomite and the Karoo aquifers should be further investigated. If these aquifers are in hydraulic connection and a flow gradient form the Karoo aquifer exists towards the dolomite aquifer, the dolomitic aquifer may be impacted post closure by contaminants.

The results must be viewed with caution as a layered homogeneous aquifer has been assumed. Heterogeneities in the aquifer are unknown and the effect of this cannot be predicted. Furthermore, no chemical interaction of the sulphate with the minerals in the surrounding bedrock has been assumed. As there may be some interaction and retardation of the plume, it is likely that this prediction will represent a worst-case scenario.

Decanting occurs when the mine water level in the rehabilitated and backfilled workings rebounds to a level above the topographic elevation, resulting in mine water discharging onto surface. The expected significance of the impact is high before mitigation, and depending on the mitigation measures, the impact significance could be lowered to moderate. The decant volume and period to decant is based on a backfilled opencast with no final void and does not take evapotranspiration into account. Based on the available opencast floor elevations all the opencast floors will be inundated.

Groundwater Management Plan Update

During the construction phase, clean and dirty runoff should be separated and contained; pollution control dams should be adequately sized; dirty water runoff should be prevented from leaving the general mining area (Storm water management); the base of dirty areas, like the ROM coal stockpile, workshops and oil and diesel storage areas should be compacted; and monitoring boreholes should be monitored.

During the operational phase the impact of polluted groundwater to the mining area should be restricted and the impact on groundwater levels in the catchment mitigated by grouting and sealing all mined-out boreholes; using or pumping mine water to dirty water dams or pollution control facilities; removing as much as possible coal from the opencast mine during the operational phase; placing carbonaceous rocks and discard in the deepest part of the pit below the long-term pit water level; backfilling, compacting and rehabilitating mined-out pits as soon as possible; constructing adequately sized pollution control facilities; implementing storm water management; containing poor quality runoff from dirty areas and diverting this water to pollution control dam for re-use; monitoring groundwater levels; updating the numerical model every two (2) years by using the measured water ingress and water levels to re-calibrate and refine the impact predictive scenario; annually interpreting the monitoring results; ensuring that the rehabilitated opencasts should be free draining away from the pit to reduce drainage into the pit; drilling boreholes into the mine workings; preparing a detailed mine closure plan and updating the geochemical assessment.

The following objectives are envisaged for the closure phase: negotiate and obtain groundwater closure objectives approved by Government during the Decommissioning Phase of the project; continue with the groundwater quality and groundwater level monitoring for a period of two to four years after mining ceases; present the results of the monitoring programme to Government on an annual basis and negotiate mine closure with Government based on the results of the groundwater monitoring undertaken. The following actions should be taken: multiple-level monitoring boreholes must be constructed to monitor base-flow quality within the identified sensitive zones and to monitor groundwater level behaviour in the backfilled pits; update existing predictive tools; reduce recharge, by capping the backfill of the opencast with an impermeable layer, if practical; flooding mine areas as soon as possible; engineering backfilled opencast topography such that runoff is directed away from the opencast areas and audit the monitoring network annually.

The groundwater monitoring network design should comply with the risk-based source-pathway -receptor principle. Groundwater Monitoring should be undertaken to SANS and DWS (then DWA) requirements. One additional borehole positioned at the OL Block can be drilled and added to the monitoring network. It is envisaged that the frequency of monitoring should continue on a quarterly basis.

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1 INTRODUCTION

GCS Water and Environmental Consultants (Pty) Ltd ("GCS") was appointed by Exxaro Resources Ltd ("Exxaro") to undertake an update of the hydrogeological study conducted by GCS in 2014 at the Exxaro Leeuwpan Colliery ("Leeuwpan"), located south-east of Delmas in Mpumalanga, South Africa (refer to Figure 1-1).

Leeuwpan is a conventional opencast-pit mine with a coal reserve base of approximately 52.9 million, which utilises dense medium separation to process coal from Seam 4 and Seam 2 for supply to metals and power-generating industries. The mine is situated approximately 5 km south east of Delmas and falls within the Victor Khanye Local Municipality area, Nkangala District Municipality in the Mpumalanga Province.

Exxaro appointed GCS to undertake a hydrogeological investigation at Leeuwpan in 2014. The investigation was required for the update and consolidation of the Environmental Management Plans (EMPs) and EMP Addendums into one consolidated EIA and EMP document according to the Minerals and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) (MPRDA). In addition, the investigation also assessed the new block OI on the farm Rietkuil 249 IR (Portions 1 and 2) and Block OL on farm Moabsvelden 248 (Portion 2, 10 and 16). This also involved the authorisation of various listed activities under the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA) and the inclusion of the activities under the National Water Act, 1998 (Act No. 37 of 1998).

In 2019, the planned expansion of OI Block towards the west and the revised mining schedules necessitated an update of the GCS (2014) study. New time-series groundwater level and quality data obtained during the 5-year monitoring period were incorporated, and the most recent infrastructure plans were included. The numerical flow and contaminant transport model was updated with the latest mining plans, schedules and groundwater levels. The hydrogeological impact assessment and Groundwater Management Plan (GMP) were revised based on the changes to the mining OI and OL areas.

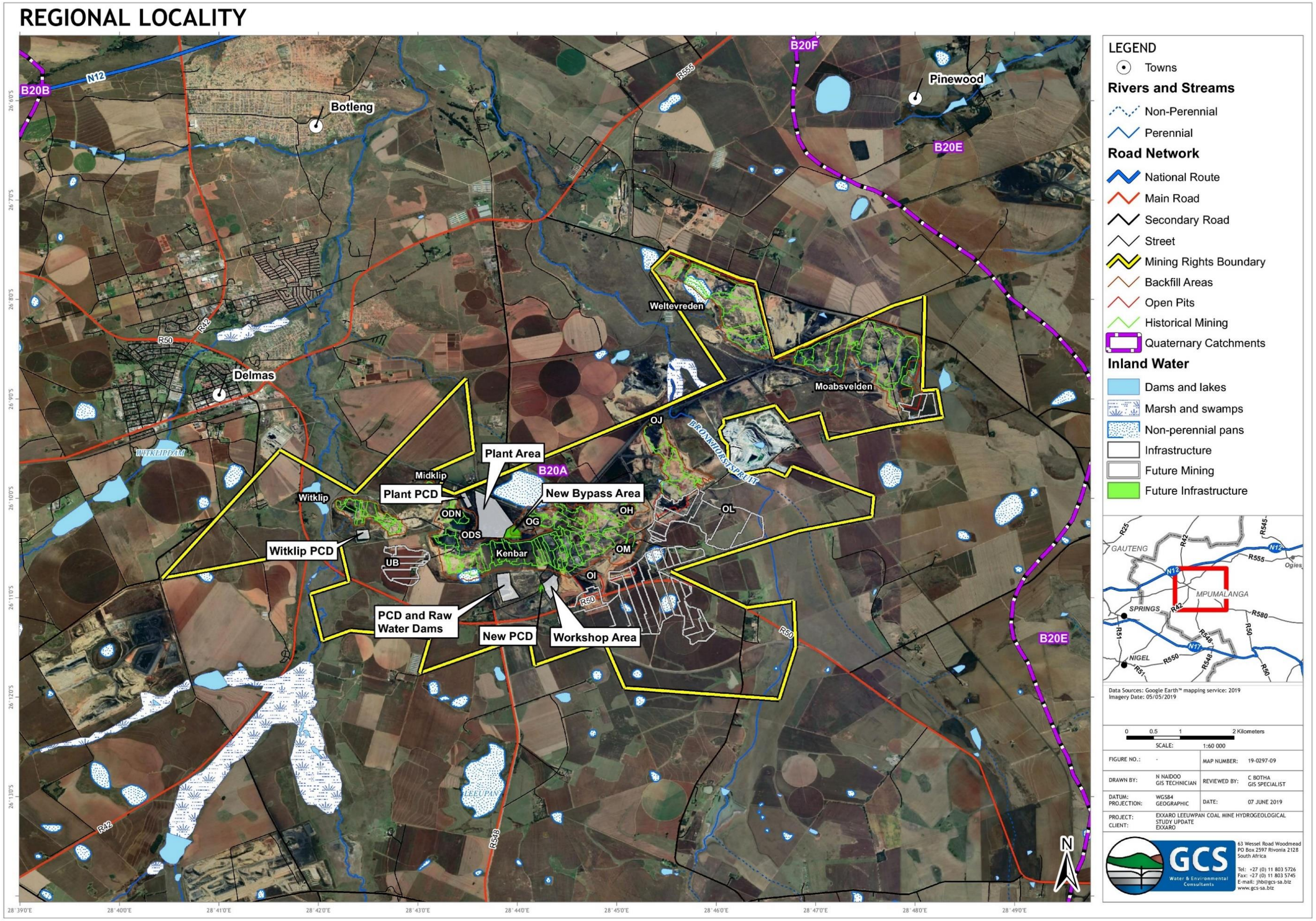


Figure 1-1: Locality Map

2 SCOPE OF WORK

The following tasks were completed for the study:

- Desktop Review
    - Project Initiation and Data Collection
    - Data Evaluation
- Conceptual Hydrogeological Model
    - Update of existing conceptual model
- Numerical Groundwater Flow and Transport Model
    - Update of model inputs
    - Model Calibration
    - Scenario Modelling
    - Hydrogeological Impact Assessment
- Groundwater Management Plan
    - Monitoring Network update
    - Groundwater Management Plan update
- Reporting
- Project Management and Meetings

3 METHODOLOGY

3.1 Desktop Review

3.1.1 Project Initiation and Data Collection

Project initiation involved the transfer of data/information from the client to GCS for the purposes of conducting this study. The client provided available information/data required to conduct the update of the hydrogeological investigation, particularly updated pit shell extents, mine infrastructure layouts and monitoring data available for the period from 2015 to 2019.

3.1.2 Data Evaluation

During the desktop study, GCS assessed available technical information including previous hydrogeological studies undertaken for the site, historical and planned pit shell extents and mine infrastructure, and groundwater level and quality monitoring data.

3.1.3 Update of existing conceptual hydrogeological model

During the previous hydrogeological study (GCS, 2014) a simplified conceptual hydrogeological model was constructed for the site. The conceptual model represents the relationship between the geological, geochemical and hydrogeological environments and their interactions with the anthropogenic environment.

The existing conceptual model was updated with the following information:

- New geological and hydrogeological data identified for the study area;
- Updated and latest pit shell extents, particularly of the expansion project of blocks OI and OL;
- Mine blocks that have been backfilled;
- Latest infrastructure plans; and
- Most recent groundwater level and quality data.

3.2 Numerical Groundwater Flow and Transport Model

3.2.1 Update of Model Inputs

The existing numerical groundwater flow and transport model for the study area was updated based on the revised conceptual model and used to re-calibrate and refine the impact predictive scenarios.

The previous model was constructed using GMS 9.1, a pre- and post-processing package for MODFLOW and MT3DMS. MODFLOW is a 3D, cell-centred, finite difference, saturated flow model developed by the United States Geological Survey (Harbaugh et al, 2005). MODFLOW can perform both steady state and transient analyses and supports a wide variety of boundary conditions and input options.

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

The existing model was updated with GMS 10.3.8. Calibration to “natural” steady-steady pre-mining conditions was achieved in the previous model. This study thus involved an update of the transient model with the latest pit shell extents and mine infrastructure and the calibration of the transient model to groundwater level and quality data measured over time.

3.2.2 Model Calibration

Transient model calibration involves the demonstration that the model can successfully simulate observed aquifer behavior over time, i.e. simulated heads for the model domain closely represent field-measured heads within a pre-established range of error and within the same timeframe. The predictive scenario setup in the previous model was updated with the latest mine plans, if different to those used at the time of study (GCS, 2014), and the simulated heads were compared to groundwater level data measured over time.

3.2.3 Scenario Modelling

The previous predictive model scenario incorporated mining backfill and discard dump activities that were existing or proposed at the time (GCS, 2014). Post-closure stress periods were also incorporated. Groundwater level drawdown during the operational phase, inflows, decant during post-closure and potential contaminant plumes were simulated.

The previous model was updated based on the revised conceptual model and the model results were used to assess potential hydrogeological impacts, including the extent of dewatering, rebounding water levels, decant locations and rates, as well as potential contaminant plume migration across the study area.

3.2.4 Hydrogeological Impact Assessment

Results of the predictive groundwater flow and contaminant plume simulations were used to assess hydrogeological impacts during the operational to post-closure phases.

3.3 Groundwater Management Plan

3.3.1 Monitoring Network Update

The existing monitoring network was evaluated in terms of its spatial and temporal representation of groundwater level and quality impacts determined or predicted for the study area, i.e. its representativeness in terms of the risk-based source-pathway-receptor principle.

3.3.2 Groundwater Management Plan Update

The GMP defined in the previous GCS study (2014) was updated according to the conceptual model and impacts deduced from the results of the updated numerical groundwater flow and contaminant transport model. Actions deemed necessary for conserving and promoting the sustainability of groundwater across the study area were reported.

4 PHYSIOGRAPHIC SETTING

4.1 Location and Climate

Leeuwpan mine is situated approximately 5 km south east of the town of Delmas and falls within the Victor Khanye Local Municipality area, Nkangala District Municipality in the Mpumalanga Province.

Leeuwpan coal mine falls under a summer rainfall region, receiving the highest rainfall reading in January and lowest in July with average mid-day temperatures of 26°C in January and 17°C in July (GCS, 2013). The rainfall station used to describe rainfall conditions on site during the GCS (2013) and GCS (2014) study was the South African Weather Service (SAWS) Delmas rain station (477309). The station recorded a Mean Annual Precipitation (MAP) of 681 mm (1907-1999).

During this investigation, rainfall data was gathered from the Leeuwpan Monitoring Station database (2017 to 2019) available on the Africa Weather Website (2019) (Figure 4-1). A complete annual dataset is only available for 2018. The rainfall patterns observed in 2018 show that the highest and lowest rainfall readings occurred later than usual when compared to previous years. A total of 602 mm of rainfall was recorded in this region during 2018. This area received the highest rainfall reading in March (156.8 mm) and lowest in August (0 mm) (Africa Weather – Leeuwpan, 2019).

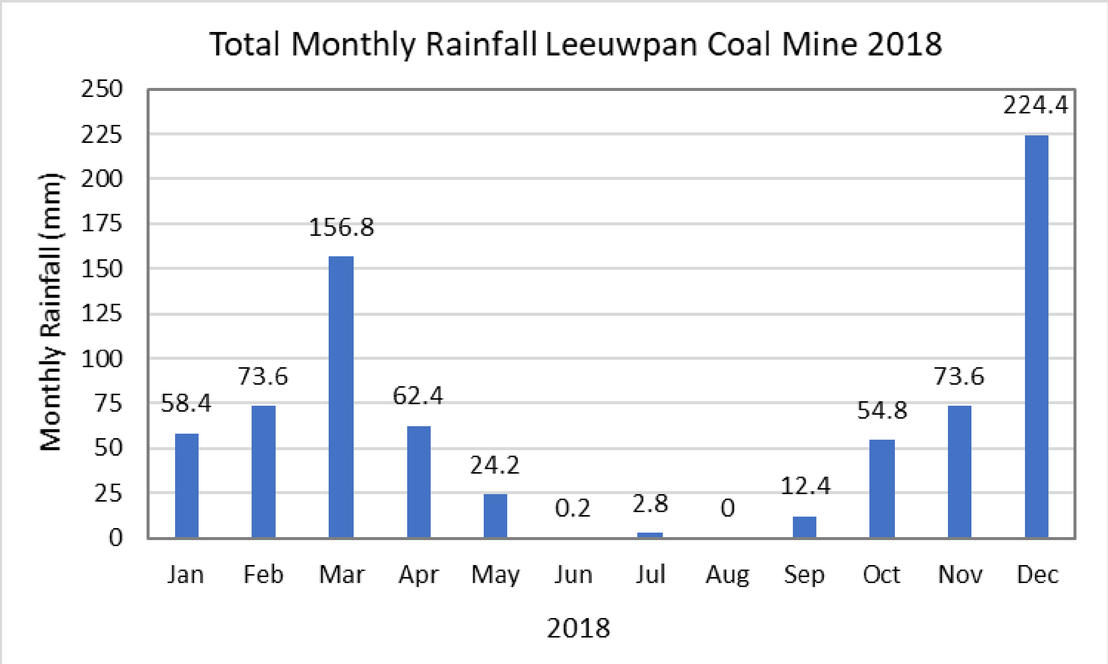


Figure 4-1: 2018 Rainfall Data (Africa Weather - Leeuwpan, 2019)

4.2 Topography and Drainage

The topography in the study area is relatively flat with a topographic high in the southern section of the mining right area. The mine is located within quaternary catchment B20A of the Olifants Water Management Area. Drainage across the study area predominantly occurs in a northerly direction and locally towards the Bronkhorstpruit River, which is flowing through the eastern to western sections of the mining right. Tributaries flow towards the Bronkhorstspruit River. Anthropogenic water bodies within the mining right include pans, farm dams, ponded water on backfilled areas, pollution control dams (PCD's), trenches, seepage at the base of opencast pits and river diversion channels.

4.3 Geological Setting

4.3.1 Regional Geology

The regional geology of the study area is presented in Figure 4-2. Sedimentary sequences of the Karoo and Transvaal Supergroups outcrop in the regional study area. Arenaceous and argillaceous rocks of the Vryheid Formation of the Ecca Group, Karoo Supergroup, include coal of the Witbank Coalfield, mined at Leeuwpan Coal Mine. The Vryheid Formation, which occurs within the larger central area of the mining right, overlies the Dwyka Group, the lowermost stratigraphic group of the Karoo Supergroup. A narrow band of Dwyka Group tillite outcrops towards the western section of the mining right. Sandstones of the Volksrust Formation of the Ecca Group, Karoo Supergroup, unconformably overly the Vryheid Formation in some areas.

Diamictite and shale of the Dwyka Group overlies chert and dolomite of the Malmani Subgroup of the Transvaal Supergroup. The Malmani Subgroup outcrops across a vast extent of the regional study area, including the eastern and far western sections of the mining right. The paleo-karst landscape of the Malmani Subgroup was present during the formation of the Karoo Supergroup, and resulted in the abnormal thickening of coal in the study area. Ferruginous shale and quartzite of the Timeball Hill Formation of the Pretoria Group, Transvaal Supergroup, outcrop north and north east of the mining right.

Jurassic dolerite dykes and sills have intruded the sedimentary rocks of the Karoo Supergroup. Localised dolerite outcrops are observed across the study area.

4.3.2 Local Geology

Surface weathering processes, the undulating tillite floor of the Dwyka Group and devolatilization and weathering due to the intrusion of dolerite dykes and sills, influence the geological and grade continuity within the study area. According to the Exxaro (2011), the overburden of the upper coal seam varies in thickness from 35 m to 90 m, and the undulating floor of the Dwyka Group controls the dip of the coal seams.

The coal measures are up to 16 m thick within the mining right are divided into a Bottom Coal Seam and Top Coal Zone. The Number 2 Seam of the Witbank Coalfield is synonymous with the Bottom Coal Seam of the mining right, and the Top Coal Zone can be correlated with the Number 4 Lower Seam, Number 4 Upper Seam and Number 5 Seam of the Witbank Coalfield (Exxaro, 2011). An interburden layer of sandstone, approximately 2 m thick and named the O-sandstone, separates the Bottom Coal Seam and Top Coal Zone.

The Top Coal Zone is on average 5 m thick and predominantly consists of dull and lustrous coal, with alternating bands of shale. The uppermost 0.5 to 0.8 m of the Top Coal Zone consists of vitrinite-rich lustrous coal (Exxaro, 2011). The Bottom Coal Seam consists of massive dull coal with scattered bands of lustrous coal, and has an average thickness of 8 m, of which the lowest 2 m consists predominantly of vitriol-rich lustrous coal. The division between the lower and middle seam is generally shale (0.4 m to 1.4 m thick). The Bottom Coal Seam overlies tillite that consists mainly of chert fragments, with a shale-rich matrix. The base of the coal is very uneven, possibly as a result of sinkholes in the dolomite, before and after coal deposition.

A coal succession in a trough-like structure (graben) is evident in the central part of the Witklip Section, and reaches a maximum thickness of 18 m. In the same section, the coal succession is capped predominantly by clay, and the capping is on average 10 m thick. At the Kenbar Section, the coal is overlain by clayey and sandy weathered sediments approximately 27m thick.

Dolerite dykes and sills have extensively intruded the Karoo Supergroup and Malmani Subgroup and are encountered within the Leeuwpan Coal mining right. A dolerite sill intrusion, of an approximate thickness of 15 m, is present at Leeuwpan and has influenced quality distribution within the coal seams due to the thermal effect. The thermal effect is directly proportional to the position and proximity of the sill in respect to the coal seams.

The dolerite sill transgresses through the coal measures on the northern border with resource block OM and overlies the majority of the OI resource, causing devolatilization to the top coal due to its proximity. The sill is a competent and hard rock layer with cooling joints on the top and bottom contacts as well as within country rock. Sub vertical chlorite and calcite filled cleats are also observed in the coal.

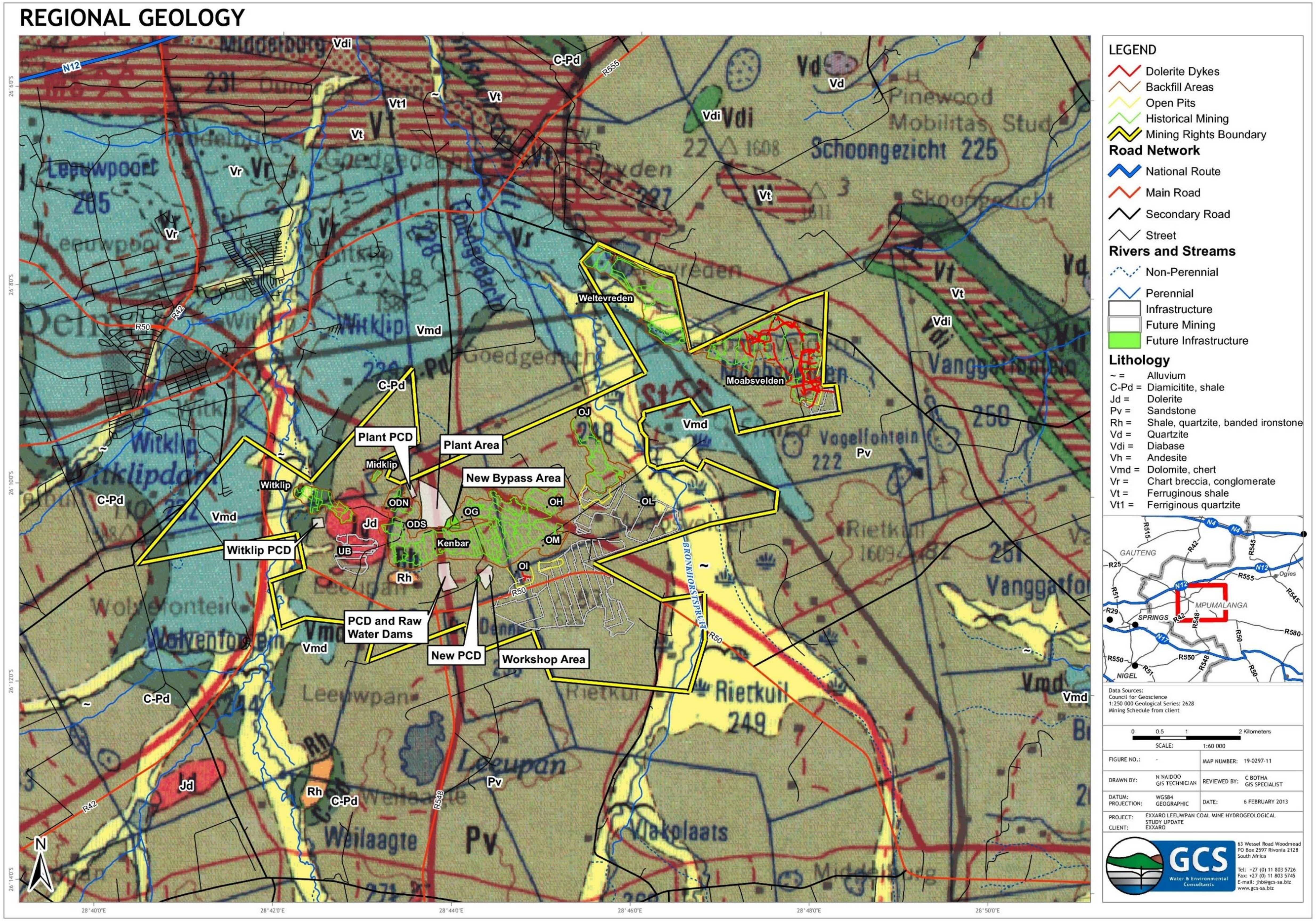


Figure 4-2: Regional Geology Map

4.4 Mining Activities

Opencast mining activities at Leeuwpan Colliery of the OF (Kenbar) pit, located to the south of the current plant area, commenced in 1992 and concluded in 2004. Thereafter mining of the OA (Witklip) pit located on the western extent of the mine commenced in 1996 and was decommissioned in March 2005. Mining at Block OE (Midklip) commenced in 1998 and was decommissioned in June 1999. The mining blocks OG, OH, OD and OM were commissioned between 1999 to 2008. These mining blocks as well as the OF (Kenbar) pit are located immediately adjacent to each other and constitute one major mining block. Mining blocks OG, OH, OD and OM were decommissioned between 2010 and 2016. Mining at Block OJ commenced in 2008 and concluded in 2018. Table 4-1 shows a summary of the current and future status of the mining blocks or pits. Figure 4-3 presents a layout of the current and future mining areas at Leeuwpan Mine.

The Wolvenfontein (UB) reserve is a westward extension of the OD and OF (Kenbar) opencast pits and mining is planned to commence in 2024 and conclude in 2029. The Weltevreden (OWM_WTN) and Moabsvelden (OWM_MN) reserves is situated approximately 4.5 km north-east of the OJ opencast pit. Opencast mining at these reserves commenced in 2011 and 2008, respectively. Block OWM_WTN was decommissioned in 2017, however, mining is currently underway in Block OWM_MN and is planned to continue until 2020.

The Block OI opencast is situated directly south-east of the OH and OM opencast mining blocks. The Block OL is located east of Block OH and south of Block OJ. The expansion of the mining activities to blocks OL and OI commenced in 2018 and is planned to continue until 2024 and 2030, respectively. Block OI is planned to extend further towards the west and has prompted an update of numerical hydrogeological model. A new PCD has also been constructed west of Block OI, and a new bypass area has been constructed at the plant area.

Stuart Coal is mining immediately north of the OWM_MN pit and north east of the OWM_WTN pit. Stuart Coal is also mining to the north of the OJ reserve. Stuart Coal and Leeuwpan share a haul road toward the OWM_MN and OWM_WTN pits. The Samquarz Silica mine is also currently in operation and located north east of the OJ opencast pit.

Table 4-1: Mine Schedule

Mine Block / Pit	Mining Dates		Current Status	Scheduled Life of Mine
	Start Date	End Date		
OA Witklip	1996	Mar-2005	Decommissioned	-
ODN	May-2008	Sep-2010	Decommissioned	-
OE Midklip	1998	Jun-1999	Decommissioned	-
OF Kenbar	1992	Mar-2004	Decommissioned	-
ODS	Mar-2004	2014	Decommissioned	-
OM	Dec-1999	2014	Decommissioned	-
OH	Sep-2002	2016	Decommissioned	-

Mine Block / Pit	Mining Dates		Current Status	Scheduled Life of Mine
	Start Date	End Date		
OG	Sep-2006	Jul-2011	Decommissioned	-
OJ	Oct-2008	2018	Decommissioned	-
OWM_WTN	Sep-2011	2017	Decommissioned	-
OWM_MN	Dec-2008	-	In Operation	2020
OL	2018	-	In Operation	2024
OI	2018	-	In Operation	2030
UB	-	-	Planned future mining	2024 - 2029

4.4.1 Mine residue

The mine residue consists of overburden and plant residue (fine and coarse). The slurry fraction recovered from the slime's dams (located west of the OB stockpile) is compacted and backfilled into to the mined-out pits. The coarser discard material is also backfilled in selective opencast areas. It is then covered with a clay layer and topsoil. Thus, no permanent mine residue disposal sites are constructed for the mining operations.

All decommissioned mining blocks have been partially to completely backfilled. Backfilling at Block OJ is currently underway. Sections of Block OWM_MN have also been backfilled; however, active mining is still underway in the block.

Overburden stockpiles are located in the area surrounding Blocks OI and OL. Backfilling at Block OI and OL will be conducted in the same manner as the other mined out pits, thus discard and slurry cake will be disposed of as part of the backfilling process.

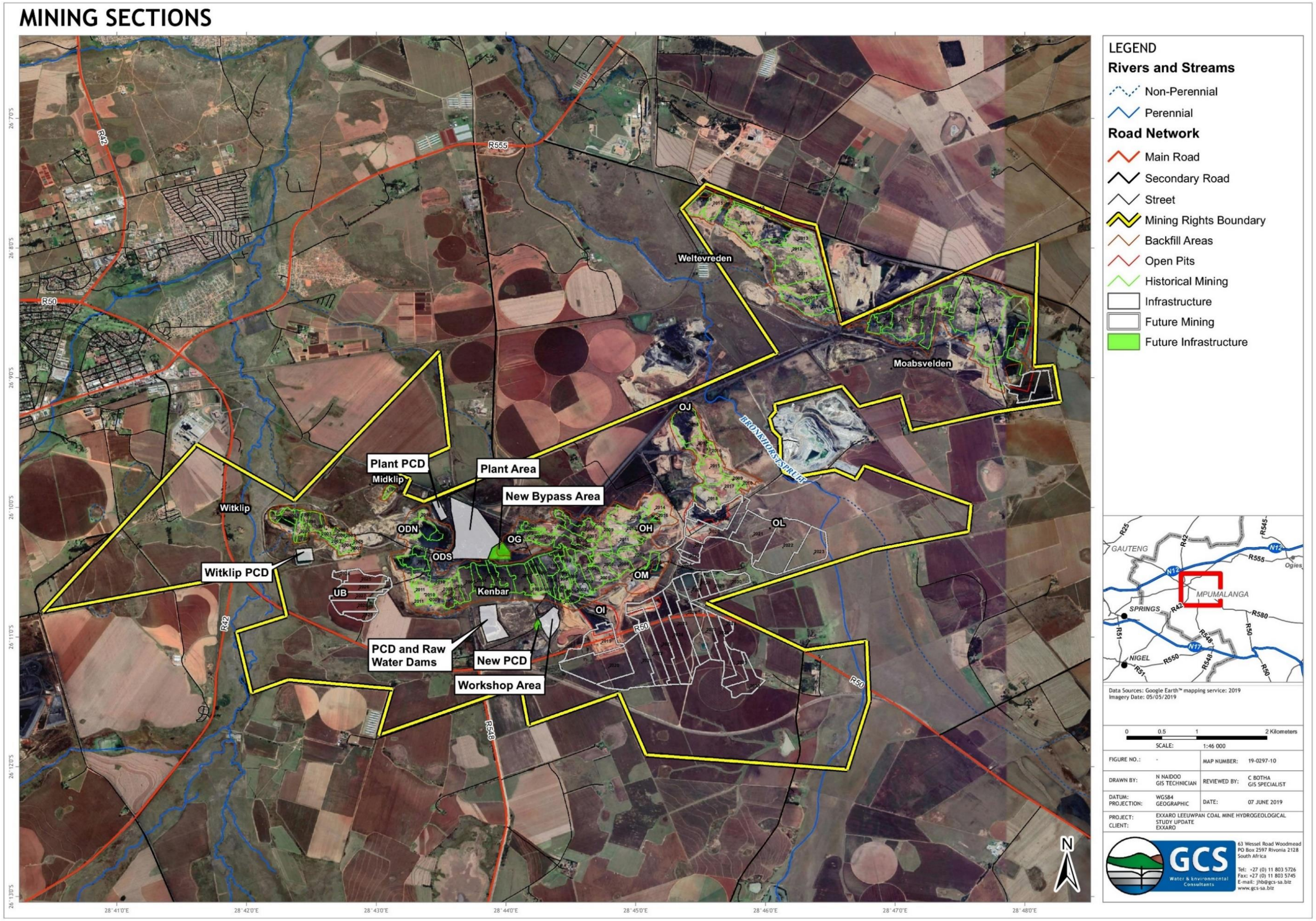


Figure 4-3: Current and future mining blocks and infrastructure

4.5 Geochemical Assessment

In 2014, a total of seventeen (17) samples were collected for geochemical testing which included one (1) soft overburden sample, one (1) sandstone sample, three (3) shale samples, eight (8) coal samples, two (2) discard samples from the plant and two (2) mixed backfill samples (comprising discard and slurry) (refer to Table 4-2).

With regards to the representativeness and quality control the following comments could be made:

- All accessible lithologies were sampled down to the mined coal at three locations in the mining pit. The complete litho-stratigraphical profile was sampled between the three locations; and
- For quality control purposes 3 (18%) of the 17 samples were analysed in duplicate in the acid-base accounting (ABA) test.

Table 4-2: Sample description

Sample ID	Rock Type	*	Description
Moabs Sandstone	Sandstone		Weathered sandstone
Moabs Shale	Shale		Highly carbonaceous
Moabs Nr 4U	Coal	4U	
Moabs Shale Interburden	Shale		Carbonaceous
Moabs Nr 4L	Coal	4L	
Moabs Nr. 2 Coal Sample 2	Coal	2	
Moabs Nr. 2 Coal Sample 1	Coal	2	
OH Shale	Shale		Highly weathered
OH Coal Sample 2	Coal	2	Burned coal with weathering to clay
OH Coal Sample 1	Coal	2	Burned coal
Weltevreden Soft Ovbn	Overburden		Soft overburden with remnants of rock
Weltevreden Weathered Coal	Coal	4	Weathered
LEEUWPAN ROM 1	ROM Coal		Run of mine coal
LEEUWPAN DIS W2	Discard/slurry cake /backfill		Discard and slurry backfilled into Witklip Pit
LEEUWPAN DIS W3	Discard/slurry cake /backfill		Discard and slurry backfilled into Witklip Pit
LEEUWPAN DIS P4	Discard		Discard
LEEUWPAN DIS P5	Discard		Discard

4.5.1 Mineralogical Composition

The mineralogy of the samples is dominated by oxide combinations of SiO_2, Al_2O_3, Fe_2O_3, and K_2O with small amounts of MnO, Cr_2O_3, MgO, CaO, P_2O_5, TiO_2, Na_2O and SO_3 forming the oxide series that combines to form chain silicates and sheet silicate minerals. In most cases the chain silicates and sheet silicates formed from the anion and cation rich oxides can act as neutralising minerals under their normal dissolution and weathering reactions. A loss of material upon ignition of the tests was observed in all samples, indicating high organic carbon and moisture content.

Phyllosilicates and tectosilicates are formed through the combination of these oxides. The high phyllosilicates and tectosilicates along with CaO, MgO and Na_2O indicate that the material does have a potential neutralising capacity and acid generation might be naturally buffered to a degree until chemical equilibrium within the aqueous system is reached and precipitation of sulphate and salt minerals can occur under saturated conditions.

The muscovite mineralogy in sandstone will possibly exist as a residual mineral after weathering of plagioclase feldspar (due to its high weathering resistance), with further exposure of these minerals to atmospheric conditions; this may result in further formation of Sericite (fine grained muscovite).

The inclusion of gypsum and dolomite (rich in calcium and magnesium) in the sandstone and discard samples, respectively, is evidence for the depositional environment of the formations with high evaporation and weathering rates.

Pyrite is present as a minor mineral in the discard sample and shale samples and is associated with the depositional environment in which the formation occurred and is commonly a trace mineral deposited along with coal. The presence of pyrite may lead to acid rock drainage (ARD) formation and thus the waste material should be managed and monitored to minimise seepage and runoff of leachate.

The average upper continental crust from Rudnick and Gao (2003) was used as reference in order to detect relatively elevated or lowered elements present in the rocks.

By comparing the trace element concentrations with the average upper continental crust elemental concentrations, the mineralogy of the material is enriched with trace elements, with the elemental concentrations of most trace elements higher than the normal crustal averages in both samples. The leachability of these elements depends highly on the acid generating potential of the material that can be countered by the neutralising minerals also present in the main mineralogy of the material. However, some metals do leach under neutral to alkaline conditions as well and leachability of elements is not necessarily driven by low pH conditions.

4.5.2 ABA and NAG tests

Acid-base Accounting (ABA) and Net-Acid Generating (NAG) tests were performed by Waterlab (Pty) Ltd. The ABA test was performed on all 17 samples and 12 samples were selected for the NAG test. From the ABA and NAG test results the following observations could be made:

- The coal and discard samples have a much higher acidification potential than neutralisation potential and a high %S (average of 0.57% and 2.04% respectively) Based on the %S and NP/AP ratio these samples have a very high potential to generate acidic drainage (Figure 4-4);
- The sandstone and soft overburden samples have a low %S and low AP with no neutralization potential. These samples have no potential for acid mine generation based on their %S and NP/AP ratio but also no significant potential to neutralise acidity generated in the mine;
- Based on the NP:AP ratio, all the samples have a possible net potential to generate acidic drainage;
- The NAG test results confirmed that the discard samples have a high potential for acid generation, while the rest of the Moabs samples are classified as uncertain or Rock Type IV;
- The sandstone and soft overburden samples have no potential for acid generation; and
- Overall, the samples have a high acidification potential with the worst-case assumptions that 1) all sulphur are from sulphides and 2) pyrite is the only sulphide present.

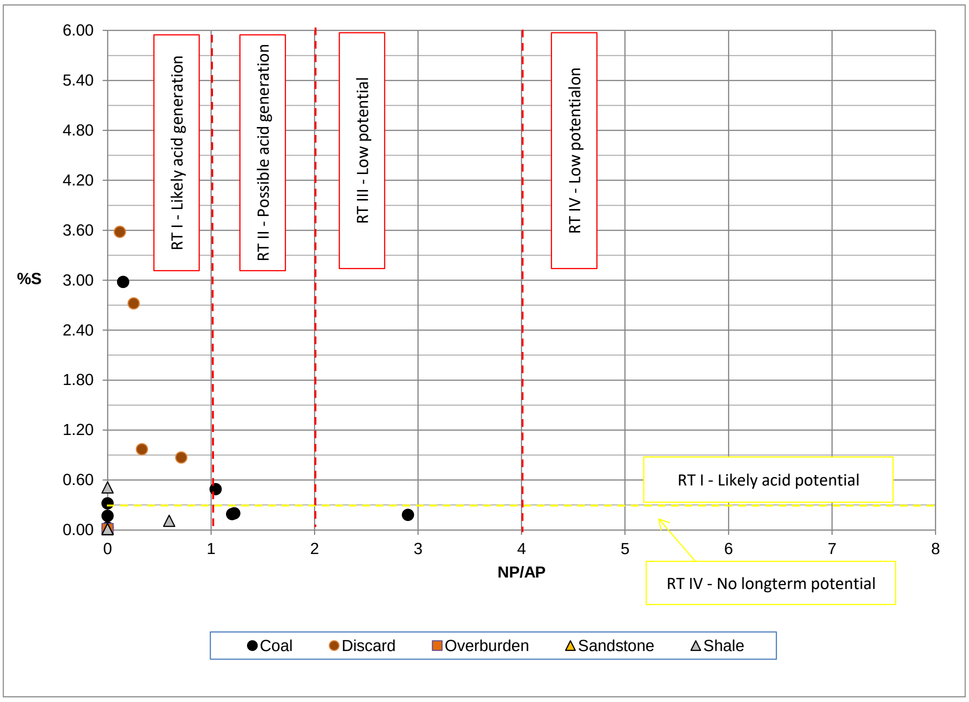


Figure 4-4: Classification of samples in terms of %S and NP/AP

4.5.3 Static Leach Testing

Selected materials were submitted for leach testing. From the leaching test results the following comments could be made:

- SO4 is the only anion that was elevated in the leachate. The elevation of SO4 is a direct result of the sulphide oxidation. High %S and AP, especially in the discard samples contribute to the elevated SO4 and acidity;
- The sandstone sample has a near-neutral pH value (6.7) which shows that the sandstone does not have a readily available net acidity. The shale samples have a pH of 7.1 and 5.2. The Moabs shale sample has a high acid potential and no neutralization potential contributing a lower pH of 5.2. Both the discard samples have higher acidification potential (AP) than neutralization potential (NP) producing lower pH values (5 and 2.9 respectively). The LEEUWPAN Discard P4 sample has an AP almost 4 times higher than the NP resulting in a very low pH of 2.9; and
- Samples with a lower pH (the samples with the highest Net Acid Potential, i.e. shale and discard) leached more metal/ trace elements. These elements include Al, As, Cr, Fe, Mn, Ni, and V.

4.5.4 Discussion

From the results of the study a first order impact assessment was performed. An environmental impact assessment is inherently a prediction of eventualities which could possibly/probably occur in future, based on an interpretation/assessment of data/information available at the time of compilation of such an assessment.

Conditions Required for Acid Mine Drainage

The following comments relate to acid mine drainage in general:

- The impact on drainage from a mine or mining waste depends on the interaction between the 1) solid, 2) water, and 3) air phase;
- The degree of acid-mine drainage will depend on the minerals present in order to generate or neutralize acidic drainage, as well as the interaction of the minerals with the oxygen and water;
- Without any of these three phases no acid mine drainage will be possible. For instance, if a mine is sealed off from the atmosphere then no oxygen ingress is possible with no resultant oxidation of sulphides; and
- If oxygen is present, but no sulphides, then mine drainage will most likely not become acidic. However, some metals may still leach at near-neutral conditions from material but at a much lower concentration than in acidic drainage.

The following comments relate to the water and oxygen ingress into the opencasts:

- During the operational phase, water is pumped from the opencasts in order to keep the pit dry. The pumped-out water has a low residence time in the pit (short contact period with rock) and no significant increase in the salt load will occur in the pit water;
- After closure the pit water level will rise until it reaches the equilibrium level, which could be the decant elevation;
- The pit backfill above the decant or equilibrium elevation will be unsaturated after closure;
- Sulphide oxidation will occur in the unsaturated zone as a result of oxygen infiltration. According to the ABA test results the waste rocks have a variable potential to generate net acidity. The sandstone and shale samples have low potential for acid generation and discard samples have a higher potential to generate acidity;
- A conceptual model of the physico-chemical processes that occur in mining waste in contact with atmosphere is depicted in Figure 4-5 below;
- Consumption of oxygen will lead to a gradient in oxygen fugacity in the material that initiates oxygen diffusion (flow from high concentration to low concentration). The oxygen concentration will be at its highest in material directly in contact with the atmosphere, and due to its consumption, the oxygen concentration will gradually become depleted within only a few metres; and
- Initially only the upper part of the material will be situated in the oxidation zone. The oxidation zone will shift deeper into the material as sulphide minerals are depleted. The temperature in the material will eventually rise due to the oxidation of sulphides. Temperature differences will result in differences in gas pressure that initiate the process of oxygen advection.

From the above discussion the following conclusion could be made:

- Acid-mine drainage will occur in the opencast mines as the material contain inadequate neutralisation potential and some contain sufficient sulphides for net acid generation (i.e. the shale and discard); and
- It is not foreseen that metals will significantly be present in neutral drainage. Al, Fe, Mn will be present at elevated concentrations in acidic mine drainage. Other metals that may leach in acidic drainage include Cr, Ni and to a lesser degree As and V.

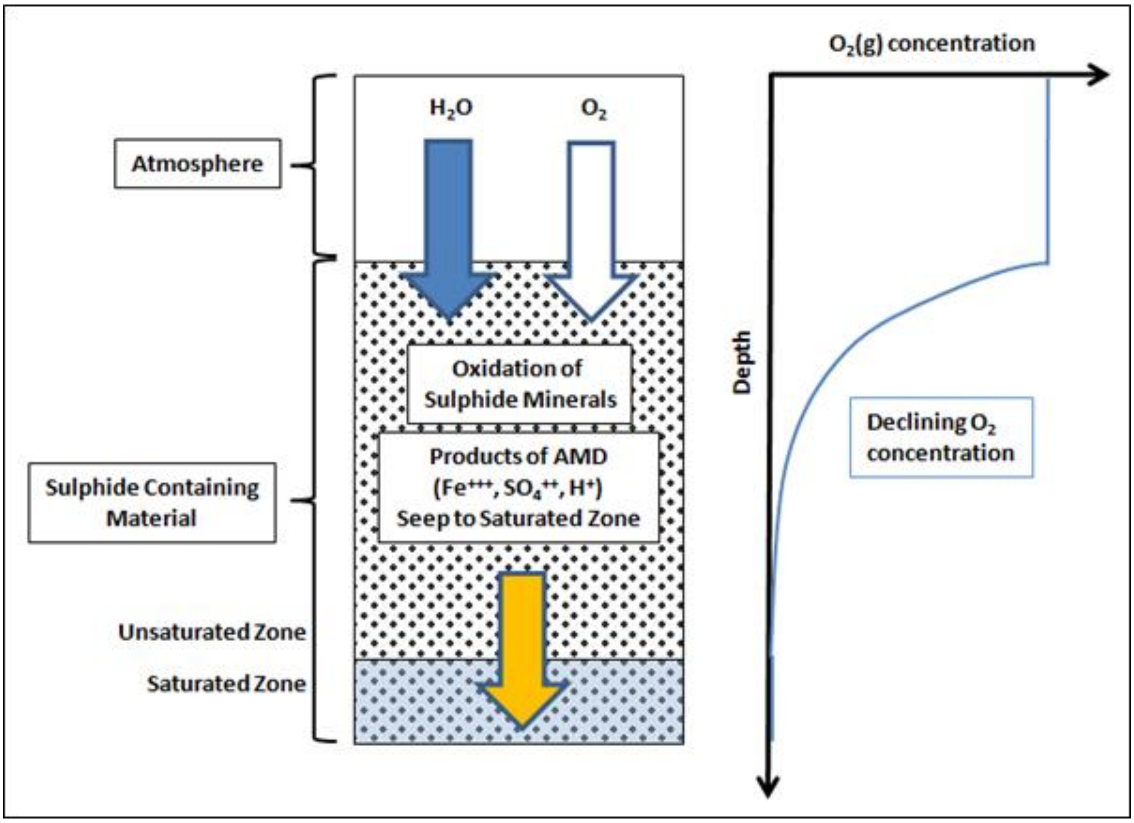


Figure 4-5: Conceptual Model of the Physico-chemical Processes in Mining Waste in Contact with the Atmosphere

Geochemical Reactions

The following observations relate to the geochemical reactions in the mine material:

- Fe is inherently associated with pyrite. The reaction of Fe^{2+} in solution under the presence of oxygen at neutral to alkaline conditions is presented in Equation 1 below. Fe^{2+} produced from the sulphide oxidation will hydrolize to form $Fe(OH)_3$ and 2 mol adicity (Equation 1);

  $$Fe^{2+} + 2.5H_2O + 0.25O_{2(aq)} \rightarrow Fe(OH)_{3(ppd)} + 2H^+ \qquad \text{Equation 1}$$

- Pyrite (FeS_2) is present in all the rock material tested. The net dissolution reaction of pyrite under neutral to alkaline oxidising conditions will form 4 mol of acidity (Equation 3). The intermediate reaction where Fe^{2+} is first formed is also shown below (Equation 2);

  $$\text{pyrite} + 3.5O_2(aq) + H_2O \rightarrow Fe^{++} + 2SO_4^{2-} + 2H^+ \qquad \text{Equation 2}$$

  $$\text{pyrite} + 3.75O_2(aq) + 3.5H_2O$$
  $$Fe(OH)_3(ppd) + 2SO_4^{2-} + 4H^+ \qquad \text{Equation 3}$$

- Water serves as the transport medium for the product of acid-mine drainage (AMD) as it percolates through the mine/waste material. The water phase also serves as the medium in which dissolution of neutralizing minerals can take place. The acid produced by the oxidation of the sulphide minerals will be consumed by calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) present in the rock. The neutralization reactions under neutral to alkaline conditions are given in Equation 4 and 5 below:

calcite + $H^+ \rightarrow HCO_3^- + Ca^{++}$ Equation 4

dolomite + $2H^+ \rightarrow 2HCO_3^- + Ca^{2+} + Mg^{2+}$ Equation 5

- Under increasing acid production (pH < 6.3) calcite and dolomite will consume additional acidity according to Equation 6 and 7 below:

calcite + $2H^+ \rightarrow CO_2(g) + Ca^{2+} + H_2O$ Equation 6

dolomite + $4H^+ \rightarrow 2CO_2(g) + Ca^{2+} + Mg^{2+} + 2H_2O$ Equation 7

- Together wil SO_4 the Ca^{2+} produced will form gypsum ($CaSO_4 \cdot 2H_2O$) as follows:

$Ca^{2+} + 2H_2O + SO_4^{2-} \rightarrow$ gypsum Equation 8

- The formation of gypsum will help to keep SO_4 values below 2 500mg/l in drainage water. However, if Ca is produced too slowly, the SO_4 concentration may reach even higher values;
- If all the carbonate minerals are depleted then the drainage from the mine material becomes acidic. Silicate minerals can also consume some of the acidity. However, silicate minerals react too slowly to prevent acidication in material with a significant potential to generate acidic drainage; and
- In acidic seepage, metals will also be leached out at elevated concentrations and the final stage of AMD would have been reached.

Expected Non-compliance in Drainage Water

The following methodology was followed in order to determine the expected non-compliance in drainage from the mine:

- The results from the ABA and leaching tests were used in order to determine expected non-compliance that may occur in seepage and pit water; and
- Generally, good correlation could be found between leaching test results and drainage from mine waste material. However, care must always be taken to interpret leaching test results for the following reasons:
  - The same water/rock ratio is not present in leaching tests than under field conditions;
  - The same water/rock contact time is not present in leaching tests than under field conditions;
  - It is assumed that the sample tested is representative of the waste material.

The following comments relate to the expected non-compliance of drainage/seepage from the mine material and discard:

- The drainage from the opencast backfill will become acidic over the long-term as the ABA results show that the material has the potential to generate acid-mine drainage. The sandstone and soft overburden have no potential for acidic generation. The shale samples show a great variance in net acidic generation, but may have a potential for acidic generation;
- Elevation of TDS and SO_4 will occur as a result of pyrite oxidation. In the open cast the SO_4 will increase roughly to about 2 500 – 3 500 mg/l over the long term;
- It is not foreseen that significant elevation in metals will occur at near-neutral conditions. After acidification non-compliance for Al, Fe and Mn may occur; and
- Cr, Ni and to a lesser degree As and V are some of the other trace elements that may be slightly elevated and may reach occasional marginal to non-compliance.

4.6 HYDROGEOLOGICAL BASELINE INFORMATION

4.6.1 General aquifer description

Three distinct aquifer types or hydrogeological units are present with the study area. These units vary by aquifer characteristics; however, the aquifers are generally interconnected by fractures and faults (GCS, 2014):

- Shallow weathered aquifer: a shallow aquifer formed within the residual and weathered zone of the Karoo Supergroup, locally perched on fresh bedrock;
- Deeper fractured aquifer: a deeper aquifer formed by fracturing of the Karoo Supergroup and dolerite intrusions; and
- Fractured karst aquifer: a fractured aquifer hosted within the dolomite- and chert-rich Malmani Subgroup.

4.6.2 Shallow weathered Aquifer

Unconsolidated colluvium and weathered sediments overlie the consolidated formations and dolerite intrusions. The underlying mudstone and siltstone bedrock often result in perched aquifer conditions. The depth of weathering generally ranges between 5 to 12 mbgl in the study area and experiences relatively high recharge from rainfall (3% of MAP) (GCS, 2014). The water level of this perched aquifer is shallow and may daylight as springs occasionally when intersected by barriers such as topography, dykes and basement highs in valleys and topographic lows/depressions (GCS, 2014). This aquifer is low yielding (0.01 – 0.14 l/s) due to the thickness. As a result, groundwater is rarely abstracted from this aquifer. This aquifer is important as it often acts as a pathway for contaminants migrating from surface activities to surface water bodies such as rivers.

4.6.3 Fractured Karoo Rock Aquifer

The Vryheid Formation of the Ecca Group, Karoo Supergroup is characterised by thick sandstone and gritstone, alternated by sandy shale and coal beds. Most of the groundwater flow associated with mining will occur along the fractures, cracks and joints that are present within Karoo Sediments, and along contacts with dolerite intrusions. These conductive zones effectively interconnect the strata of the Karoo sediments, both vertically and horizontally into a highly heterogeneous and anisotropic unit.

The dolerite sill and dyke intrusions prevalent in the Karoo Supergroup and the study area generally act as aquitards and compartmentalize the groundwater regime. However fractured contact zones between the host rock and the intrusions often represent highly conductive groundwater flow paths. The horizontally and vertically extensive nature of the dolerite intrusions means that these conductive zones are interconnected and govern groundwater flows. The aquifer characteristics of these contact zones are heterogeneous. The newly drilled boreholes where dolerite was intersected at shallow depths during drilling in 2014 did not encounter any water strikes (GCS, 2014).

The fractured Karoo aquifer can be classified as a minor (low yielding) aquifer system (Parsons, 1995) which displays variable yields and water quality. The Ecca Group is not known for the development of major aquifers, but occasional moderate - yielding boreholes may be present. This aquifer is reported to be approximately 40 m thick and exhibits characteristics of the intergranular and fractured regime (Barnard, 1999), which indicates that groundwater storage and flow occurs mainly within the fractures of the rock. Dominant yield classes vary from the 0.1 - 5.0 l/s ranges.

4.6.4 Malmani Dolomitic Aquifer

The formation consists mainly of alternating layers of chert free dolomite and chert rich dolomite (Visser, 1989). The Dwyka Group of the Karoo Supergroup separates the dolomitic aquifer from the overlying Vryheid Formation. The Dwyka tillite consists of gravelly diamictite with minor shale and mudstone that is less permeable than both the Vryheid Formation and the Malmani dolomite. The Dwyka is normally considered an aquiclude. It should however be verified if this is the case in the Leeuwpan mining area, especially as a number of dykes, sinkholes and boreholes may have connected the aquifers.

An effective depth of 300 m has been accepted as the maximum depth to which significant dissolution of the dolomite has taken place. A hydraulic conductivity that varies between 10 and 100 m/day is considered representative of the Malmani dolomite.

The Malmani Subgroup is a major aquifer system which is normally high yielding and produces good quality water. This aquifer can be classified as a karst aquifer (Barnard, 1999), denoting cavities associated with fracturing and jointing, and the groundwater yield is normally more than 5 l/s.

4.6.5 Hydrocensus and Monitoring Boreholes

4.6.5.1 Previous Hydrocensus

GCS conducted a hydrocensus in the project area during April and July 2012 within a 2 km radius of the proposed mining activities. A total of 59 boreholes were visited of which eleven (11) boreholes formed part of the existing Leeuwpan monitoring network. A total of 48 privately owned boreholes were identified of which eleven (11) boreholes were not in use. Information pertaining to water use of the 48 boreholes is shown below:

- 84% of the boreholes were used for domestic, stock watering purposes and limited irrigation;
- Thirteen (13) boreholes (68%) were used for large scale (central pivots) irrigational purposes. Some of these boreholes were also used for domestic and stock watering purposes.

The boreholes are used for mainly domestic supply, small-scale irrigation (gardens), livestock watering as well as large scale pivot irrigation of crops. The boreholes used for large scale irrigation exploit the dolomitic aquifer as the yields from the Karoo Supergroup are too low to sustain the high abstraction rates. A summary of the hydrocensus boreholes is provided in Appendix A.

4.6.5.2 Leeuwpan Monitoring Boreholes

Leeuwpan Colliery has an active groundwater monitoring programme, which originally consisted of eighteen (18) boreholes. Of the original eighteen (18) boreholes, six (6) were non-operational during the GCS (2014) study. Percussion drilling of seventeen (17) additional monitoring boreholes commenced on 21 November 2013 and was completed on 30 November 2013, including five (5) pairs of shallow and deep borehole combinations.

Between the period of 2015 to 2019, seven (7) of the original monitoring boreholes were monitored and sixteen (16) of the newly drilled boreholes. Groundwater levels were not measured for two (2) of the newly drilled boreholes (KENMB01 and KENMB2_S) during this monitoring period, however, hydrochemical results are available for the boreholes in 2015. Two (2) of the hydrocensus boreholes identified in 2012 were also monitored during this period (RIE4 and RIE10). An additional borehole has been added to the monitoring network since the GCS (2014) study (RIE10B). A total of 26 boreholes were monitored during the 2015 to 2019 monitoring period (refer to

Table 4-3 and Figure 4-6). Golder Associates assessed the monitoring results during the four (4) quarters of 2018 and the first quarter of 2019.

Table 4-3: Leeuwpan 2015 - 2019 Monitoring Network

Sample ID	Description	Coordinates (WGS84, LO29)	
		X	Y
KENMB01	Fuel dispensary	-26210.54	-2897024.26
KENMB2_D	Silver Dam 2	-26915.09	-2896734.43
KENMB2_S	Silver Dam 1	-26946.18	-2896732.5
KENMB3_D	Plant / Stockpile 1	-26967.21	-2895847.87
KENMB3_S	Plant / Stockpile 2	-26977.03	-2895839.03
LEEMB18_D	Plant Conveyor 2	-27239.58	-2895496.9
LW07	North of Witklip	-28940	-2895277
LW08	South west of Kenbar	-27282	-2897355
LWG02	South east of Kenbar	-26296	-2896700
MOAMB10	Block OI New Mine Area 1	-23468.44	-2895139.21
MOAMB4	Block OH	-25613.14	-2895412.71
MOAMB7	Block OJ / Stuart Coal Upstream	-24450.44	-2893907.47
MOAMB9	Block OI New Mine Area 2	-23301.68	-2896308.21
RIE10	Rietkuil Monitoring Borehole	-23725.82	-2899313
RIE10B	Rietkuil Monitoring Borehole	-23620.389	-2899158.569
RIE4	Rietkuil Monitoring Borehole	-23148.12	-2897771
RKL01	Rietkuil Monitoring Borehole	-25585	-2897302
RKL02	Rietkuil Monitoring Borehole	-23333	-2897155
WELMB13_D	Moabsvelden 1	-22155.85	-2892777.94
WELMB13_S	Moabsvelden 2	-22175.52	-2892795.48
WITMB14	Block OA	-29453.45	-2895360.47
WOLMB15_D	ODN/PCD1	-27626.03	-2895239.12
WOLMB15_S	ODN/PCD2	-27611.42	-2895244.74
WTN02D	Weltevreden Monitoring Borehole	-23069	-2893073
WWN02D	Wolwenfontein Monitoring Borehole	-28169	-2896156
WWNMB16	Block UB	-28888.23	-2896643.72

4.6.5.3 2013/2014 Monitoring Borehole Siting and Drilling (GCS, 2014)

GCS conducted a geophysical investigation between 23 October 2013 and 31 October 2013 with the intent of siting the monitoring boreholes drilled in 2013. No major anomalies were identified during the investigation.

Percussion drilling of seventeen (17) additional monitoring boreholes commenced on 21 November 2013 and were completed on 30 November 2013. Drilling depths ranged between 10 and 55 m. There were five (5) pairs of shallow and deep borehole combinations included in the drilling programme. The boreholes were drilled at a diameter of 203 mm to a depth with more competent rock and thereafter drilled at a diameter of 165 mm to completion. None of the boreholes intercepted dolomite of the Malmani Subgroup.

The upper 5 m to maximum 26 m consisted of clay-rich regolith of weathered Karoo mudstone and dolerite. Boreholes located on the outskirts of the site generally intersected less clay and more colluvial and tillite materials. The presence of dolerite in boreholes KENMB01, KENMB2_D, LEEMB18_D and WOLMB15_D was encountered at depths varying from 8 mbgl to 10 mbgl. A dolerite sill is likely to cover the areas near Block ODN, OD, OI, OL, and eastern portions of OWN_MN as identified by aeromagnetic data (Mahanyele, 2010). The weathered dolerite sill has weathered to clay in these areas at shallow depths. The Dwyka tillite depths across the site varied from 13 mbgl to as deep as 54 mbgl.

The water strikes intersected during the drilling program was encountered on contact zones between highly weathered rock or materials and more competent rock. No water strikes were encountered within the dolerite sill. Only 2 of the 17 boreholes had water strikes in excess of 1.5 l/s. MOAMB10 intersected water within the tillite at 26 mbgl. WITMB14 intersected 5 l/s on the contact of tillite and sandstone at 13 m. The aquifer can generally be considered a minor aquifer based on the drilling.

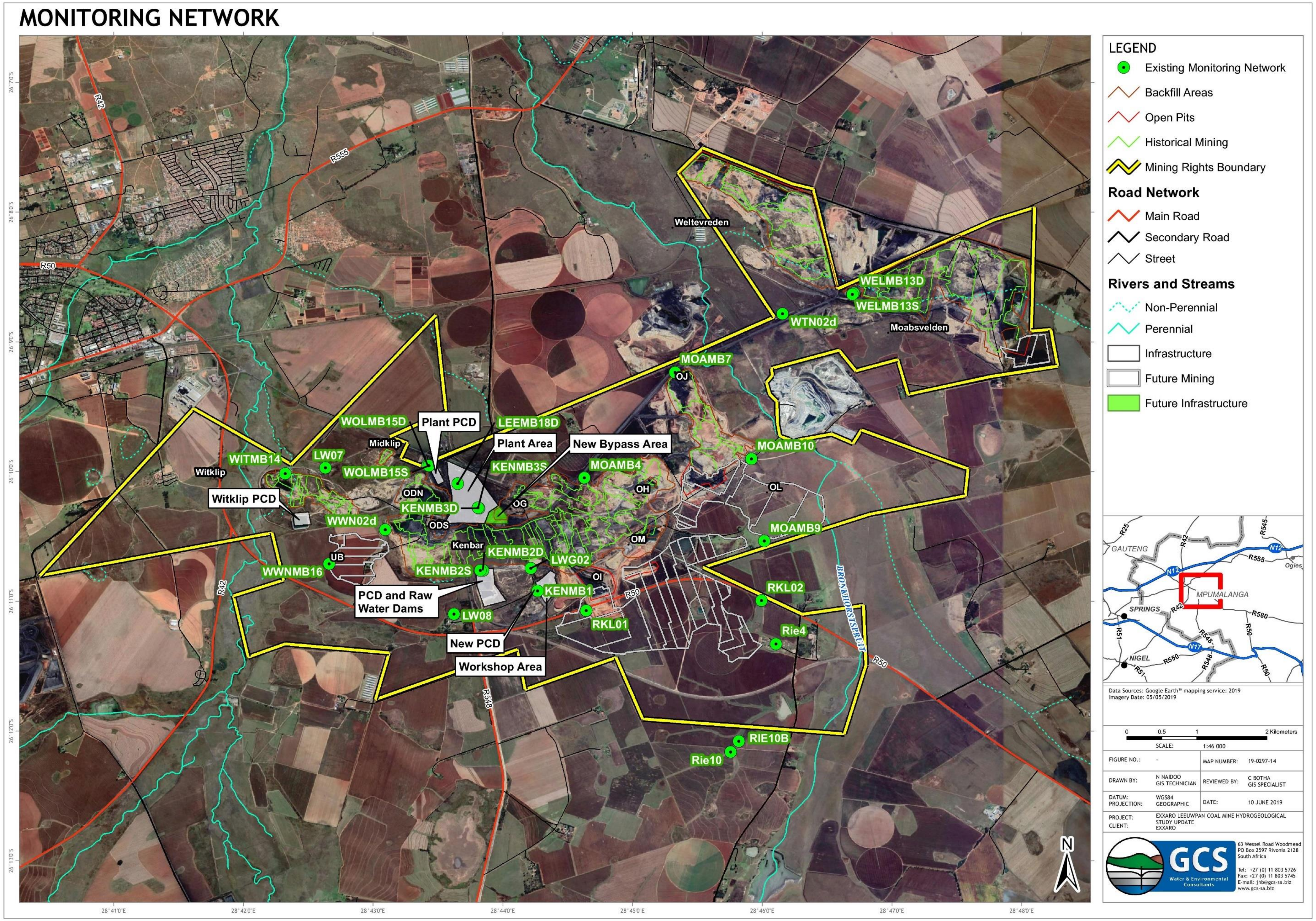


Figure 4-6: 2015 to 2019 Monitoring Network

4.6.6 Groundwater Levels

Groundwater levels were measured in accessible monitoring boreholes between 2015 to 2019. Groundwater levels recorded in the GCS (2014) study were also included during the assessment of the monitoring network. Seasonal fluctuations are evident in most boreholes, with several boreholes exhibiting impacted water levels by either mining activities or abstraction activities.

During the GCS (2014) study, a linear correlation was observed between groundwater levels and surface topography elevations. A good correlation of groundwater levels in the shallow weathered Karoo aquifer was found (R^2 = 95%). The correlation of groundwater levels versus surface topography in the deeper fractured Karoo aquifer was poor to fair (61%) as can be expected due to heterogeneities and minor impact by mining activities. The correlation of all the boreholes grouped together was also good at 84%. This evidence suggested that the groundwater levels for the area generally follow topography in the absence of anthropogenic activities in the identified aquifers.

The water levels of mine monitoring boreholes drilled into the shallow weathered Karoo aquifer are relative shallow and ranged from 1.9 to 9.8 mbgl with an average groundwater level of 7 mbgl. The static water levels of the borehole's representative of the deeper fractured Karoo aquifer ranged between 2.1 and 53 mbgl with the average calculated as 16.6 mbgl.

Based on the GCS (2014) study, boreholes included in the 2015 to 2019 monitoring study do not intercept the dolomitic aquifer. However, the depth of boreholes RIE4, RIE10 and RIE10B are unknown and it should be verified whether these boreholes intercept the dolomitic aquifer. Therefore, the groundwater levels of the karst aquifer cannot be assessed during this investigation. According to GCS (2014), the groundwater levels ranged from 5.5 to 34 mbgl and averaged at ~17 mbgl within the dolomitic aquifer.

Groundwater flows predominantly towards the northwest and northeast, following the topography towards drainage lines. Local groundwater divides are evident around RKL01 and RKL02, as well as MOAMB4 and WOLMB15D. Slightly lowered groundwater levels are observed within the Kenbar area. Groundwater depressions, deeper than anticipated for the natural groundwater table, are evident at boreholes MOAMB7 and MOAMB9, likely attributed to cumulative dewatering impacts from an adjacent mine and Block OJ at MOAMB7, and surrounding abstraction activities at MOAMB9. However, continued monitoring is required to assess the activities potentially impacting the groundwater in these areas.

The time-series water level graphs for the 2015 to 2019 monitoring boreholes have been included in Appendix B. The following observations have been made based on the monitoring data:

- It is postulated that the following boreholes are currently, or have been historically, affected by mine dewatering:
    - LWG02 – average groundwater level of ~28 mbgl;
    - KENMB02D – water level slightly increased from 2013 (24 mbgl) to early-2016 (17.5 mbgl), but gradually decreased from this period onwards (24.5 mbgl);
    - WWN02D – water level significantly decreased from ~3 mbgl in 2012 to 18 mbgl in 2015. The water level gradually recovered to ~2 mbgl in mid-2015 but declined to ~15 mbgl in March 2019.
    - MOAMB7 – water level decreased from ~35 mbgl in 2013 to ~39 mbgl in 2016, with minor recovery observed. The deep groundwater level is potentially attributed to the cumulative effect of historical dewatering at Block OJ and dewatering at an adjacent mine.
    - WTN02D – historical dewatering at an adjacent mine potentially resulted in the deep groundwater level of ~29 mbgl observed in WTN02D in 2012. The water level significantly recovered to ~2 mbgl in 2017. Water level measurements were not taken subsequent to 2017.
    - LEEMB18D – the water level has gradually increased from ~14 mbgl in 2015 to ~7 mbgl in 2019.
    - KENMB03D – the water level has gradually increased from ~20 mbgl in 2015 to ~13 mbgl in 2018.
    - KENMB03S - the water level has gradually increased from ~9.3 mbgl in 2015 to ~6.9 mbgl in 2018.
    - WOLMB15S - the water level has gradually increased from ~7.9 mbgl in 2013 to ~1.3 mbgl in 2019.
    - WOLMB15D - the water level has gradually increased from ~9.3 mbgl in 2015 to ~2.3 mbgl in 2019.
    - Boreholes within the plant area have exhibited increasing groundwater levels, likely due to the cessation of dewatering in the surrounding mine blocks.
- The water levels in the following boreholes indicate a low impact by an anthropogenic activity, potentially mine dewatering:
    - MOAMB4 – the water level decreased from ~9 mbgl in 2013 to ~16 mbgl in 2016. Minor recovery was subsequently observed.
    - MOAMB10 – groundwater level fluctuations indicate an impact by an anthropogenic activity, potentially cumulative dewatering impacts by Block OI and OJ, and an adjacent mine.

- WELMB13D – groundwater level is on average ~18 mbgl, with an isolated increase recorded in 2016. The water level subsequently declined to ~18 mbgl.
- WELMB13S – dewatering could have resulted in a groundwater level decline from ~2 mbgl in 2013 to ~7 mbgl in 2015, however, the water level has subsequently recovered.

- It is postulated that the following boreholes are not affected by mine dewatering, however, some are potentially impacted by abstraction activities:
  - LW07, WITMB14, WWNMB16, LW08, RKL01, RKL02, RIE4, RIE10, RIE10B and MOAMB9
  - Those boreholes potentially impacted by abstraction activities, include:
    - WWNMB16 – a ~7 m decline in the water level was recorded in June 2017, however the water level subsequently recovered to ~13.5 mbgl in March 2018.
    - LW08 – prominent water level fluctuations observed;
    - RIE10B – decrease in water level from ~23 mbgl in 2015 to ~33 mbgl in March 2016, with subsequent gradual groundwater level rise to ~22 mbgl in 2019;
    - RKL02 – water level decreased from ~3 mbgl in 2012 to ~9 mbgl in 2015, with gradual recovery to ~3 mbgl in 2019;
    - MOAMB9 – significant groundwater level decrease observed from ~12 mbgl in 2013 to ~44 mbgl in 2015. The water level has subsequently remained constant at ~49 mbgl.

4.6.7 Groundwater Quality

Groundwater quality sampling was conducted in 2012 during a hydrocensus, in 2013 and 2014 after additional monitoring boreholes were drilled for the GCS (2014) study and during the 2015 to 2019 monitoring network.

The following sections summarise the groundwater quality interpretations of the GCS (2014) study and provides an analysis of the 2015 to 2019 monitoring data.

4.6.7.1 Groundwater quality (GCS, 2014)

During the GCS (2014) study, total of 41 groundwater samples taken during the hydrocensus and from existing and newly drilled monitoring boreholes were analysed. The results were compared to the Department of Water Affairs' South African Water Quality Guidelines for Domestic Use Target Values (DWA SAWQTV) and South Africa National Standard (SANS 241-1:2011) Drinking Water Standard in order to evaluate the water quality. The average background groundwater quality was also included in the analytical result tables for comparative purposes. The baseline groundwater characteristics were presented with Piper- and Stiff diagrams for the analytical results of groundwater collected from hydrocensus and monitoring boreholes.

Hydrocensus Water Quality Results (2012) (GCS, 2014)

In 2012, GCS collected a total of 16 water samples for the hydrocensus. These samples were mostly obtained from production boreholes used for domestic and livestock water supply. The results indicated that Rie1 and Rie2 exceeded SANS 241 Drinking water limits for nitrates (NO_3), while Rie5 exceeded the manganese and iron concentration limits. The remainder of the collected samples remained compliant to the relevant limits of drinking water specified above. With the use of piper and stiff diagrams, most of the hydrocensus water samples indicated water with a calcium-magnesium-bicarbonate nature, which is indicative of an aquifer of dolomitic nature. Several of the privately-owned hydrocensus boreholes intercept the dolomitic aquifer.

Existing Monitoring Boreholes' Water Quality Results (2012) (GCS, 2014)

A few of the existing groundwater monitoring boreholes indicated exceedance of the SANS 241 Drinking water standard including monitoring boreholes WTN02S, which exceeded the fluoride concentration standard, WTN02S and WTN01S, which exceeded the manganese concentration standard, monitoring boreholes E2, WWN02S and WWN02D exceeded the iron concentration standard, and WWN01 slightly exceeded the sulphate concentration standard. The WWN02D and WWN02S sulphate concentrations remained compliant with the SANS 241 Drinking water standard but exceeded the SAWG Domestic Use Target Value for sulphate. Boreholes WWN01, WWN02S and WWN02D are located upgradient of the dam west of Block ODS. By plotting the results on a piper diagram, it was evident that boreholes WWN02D, WWN02S, WTN02S and WWN01 had a sulphate-dominant hydrochemical character, which suggests mining-related impacts. The rest of the monitoring boreholes indicate a more calcium-magnesium-bicarbonate nature.

New Monitoring Boreholes Water Quality Results (2013 - 2014) (GCS, 2014)

Subsequent to the 2013 drilling of additional monitoring boreholes, fourteen (14) groundwater samples were collected from water-bearing boreholes. Six (6) samples were collected during aquifer tests and eight additional groundwater samples were collected using bailors in January 2014. Borehole KENMB01, KENMB2_S and LEEMB18_S could not be sampled due an insufficient water column in the boreholes at the time of sampling.

Boreholes KENMB03D, MOAMB10, LEEMB18D and KENMB02D exceeded the SANS 241 Drinking water standard for sulphate concentration, while KENMB03D, MOAMB10 and KENMB02D exceeded the standard for total dissolved solids (TDS). Boreholes MOAMB10 and WELMB13D exceeded the SANS 241 Drinking water standard for manganese concentration while KENMB02D and WELMB13D exceeded the iron concentration and electrical conductivity (EC) standards.

It was determined with the use of piper and stiff diagrams, that the dominant water type is calcium/magnesium-sulphate rich which is potentially indicative of mining related impacts. Only boreholes WITMB14, KENMB03S, WWNMB16 and MOAMB9 exhibited a calcium/magnesium-bicarbonate water type.

Spatial Analysis (GCS, 2014)

The hydrochemical results of all samples were spatially analyzed to determine the collective influence of contamination across the Leeuwpan Mine area. The dominant water type was determined as calcium/magnesium-bicarbonate and it was concluded that water was mostly un-impacted from mining activity (refer to Figure 4-7). The secondary water type was found to be calcium/magnesium-sulphate-chloride, which is indicative of the impact of mining activities on groundwater. Sodium-bicarbonate type was also present in the mine area.

Each mining section was discussed in the headings below:

Plant, PCD, OF Block Opencast

The sulphate concentrations were high in boreholes LEEMB18D, KENMB03S, KENMB03D, and KENMB02D located within the plant area. Boreholes WOLMB15S and WOLMB15D located down gradient of the plant PCD also indicated potential impacts by mining related activities.

OWM_WTN and OWM_MN Block Opencast

High sulphate concentrations were also encountered in the north easterly part of the mine toward the Moabsvelden and Weltevreden pits in boreholes, WTN02D, WTN02S, WELMB13S and WELMB13D. Deep and shallow boreholes (WELMB13D and WELMB13S) located down gradient of the OWM_MN Block (Moabsvelden) opencast were also potentially impacted by mining related contaminants. Boreholes WTN02S and WTN02D are located adjacent to a haul road and was most likely impacted by a secondary source. The shallow borehole WTN02S contained sulphate concentrations above the background levels (although still compliant). It is likely that this borehole had been impacted by a shallow contaminant source associated with the haul road (coal spillage).

OJ Block Opencast

The borehole MOAMB10 located adjacent to OJ Block opencast had been negatively impacted by mining in term of elevated sulphate, TDS and EC. The private borehole Moa1 contained elevated SO_4 concentrations (although still complaint), it is however unlikely to be directly impacted by mining related activities.

Emergency overflow dam

The borehole KENMB02D located down gradient of the No. 5. Emergency overflow dam exhibited EC, TDS and sulphate concentrations exceeding the SANS 241 Drinking water standard and calcium and magnesium concentrations exceeding the SAWG Domestic Use Target Values. The elevated constituent concentrations indicated an impact by mining related contaminants.

Earth dam west of Block OD opencast

Boreholes WWN02S, WWN02D and WNN01 are located adjacent to a dam west of the OD block opencast and could also have been impacted by mining related contaminants, as elevated EC, TDS, sulphate, calcium and magnesium concentrations exceeded the SAWG Domestic Use Target Value.

OA Block (Witklip) Opencast

Borehole WITMB14 located down gradient of the Witklip pit (Block OA) exhibited elevated EC, TDS, calcium and magnesium concentrations above the SAWG Domestic Use Target Values, which indicated a potential impact by mining related contaminants.

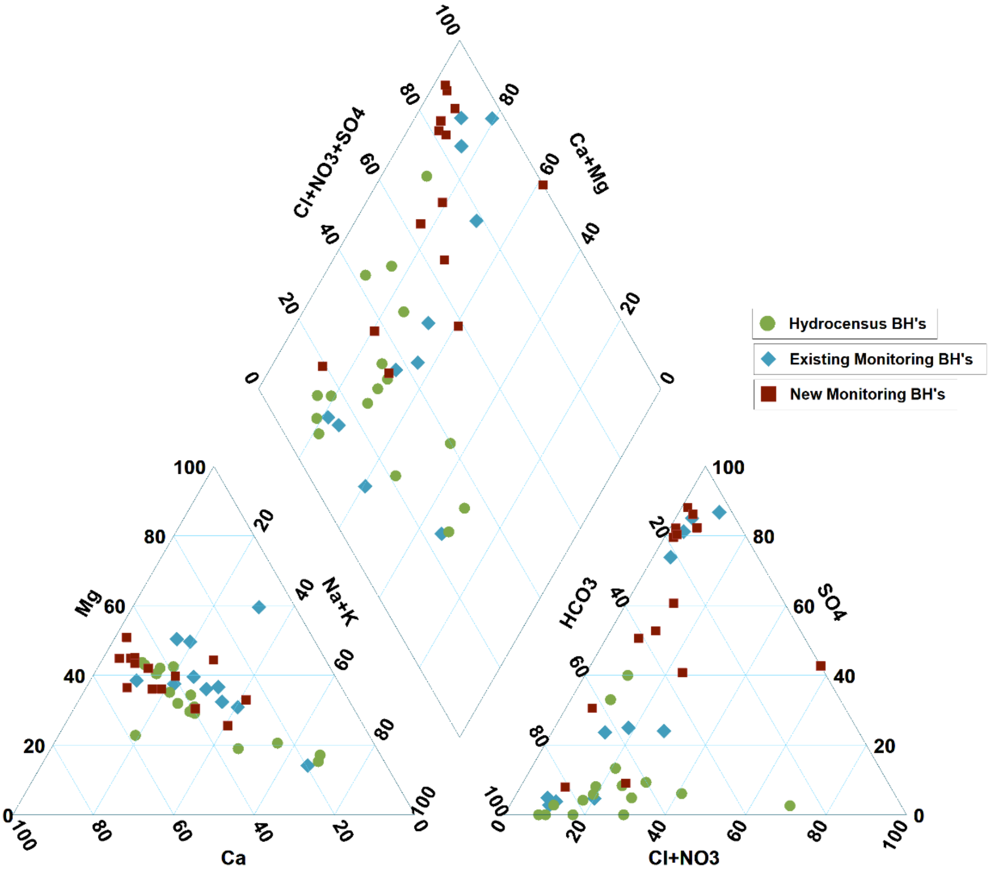


Figure 4-7: Piper plot of 2012 hydrocensus and monitoring results, and 2013-2014 monitoring results

4.6.7.2 Groundwater quality of 2015 to 2019 monitoring record

The groundwater quality results of the 2015 to 2019 monitoring network were made available by Leeuwpan Coal Mine and interpreted during this investigation. The results were compared to the Department of Water Affairs' South African Water Quality Guidelines for Domestic Use Target Values (DWA SAWQTV) and South Africa National Standard (SANS 241-1:2015) Drinking Water Standard in order to evaluate the water quality. TDS, pH, sulphate and iron time-series graphs were created for the monitoring boreholes with relevant time-series data and included in Appendix C.

A summary of the results for each monitoring borehole follows:

- KENMB01 – in 2015 EC, calcium, and magnesium concentrations exceeded DWA SAWQTV for Domestic Use while nickel exceeded the SANS 241-1:2015 Drinking Water Standard.
- KENMB02D – EC, TDS and sulphate concentrations have continuously exceeded both the DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard

since September 2015 till March 2019. Conductivity and sulphate concentrations show an increasing trend but have stabilized. Magnesium and calcium concentrations have continuously exceeded the DWA SAWQTV for Domestic Use since July 2015 but have maintained a relatively constant concentration trend. Iron exceeded the DWA SAWQTV for Domestic Use during December 2019 but has remained predominantly compliant.

- KENMB02S - EC, sulphate and manganese concentrations exceeded both the DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard during the January 2015 sampling event. Calcium and magnesium concentrations significantly exceeded the DWA SAWQTV for Domestic Use.
- KENMB03D - relatively compliant, with an isolated exceedance of the sulphate concentration in terms of the DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard during the June 2016 sampling event. TDS, calcium and magnesium concentrations exceeded DWA SAWQTV for Domestic Use during the same sampling event. Copper also exceeded the DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard during the December 2015 sampling event. Since the start of 2015, fluoride and iron concentrations exceeded the DWA SAWQTV for Domestic Use only once.
- KENMB03S - nitrate concentration exceeded both the DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard during the June 2016 sampling event. EC, TDS and calcium concentrations continuously exceeded the DWA SAWQTV for Domestic Use since January 2015, however concentrations were relatively stable Sulphates, magnesium, manganese, nitrate and sodium exceeded the DWA SAWQTV for Domestic Use intermittently. An isolated peak in constituent concentrations, including EC, TDS, sulphate and sodium was observed in September 2018, with a slight decrease in the constituent concentrations subsequently recorded in December 2018.
- LEEMB18D – TDS has intermittently exceeded the SANS 241-1:2015 Drinking Water Standard, while continuously exceeding DWA SAWQTV for Domestic Use since January 2015. Sulphate has predominantly exceeded both the DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard. EC, calcium, and magnesium concentrations continuously exceeded the DWA SAWQTV for Domestic Use since January 2015. Iron and manganese concentrations intermittently exceeded the DWA SAWQTV for Domestic Use but have been compliant during the past two sampling events.
- LW07 - iron and manganese concentrations continuously exceeded the DWA SAWQTV for Domestic Use since August 2015. Calcium slightly exceeded DWA SAWQTV for

Domestic Use during the March 2019 sampling event. LW07 has mostly remained compliant with both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard.

- LW08 - iron and manganese concentrations continuously exceeded DWA SAWQTV for Domestic Use since July 2015. During March 2016 iron exceeded both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard. LW08 has mostly remained compliant with both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard.
- LWG02 - sulphates, iron and manganese concentrations exceeded DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard in the latter part of 2015. EC and TDS also exceeded DWA SAWQTV for Domestic Use in the latter part of 2015, however, calcium and magnesium concentrations exceeded these standards throughout 2015. The groundwater has remained compliant since 2016, with only manganese being intermittently elevated.
- MOAMB10- EC, TDS, calcium, magnesium, sulphate and manganese concentrations exceeded DWA SAWQTV for Domestic Use during July 2015 and December 2016. TDS, sulphate and manganese also exceeded the SANS 241-1:2015 Drinking Water Standard during these two (2) sampling events. Nitrate exceeded both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard during January 2015 and May 2017 sampling events. MOAMB10 has remained compliant with both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard since 2018.
- MOAMB4 – EC and TDS were elevated above the DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard (TDS only) from September 2015 to March 2016, with a slightly acidic pH. Low EC and TDS concentrations were recorded from 2016 onwards. Iron and manganese were intermittently elevated between 2015 to mid-2018, with manganese predominantly exceeding the SANS 241-1:2015 Drinking Water Standard. Groundwater quality was compliant during the latter part of 2018.
- MOAMB7 – exhibited slightly acidic pH levels throughout the monitoring period, with intermittently elevated manganese concentrations exceeding the DWA SAWQTV for Domestic Use. MOAMB7 predominantly complies with both DWA SAWQTV for Domestic Use and the SANS 241-1:2015 Drinking Water Standard.
- MOAMB9 - iron and manganese concentrations have continuously exceeded the DWA SAWQTV for Domestic Use since August 2015. Except for iron and manganese concentration exceedance, MOAMB9 currently complies with both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard.

- RIE4 – Nitrate, aluminium and iron were significantly elevated above the SANS 241-1:2015 Drinking Water Standard in 2012. In March 2019, only iron and manganese concentrations exceeded the SANS 241-1:2015 Drinking Water Standard.
- RIE10 - calcium exceeded DWA SAWQTV for Domestic Use during the latter part of 2018, and manganese was elevated in June 2018. RIE10 has mostly remained compliant with both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard.
- RIE10B – calcium has predominantly exceeded DWA SAWQTV for Domestic Use, but not significantly. Nitrate, aluminium, iron and manganese intermittently exceeded the DWA SAWQTV for Domestic Use during the monitoring period. RIE10B has predominantly complied with both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard.
- RKL01 - iron and manganese concentrations have predominantly exceeded both DWA SAWQTV for Domestic Use and SANS 241-1:2015 since July 2015. Calcium exceeded the DWA SAWQTV for Domestic Use during December 2018 and March 2019 sampling events. Iron has been significantly elevated and should be monitored, however, iron concentrations in the last two sampling events were the lowest recorded. An increase in EC, TDS and sulphate concentrations was observed during the last two sampling events and could be indicative of a trend of increasing constituent concentrations, which should be closely monitored. RKL01 is predominantly compliant with both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard.
- RKL02 - iron and manganese concentrations have been consistently elevated above DWA SAWQTV for Domestic Use and/or the SANS 241-1:2015 Drinking Water Standard since mid-2015. Calcium concentration exceeded the DWA SAWQTV for Domestic Use during March 2017. RKL02 predominantly complies with both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard, except for elevated iron and manganese concentrations.
- WELMB13D – slightly acidic pH levels were recorded for most of the monitoring period, however, since March 2017 the pH level has increased to near neutral levels. Iron and manganese are continuously elevated, with iron intermittently exceeding both the DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard. However, iron and manganese concentrations have predominantly decreased with the increase in pH of the groundwater. WELMB13D is predominantly compliant to both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard.

- WELMB13S – since September 2018, TDS, EC, calcium, magnesium, sulphate, iron and manganese have been significantly elevated, exceeding the DWA SAWQTV for Domestic Use and/or SANS 241-1:2015 Drinking Water Standard. Prior to 2018, calcium and magnesium were intermittently elevated, with iron and manganese continuously elevated between July 2015 and December 2016. EC, TDS and sulphate were slightly elevated in December 2015. A distinct deterioration in the water quality is evident from mid-2018 and should be monitored continuously.
- WITMB14 - EC, TDS, calcium and magnesium concentrations have intermittently exceeded the DWA SAWQTV for Domestic Use. Iron and manganese concentrations exceeded DWA SAWQTV for Domestic Use during January 2015 (only manganese) and May 2018. No distinct improvement or deterioration in the water quality has been observed.
- WOLMB15D – intermittently elevated EC, TDS, calcium, magnesium and sulphate concentrations which have exceeded the DWA SAWQTV Drinking Water Requirements during the monitoring period. Since September 2018, the water quality has deteriorated compared to previous sampling events and may be indicative of contamination.
- WOLMB15S – EC, TDS, calcium, magnesium and sulphates have continuously exceeded the DWA SAWQTV for Domestic Use since September 2015, with an increasing trend in the constituent concentrations. Since mid-2017, EC, TDS and sulphate have also exceeded the SANS 241-1:2015 Drinking Water Standard. Iron and manganese concentrations are always low during the monitoring period. However, the water quality appears to be deteriorating compared to pre-2017 sampling events and may indicate a source of enduring contamination to the shallow groundwater environment.
- WTN02D - no exceedance of constituent concentrations during the January 2012 and June 2017 sampling events.
- WWN02D – intermittently elevated EC, TDS, calcium, magnesium, sulphate, iron and manganese concentrations which have exceeded the DWA SAWQTV for Domestic Use. Only iron and manganese have also exceeded the SANS 241-1:2015 Drinking Water Standard in mid-2016 and mid-2018 (iron only). A minor improvement in the water quality has been observed since December 2018.
- WWNMB16 - nitrate concentrations have exceeded the DWA SAWQTV Drinking Water Requirements since June 2016. Except for the nitrate concentration, the water quality is compliant to both DWA SAWQTV for Domestic Use and SANS 241-1:2015 Drinking Water Standard.

Spatial Analysis

The hydrochemical results of all samples have been spatially analysed to determine the collective influence of contamination across the Leeuwpan Mine area during the 2015 to 2019 monitoring period.

Each mining section is discussed in the headings below:

Plant, PCD and OF Block Opencast

Contamination in terms of elevated TDS, sulphate, iron and manganese is evident for most boreholes located within this area, including LEEMB18D, KENMB03S, WOLMB15S and WOLMB15D, particularly since 2017/2018. LEEMB18D and WOLMB15S exhibit the poorest water quality in this area, and WOLMB15S indicates deteriorating water quality. The piper plot in Figure 4-8 indicates that these boreholes have a calcium/magnesium-sulphate water type.

KENMB03D does not indicate long-term contamination, which could be attributed to limited interconnectivity between the shallow and deeper Karoo aquifer in the vicinity of the borehole, as evidenced by the groundwater levels. However, the groundwater has a sodium bicarbonate type hydrochemical character. This area should be monitored on a quarterly basis.

OWM_WTN and OWM_MN Block Opencast

Boreholes WELMB13D and WELMB13S, located down gradient of the OWM_MN Block (Moabsvelden) opencast, were potentially impacted by mining related contaminants prior to 2017/2018. However, the water quality at WELB13S has significantly deteriorated since 2018, whereas the water quality has improved at WELMB13D. The shallow aquifer thus exhibits poorer water quality than the deeper aquifer, however, it is postulated that there is limited interconnectivity between the shallow and deeper Karoo aquifers in the vicinity of these boreholes based on the groundwater levels. Figure 4-8 indicates that these boreholes have a calcium/magnesium-sulphate water type.

Borehole WTN02D is located adjacent to a haul road and has not exhibited elevated constituent concentrations during the 2015 to 2019 monitoring period. The hydrochemical character of the WTN02D groundwater is calcium/magnesium-sulphate/bicarbonate type.

OJ Block Opencast

The borehole MOAMB10 located adjacent to OJ Block opencast only exhibited contamination in the July 2015 and December 2016 sampling events and has otherwise not indicated contamination from mining activities during the 2015 to 2019 monitoring period. It is postulated that the water quality at this borehole has improved compared to the sampling conducted in the GCS (2014) study, however, based on Figure 4-8 the hydrochemical character of the groundwater is calcium/magnesium-sulphate. Borehole MOAMB7 has exhibited slightly acidic pH levels and elevated manganese but is predominantly compliant. However, the groundwater is of a calcium/magnesium-sulphate/bicarbonate type.

PCD and Raw Water Dams, and OF Block Opencast

The borehole KENMB02D located down gradient of the No. 5. Emergency overflow dam could be impacted by mining related contaminants, evidenced by continuously elevated TDS and sulphate concentrations. The water quality in this area appears to be deteriorating. Contamination was also evident for borehole KENMB02S during the single sampling event in 2015. The groundwater is characterised as calcium/magnesium-sulphate type.

Earth dam west of Block OD opencast

High TDS and sulphate concentrations at borehole WWN02D have indicated a potential impact by mining related contaminants on groundwater in this area, however since December 2018, the water quality appears to be improving. The groundwater is characterised as calcium/magnesium-sulphate type.

OA Block (Witklip) Opencast

Borehole WITMB14 located down gradient of the Witklip pit (Block OA) has exhibited a potential impact by mining related contaminants due to intermittently elevated EC, TDS and metal concentrations, however, the borehole remains compliant with the SANS 241-1:2015 Drinking Water Standard. Borehole LW07 located upgradient of OA Block does not indicate contamination by mining related contaminations. Slightly elevated iron and manganese concentrations at this borehole could be representative of natural conditions in this area. The groundwater is characterised as calcium/magnesium-bicarbonate type.

Workshop Area and OF Block Opencast

Moderate contamination was evident at boreholes LWG02 and KENMB01 in 2015, with elevated sulphates at LWG02. However, the water quality improved in 2016 and 2017, with no elevated constituent concentrations, except for one elevated manganese concentrations at LWG02. The groundwater at LWG02 is characterised as mixed, however, KENMB01 is of a calcium/magnesium-bicarbonate type.

OH Block Opencast

Borehole MOAMB4 exhibited slightly acidic pH levels in 2015 and 2016, with elevated EC, TDS and metals. Sulphates have not been elevated at this borehole. The water quality has generally improved, particularly during the latter part of 2018 and is of a calcium/magnesium-bicarbonate type.

OI Block Opencast

Elevated metals concentrations have been recorded at RKL01, south of the existing OI opencast pit. TDS and sulphate concentrations are not elevated, however, an increasing trend in their concentrations is evident. The groundwater is predominantly of a calcium/magnesium-bicarbonate type.

Surrounding Agricultural Area

Boreholes MOAMB9, RKL02, RIE4, RIE10, RIE10B, WWNMB16 and LW08 are currently located closer to agricultural land than mining activities and are predominantly compliant to the relevant water quality standards. Slightly elevated metals and nitrates have been recorded at most of these boreholes. The groundwater is of a calcium/magnesium-bicarbonate type.

Water Type Distribution

Based on Figure 4-8, the dominant water type across the study area is calcium/magnesium-bicarbonate, however, within close proximity of mining activities the water type is predominantly calcium/magnesium-sulphate type, which is indicative of the impact of mining activities on groundwater. Mixed and sodium-bicarbonate type was also present in the mine area.

TDS Distribution (Figure 4-9)

TDS concentrations exceed the SANS 241-1:2015 Drinking Water Standard in the shallow aquifer down gradient of the OWM_MN Block (Moabsvelden) opencast, south of the Kenbar (OF) mining block at the PCD and raw water dams and in the shallow aquifer immediately north of the Plant PCD. Elevated TDS concentrations that exceed only the DWA SAWQTV for Domestic Use are observed at the OA Block, at the earth dam west of the ODS Block and in the shallow and deep Karoo aquifers in the plant area (except KENMB03D).

Sulphate Distribution (Figure 4-10)

Sulphate concentrations exceed the SANS 241-1:2015 Drinking Water Standard in the north western section of the plant area and PCD, south of the OF (Kenbar) Block at the PCD and raw water dams and in the shallow aquifer down gradient of the OWM_MN Block (Moabsvelden) opencast. Sulphate concentrations only exceed the DWA SAWQTV for Domestic Use in the shallow aquifer in the south eastern section of the plant area and at the earth dam west of the ODS Block.

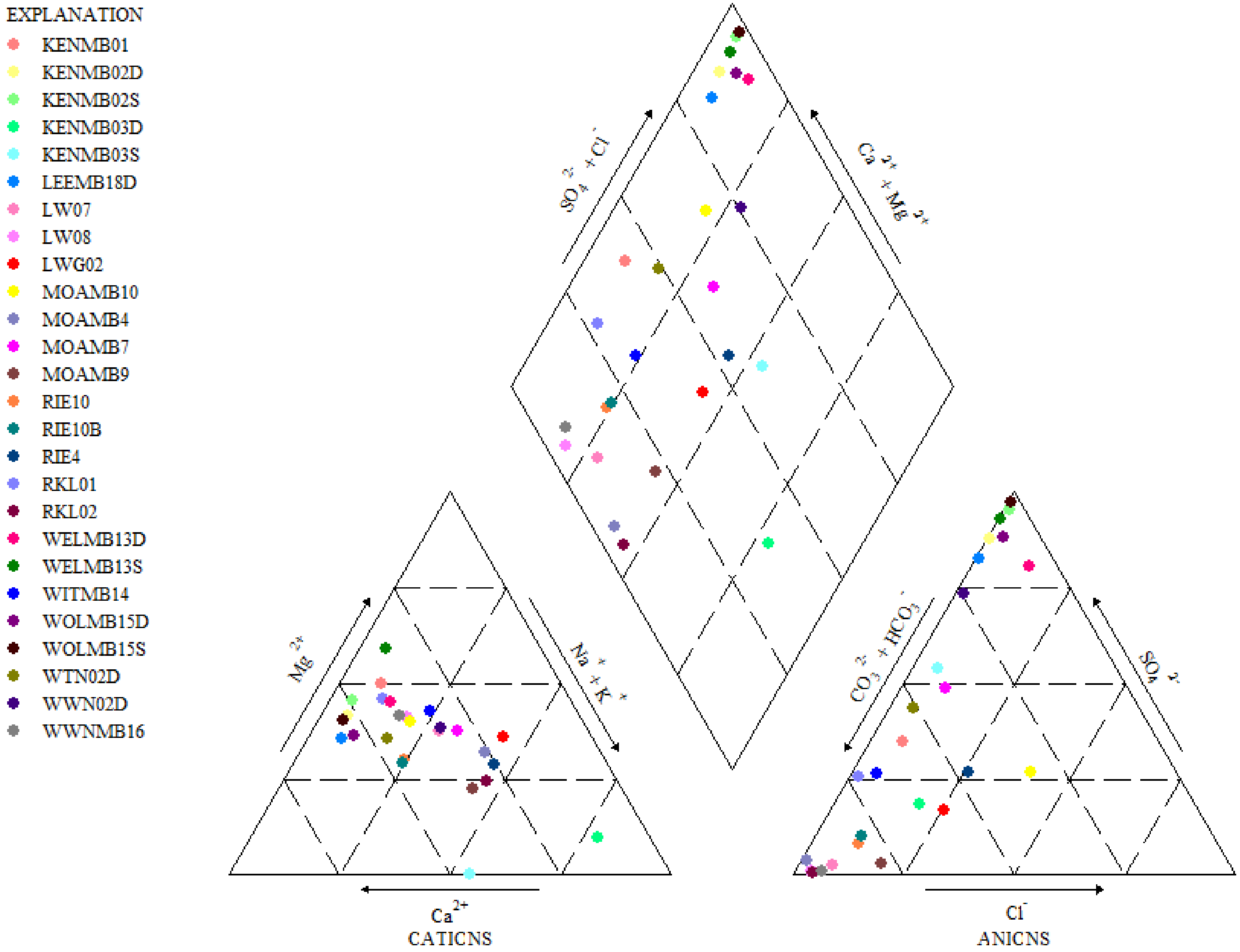


Figure 4-8: 2015 to 2019 Monitoring Network Piper Plot

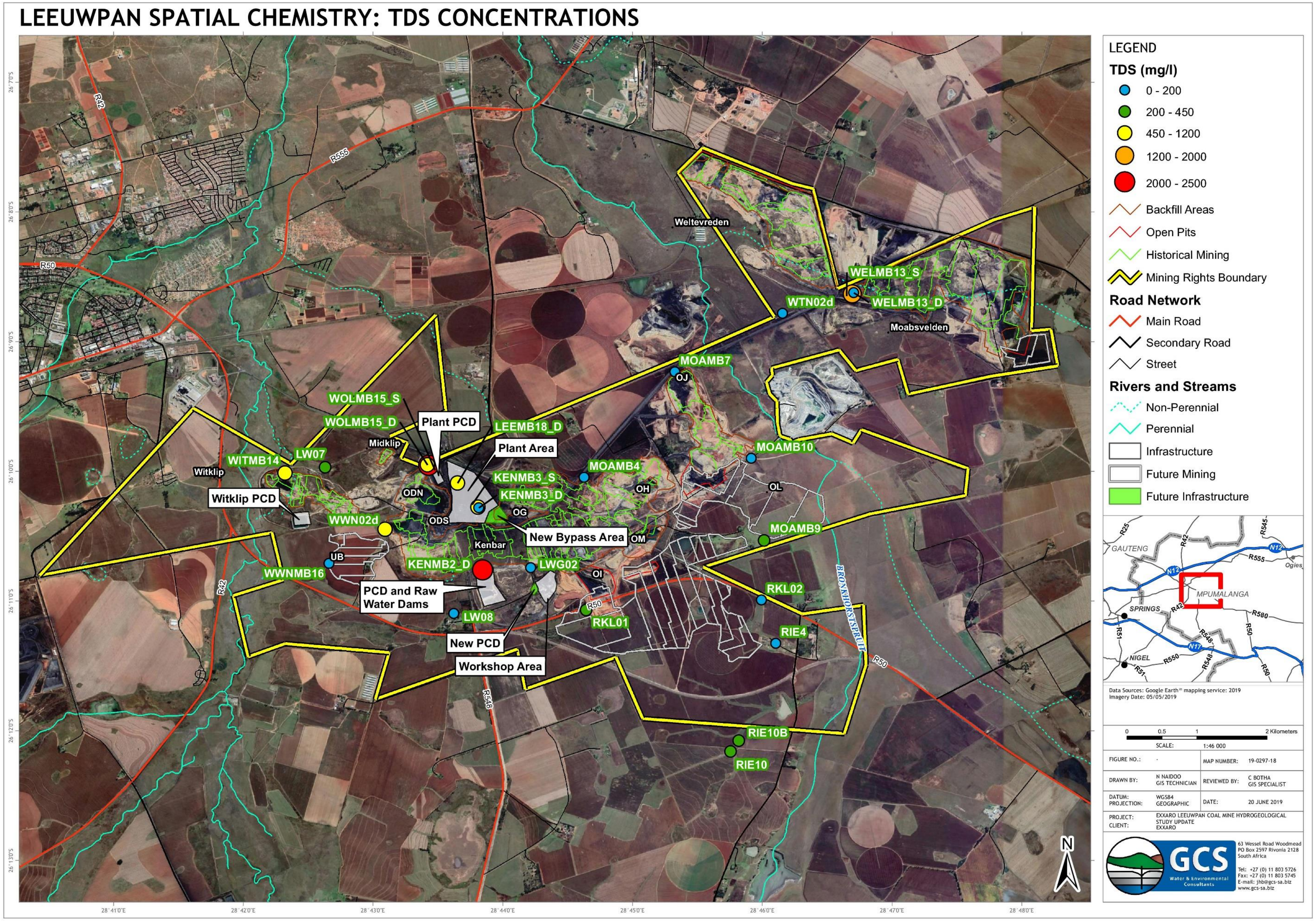


Figure 4-9: Spatial TDS Concentrations (mg/l)

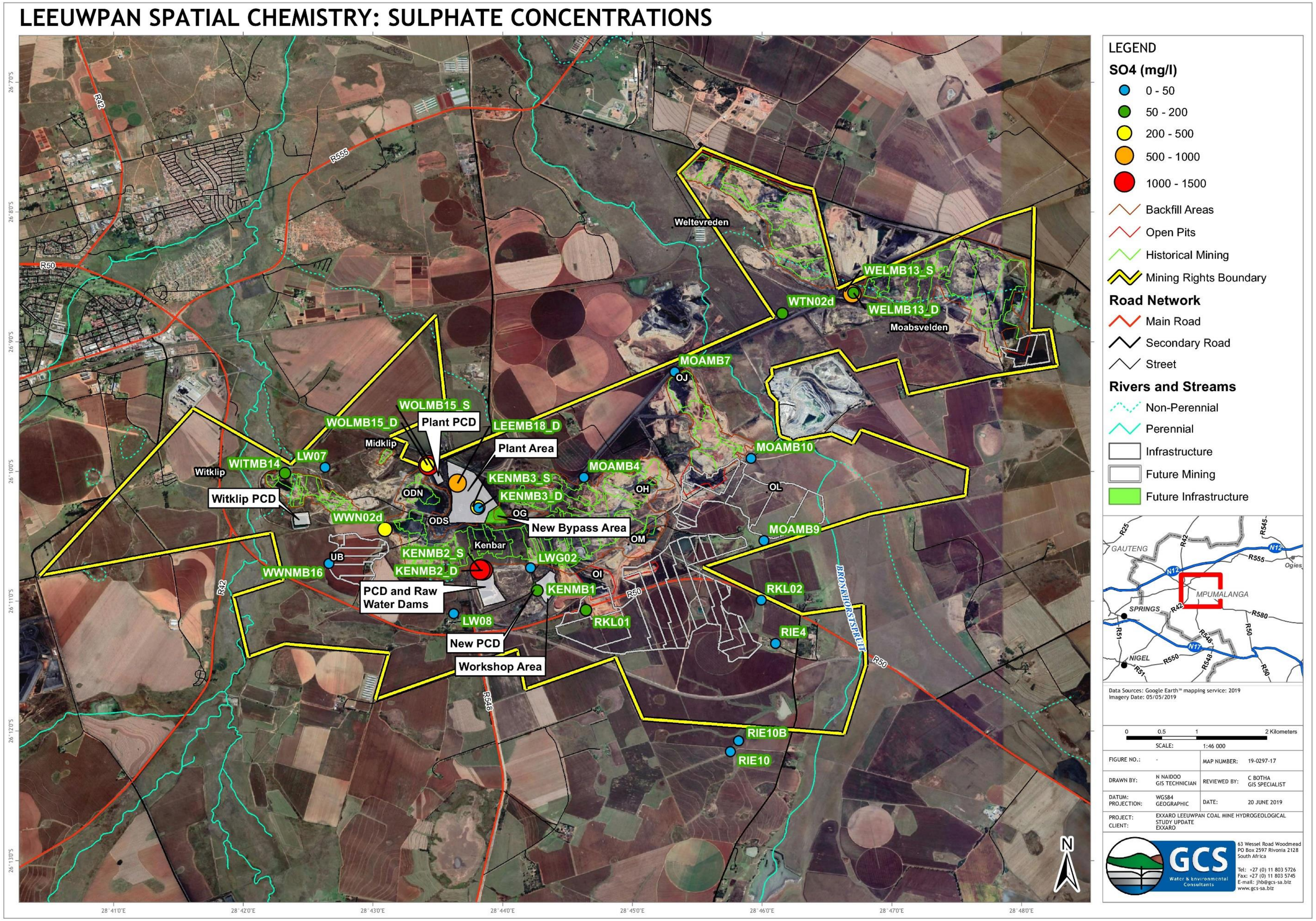


Figure 4-10: Spatial Sulphate (SO_4) Concentrations (mg/l)

4.6.8 Aquifer parameters

During the GCS (2014) study, pumping tests, consisting of constant discharge and recovery tests, were conducted on selected newly drilled monitoring boreholes at Leeuwpan. Slug tests (falling head test) were conducted on the lower yielding boreholes. During drilling of the monitoring boreholes there were no major water strikes intersected except for WITMB14 and MOAMB9. Aquifer testing commenced on 4 December 2013 and completed on 13 December 2013.

Table 4-4 provides a summary of the aquifer test results. The Hvorslev, Bower & Rice and Cooper curve fitting methods were used to estimate the hydraulic conductivity, while the Cooper Jacob method was used to estimate the transmissivity of the aquifer tests. The hydraulic conductivity ranges from 0.01-0.60 m/day with a harmonic mean of ~0.05 m/day. The transmissivity ranges from 0.20 to 20 m^2/day with a harmonic mean of ~0.7 m^2/day. These values are typical of the Karoo type aquifers and correspond with the values identified in previous studies (Cleanstream Environmental Services, 2007).

Table 4-4: Summary of aquifer test results (GCS, 2014)

BH ID	Hvorslev (K)	Bower & Rice (K)	Cooper (T)	Cooper Jacob (T)
	Hydraulic conductivity (m/day)		Transmissivity (m^2/day)	
MOAMB10				>20
MOAMB9				2.30
KENMB2_S	No displacement			
KENMB2_D				2.60
KENMB3_S	No displacement			
KENMB01	0.33	0.23		
WOLMB15_D	0.26	0.20		
WOLMB15_S	0.01	0.01	0.22	
LEEMB18_D	0.05	0.04	1.40	
MOAMB4				0.26
WELMB13_S	0.29	0.21		
LEEMB18_S	No displacement			
MOAMB7	No displacement			
KENMB3_D				2.20
WELMB13_D	0.15	0.10		
WWNMB16	0.60	0.60		
WITMB14	No displacement			
Harmonic mean	0.048 (m/d)		0.67 (m^2/d)	

5 CONCEPTUAL HYDROGEOLOGICAL MODEL UPDATE

The conceptual model describes the hydrogeological environment and is used to design and construct the numerical model to represent simplified, but relevant conditions of the groundwater system. The conditions should be chosen in view of the specific objective of the modelling and might not be relevant for other modelling objectives. The conceptual model is based on the source-pathway-receptor principle. The conceptual model based on the regional and site-specific geology can be generalised as depicted in Figure 5-1 below (GCS, 2014).

5.1 Source

Leeuwpan Colliery is an existing operation and as a result there are numerous contaminant sources present within the mining rights area, including the plant area, pollution and return water dams, overburden and discard dumps, rehabilitated opencast and operational opencast areas. The workshops and petroleum handling facilities are also likely to be petroleum hydrocarbon contaminant sources. The pollution control dams are lined with either a clay or HDPE liner. New PCD's have been lined with an HDPE liner to reduce potential seepage, including the new PCD located west of the OI mining block.

During the operational phase of the opencast mining, the mined-out areas are backfilled with waste rock material as well as coal discard and slurry cake. Blocks OA (Witklip), OE (Midklip), OF (Kenbar), ODN, ODS, OM, OH, OG, OWM_WTN (Weltevreden) and areas of OJ and OWM_MN (Moabsvelden) were backfilled at the time of the investigation. Mining has ceased in Block OJ; however, some sections of the block are still to be backfilled. The OWM_MN, OI and OL Block opencasts were being mined at various stages during this investigation. The proposed UB mining block could also represent a potential source of contamination when future mining commences.

After closure the water level in the pits will rise as a result of groundwater inflow, pit wall runoff, and natural ingress of rainwater. Concurrent and partial backfilling or complete backfilling could be considered for the voids. The groundwater levels in the rehabilitated backfilled areas will rebound upon the cessation of dewatering and recover to a new equilibrium level, which could be the decant elevation.

Above the equilibrated groundwater level, the backfilled material will be unsaturated, and the potential oxidation of sulphur minerals within the pit backfill or exposed along the pit walls could likely impact the overall mine water quality.

5.2 Pathway

Leeuwpan Coal Mine is situated within the larger Karoo Supergroup weathered and fractured rock aquifer, a typical unconfined to semi-confined aquifer. Groundwater flow occurs mainly within joints, fault zones and bedding plane contacts. The three aquifer/hydrogeological units present within the Leeuwpan area include:

- Shallow weathered aquifer: a shallow aquifer formed within the residual and weathered zone of the Karoo Supergroup, locally perched on fresh bedrock;
- Deeper fractured aquifer: a deeper aquifer formed by fracturing of the Karoo Supergroup and dolerite intrusions; and
- Fractured karst aquifer: a fractured aquifer hosted within the dolomite- and chert-rich Malmani Subgroup.

The Dwyka tillite aquitard separates the overlying Karoo aquifer from the dolomitic karst aquifer, however, it is postulated that there is some interconnectivity between the aquifers. The interaction between the Karoo and karst aquifer should be assessed and will become important to investigate for the post closure phase. However, the shallow weathered and deeper fractured Karoo aquifers are likely to remain the aquifers of concern.

The recharge in the area within which rocks of the Karoo Supergroup outcrop, is estimated between 1 and 3% (7 mm to 20 mm/annum) of mean annual precipitation (MAP). Where dolomite outcrops occur, the effective recharge percentage is likely to be higher and is estimated to be between 2 and 6% (14 mm to 41 mm/annum) of the MAP.

Groundwater flows predominantly towards the northwest and northeast, following the topography towards drainage lines. Local groundwater divides are evident around boreholes RKL01 and RKL02, as well as MOAMB4 and WOLMB15D/S. Slightly lowered groundwater levels are observed within the Kenbar area. Groundwater depressions, deeper than expected for the natural groundwater table, are evident at boreholes MOAMB7 and MOAMB9, likely attributed to cumulative dewatering impacts from an adjacent mine and Block OJ at MOAMB7, and surrounding abstraction activities at MOAMB9.

The unsaturated zone, which currently varies between~1 - 53 mbgl in the study area, consists of colluvial material and clay (residual dolerite and shale) underlain by weathered to fractured sandstone / siltstone / mudstone / shale and coal of the Ecca Group, which become less weathered and fractured with depth. The Dwyka tillite is highly weathered at shallow depths and is found to be more competent at depth. A dolerite sill likely covers the areas near Block ODN, ODS, OI, OL, and eastern portions of OWN_MN (Leeuwpan, 2019).

No water strikes were associated with the sill during previous field investigations (GCS, 2014). Water strikes were encountered on contact zones between highly weathered rock or materials and more competent rock. The shallow weathered Karoo aquifer can generally be considered a minor aquifer as substantiated by previous drilling results (only 3 of the 17 boreholes drilled in 2014 had water strikes in excess of 0.1 l/s). Two boreholes drilled into the fractured Karoo aquifer had yields of 1.6 and 5 l/s.

The hydraulic conductivity of the shallow and deep Karoo aquifers range between 0.01 to 0.6 m/day, based on aquifer tests conducted previously (GCS, 2014). These values are typical of Karoo type aquifers and correspond with the values identified in previous studies.

The surrounding river systems also act as potential pathways for contamination, particularly when decant or contaminated seepage is intercepted. The surrounding river system is the Bronkhorstspruit River system. When decanting occurs from the operations the contaminated water may enter the streams, were the contaminants are transported to downstream receptors. Seepage emanating from certain areas may impact on the perched aquifer and migrate towards surface drainage features.

5.3 Receptor

Contamination from the mining areas is contained within the mining right. It is furthermore evident that several monitoring boreholes have been impacted by contaminants, particularly at the plant and PCD areas. The dominant water type across the study area is calcium/magnesium-bicarbonate, however, within close vicinity of mining activities the water type is predominantly calcium/magnesium-sulphate type, which is indicative of the impact of mining activities on groundwater. Mixed and sodium-bicarbonate type was also present in the mine area. Sulphate concentrations are predominantly elevated in the plant area, north of the Kenbar (OF) Block, and south of the mining block at the PCD and raw water dams. Slightly elevated sulphate concentrations are also observed down gradient of the OWM_MN Block (Moabsvelden) opencast.

The majority of privately-owned boreholes are associated with the underlying dolomitic aquifer which is unlikely to be impacted by any mining related dewatering activities. The impact of abstraction for irrigation and industrial users should however be assessed.

It is likely that preferential flow paths along faults and dolerite intrusion related to fracturing is not significant in the area based on the available data. While it is still anticipated that localised preferential flow zones will exist in relation to dolerite dykes, these zones have not been recorded and it is thought that they are not well developed.

As mentioned above the drainage occurs towards the low-lying areas such as rivers and streams (Bronkhorstspruit and its tributaries). Some of these streams could be impacted by contaminated seepage and decant in the future. It must be noted that a number of mines are located in the area which may also impact on these drainage networks.

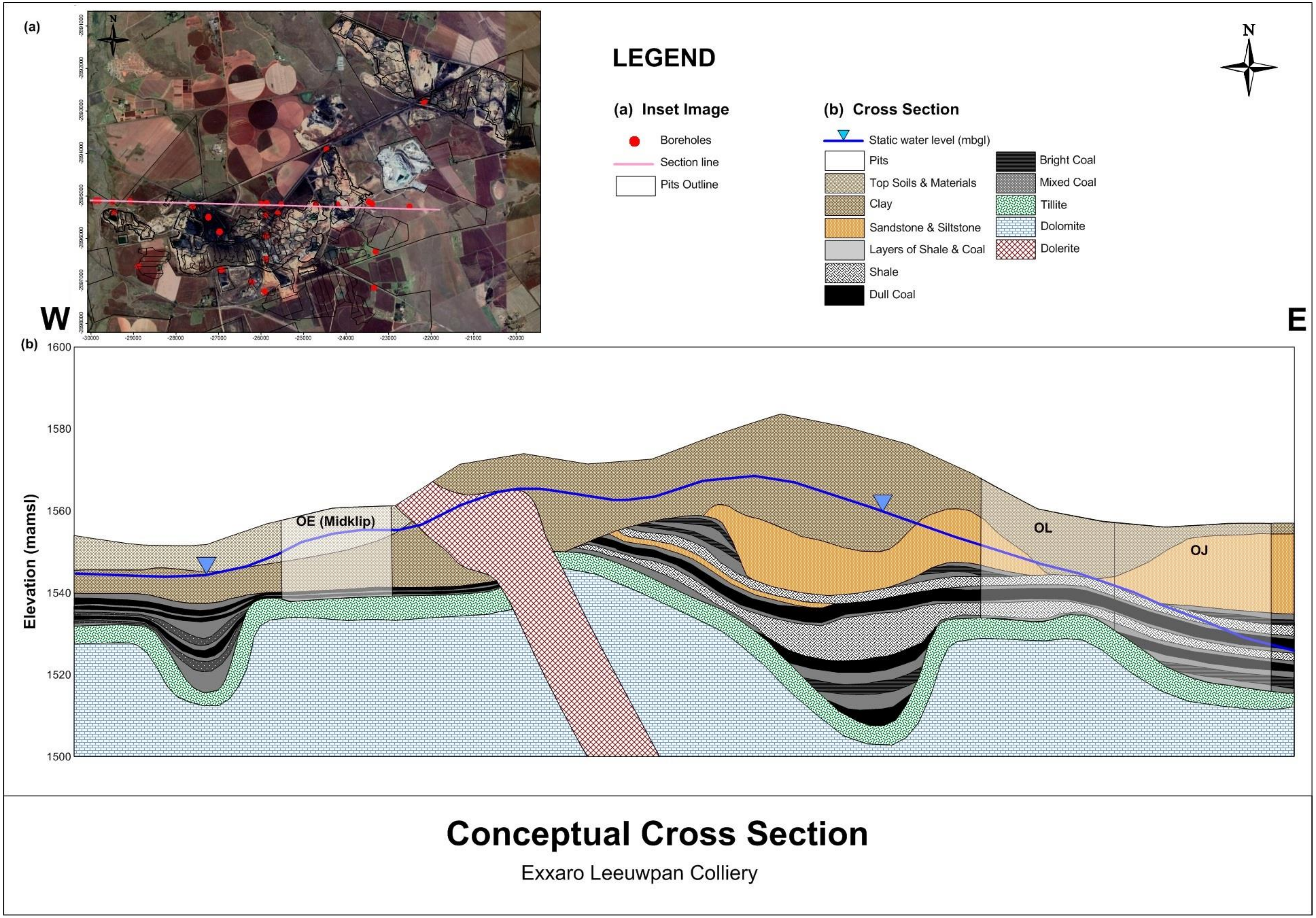


Figure 5-1: Leeuwpan Conceptual Cross Section (modified after GCS, 2014)

6 NUMERICAL HYDROGEOLOGICAL MODEL UPDATE

6.1 Model Planning

The update of the numerical groundwater flow and transport model was subcontracted to Geostratum Groundwater and Geochemistry Consulting (Reg: 2013/102316/07).

6.1.1 Objective of the Model

The objective of the model is to simulate groundwater ingress into the mine and the migration of potential contaminant plumes. Scenario modelling is typically used to run future scenarios on varying changes in the natural environment or anthropogenic inputs. The potential scenarios simulated using the model include the following:

- Groundwater inflows and the extent of potential dewatering at the mine blocks, particularly at OI and OL;
- Potential impacts on surrounding groundwater users;
- Potential contaminant plumes that may originate from the mining areas.

6.1.2 Model Confidence Level Classification

An Australian Guideline Class 1 model classification was pursued and was evaluated from a semi-quantitative assessment of the available data on which the model was based, the manner in which the model was calibrated and how the predictions were formulated. The level of confidence depended upon the available data for the conceptualisation, design and construction of the model.

Consideration was given to the spatial and temporal coverage of the available datasets in order to characterise the aquifer and the historic groundwater behaviour that was useful in model calibration. Factors that may affect the model confidence level during the calibration procedure were considered, and included the types and quality of data that was incorporated in the calibration, the degree to which the model was able to reproduce observations, and whether the model was able to represent present-day hydrogeological conditions. The time frame and level of stresses applied in the predictive models were consistent to that of the model calibration process.

6.1.3 Model Limitations and Exclusions

Groundwater flow models are inherently simplified mathematical representations of complex aquifer systems. The simplification limits the accuracy with which groundwater systems can be simulated in general. There are numerous sources of error and uncertainty in groundwater flow models. Model error commonly stems from practical limitations of grid spacing, time discretisation, parameter structure, insufficient calibration data, and the effects of processes not simulated by the model. These factors, alongside unavoidable error in field observations and measurements, result in uncertainty in the model predictions.

The complexities of fractured rock aquifers imply that the model can only be used as a guide to determine the order of magnitude of dewatering and contaminant transport. The interpretation of modelled results should be based on the assumptions the model was built on and actual results will vary as unknown aquifer conditions and parameters vary in the natural system.

6.2 Model Design and Construction

The design and construction of the groundwater flow model involves converting the conceptual model into a numerical model. The design is typically a description of the modelling approach being proposed and how the conceptualisation will be represented. Model construction is the implementation of that approach.

6.2.1 Governing Equations

The numerical model used in this modelling study was based on the conceptual model developed from the findings of the desktop and the baseline investigations. The simulation model simulates groundwater flow based on a three-dimensional cell-centred grid and may be described by the following partial differential equation:

(1)
$$\frac{\partial}{\partial x}(K_{xx}\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_{yy}\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_{zz}\frac{\partial h}{\partial z})\pm W = S_s\frac{\partial h}{\partial t}$$

where:

- *Kxx, Kyy, and Kzz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);*
- *h is the potentiometric head (L);*
- *W is a volumetric flux per unit volume representing sources and/or sinks of water,*

with:

- *W < 0.0 for flow out of the ground-water system, and W>0.0 for flow in (T-1);*
- *Ss is the specific storage of the porous material (L-1); and*
- *t is time (T).*

Equation 1, when combined with boundary and initial conditions, describes transient three-dimensional ground-water flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions (Harbaugh et al. 2005).

6.2.2 Model Software Package

The model was updated using GMS 10.3.8, a pre- and post-processing package. GMS uses the well-established MODFLOW-2005 (Harbaugh et al, 2005) and MT3DMS (Zheng & Wang, 1999) numerical codes.

MODFLOW is a modular three-dimensional groundwater flow model developed by the United States Geological Survey (Harbaugh et al., 2005). MODFLOW uses 3D finite difference discretisation and flow codes to solve the governing equations of groundwater flow. MODFLOW NWT (Niswonger et al., 2011) was used in the simulation of the groundwater flow model. Both are widely used simulation codes and are well documented.

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

6.2.3 Model Dimension

The groundwater model was formulated in three-dimensions (3D) in order to simulate groundwater movement in both the horizontal and vertical planes. The conceptual model contains more than one overlying hydrogeological unit with depth, with both horizontal flow in individual units and vertical flow between adjoining units that are important.

6.2.4 Model Extent and Boundary Conditions

A relatively large model domain was selected in order to ensure that boundary conditions did not unduly influence modelling outcomes. Boundary conditions express the way in which the considered domain interacts with its environment. In other words, they express the conditions of known water flux, or known variables, such as the hydraulic head. Different boundary conditions result in different solutions, hence the importance of stating the correct boundary conditions. Boundary condition options in MODFLOW can be specified either as:

- specified head or Dirichlet; or
- specified flux or Neumann; or
- mixed or Cauchy boundary conditions.

From the conceptual point of view, it was essential to meet two criteria to the maximum extent possible:

- the modelled area should be defined by natural geological and hydrogeological boundary conditions, i.e. the model domain should preferably encompass entire hydrogeological structures; and
- the mesh size of model grid has to correspond to the nature of the problem being addressed by the model.

The model boundaries and model grid are shown in Figure 6-1. The flow of groundwater in nature is impacted by boundary conditions. Where practical, natural topographical and groundwater water divides were used as flow boundaries in the top layer, assuming that the groundwater elevation follows the topography (see Section 4.6.6). A topographical divide flow boundary (groundwater divide) was used in the western, southern and eastern sections of the modelled area.

Constant head boundaries were used as part of the northern boundary to ensure numerical stability. A constant head boundary was used over a length of three kilometres of the Bronkhorstspruit. These boundaries were used in the north of the area, where flow is likely to occur parallel to streams (i.e. groundwater unlikely to move across a streamline during unstressed conditions). The model boundaries were constructed a sufficient distance from the mining areas so as not to influence the model solution. Of the three model layers, the model boundaries in layer 2 to 3 have the same lateral extent as the top layer.

6.2.5 Construction of the Finite Difference Grid

Numerical models require the model domain to be discretised into a grid that defines the locations of the nodes at which hydraulic heads are calculated and the geometry of the cells that controls the calculation of the volumetric flow rates of water. Compilation of the finite difference grid using the GMS 10.3.8 graphic user interface facilitated the construction of a rectangular horizontal grid, as well as vertical geometry provided for each of the layers. The modelling area was discretised by a 300 x 250 grid in the x and y direction, (see Figure 6-1). A refined cell size of 50 m x 50 was used in the mining area with gradual increase to about 400m on a regional scale. The discretisation of the model grid into smaller cells around the mining areas area will give the refined cells more calculation weight and modelling accuracy. The distant portions of the flow field are described with fewer and larger cells, which keep the model size reasonable. The refinement of the grid did not influence the water mass balance from the original uniform grid used initially.

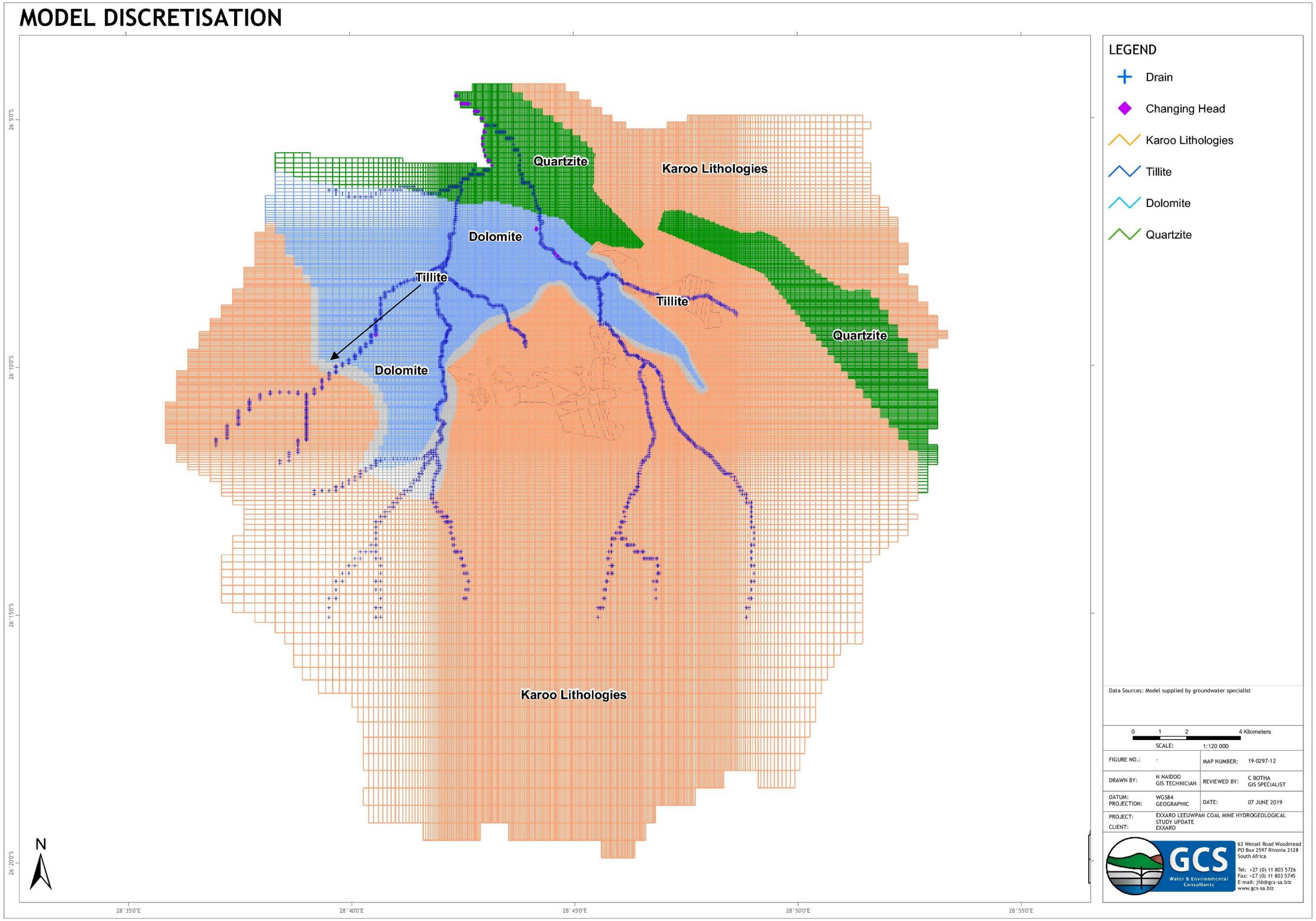


Figure 6-1: Model Discretisation and Boundaries

6.2.6 Vertical and Lateral Discretization

The subsurface was modelled in three dimensions (three-layer model), as depicted in Figure 6-2 to Figure 6-4 below. The upper 40 m thick layer represents the weathered and fractured Karoo aquifer system within which the coal resides, as well as the much older dolomite and Timball Hill formation ferruginous quartzite/shale inliers. Where the coal seams are at a deeper level, the bottom of this layer was lowered to reflect the actual coal floor. In the two deeper layers, the Dwyka tillite underlies the Karoo sediments as a thin 10 m layer, while the dolomite underlies this all as a third layer of 50m. The quartzite was represented from the first to the third layer. The materials were digitized form the applicable geological map but adjusted somewhat close to the mining area to include all pits in the Karoo Supergroup. In particular, the model was designed to represent the Dwyka tillite in the second layer and the underlying dolomite in the third layer. Although the dip of the bedrock (especially the quartzite) is not included in the model layout, it is also insignificant to the depth of the model. It is also far enough removed from the area of interest to have any substantial influence on the groundwater flow.

6.2.7 Temporal Discretization

Time parameters are relevant when modelling transient (time-dependent) conditions. They include time units, the length and number of time periods and the number of time steps within each time period. The model parameters associated with boundary conditions and various stresses remain constant during one time period. Having more time periods allows these parameters to change in time more often.

Steady state conditions were first set in order to simulate the natural pre-mining environment. Steady state implied that the system was in equilibrium before external stresses were applied to the environment. This was followed by transient simulations whereby mining commenced in 1993 and is likely to be completed at the end of 2030. The mining period from 1993 to 2019 was used for the transient model calibration. Mining of OI and OL was simulated to conclude in 2030 and 2024, respectively, as indicated on the latest mine plans received from Leeuwpan Coal Mine in May 2019. Mine closure was thus assumed after 2030. A total of 45 stress periods were used.

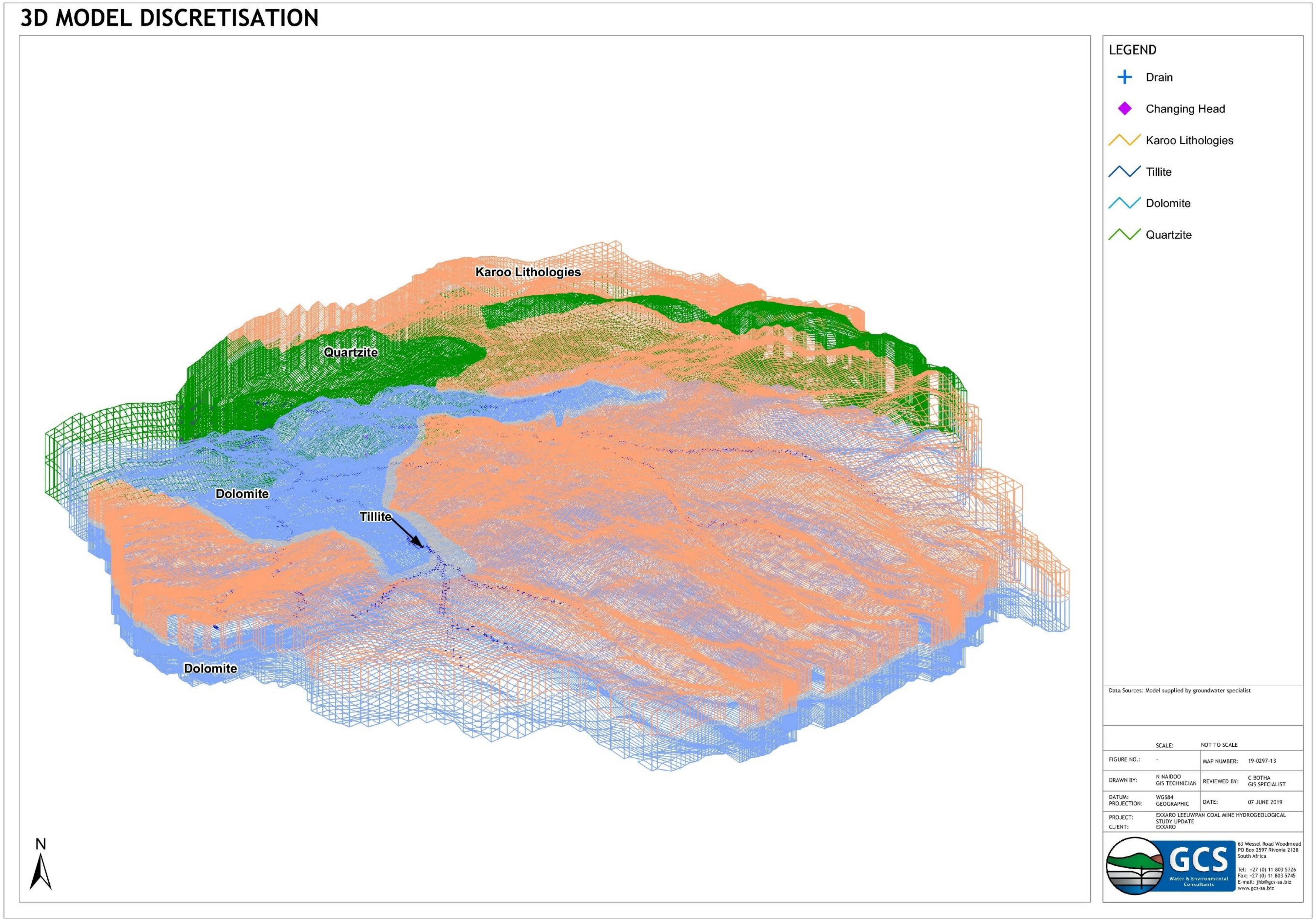


Figure 6-2: 3D Model Discretisation

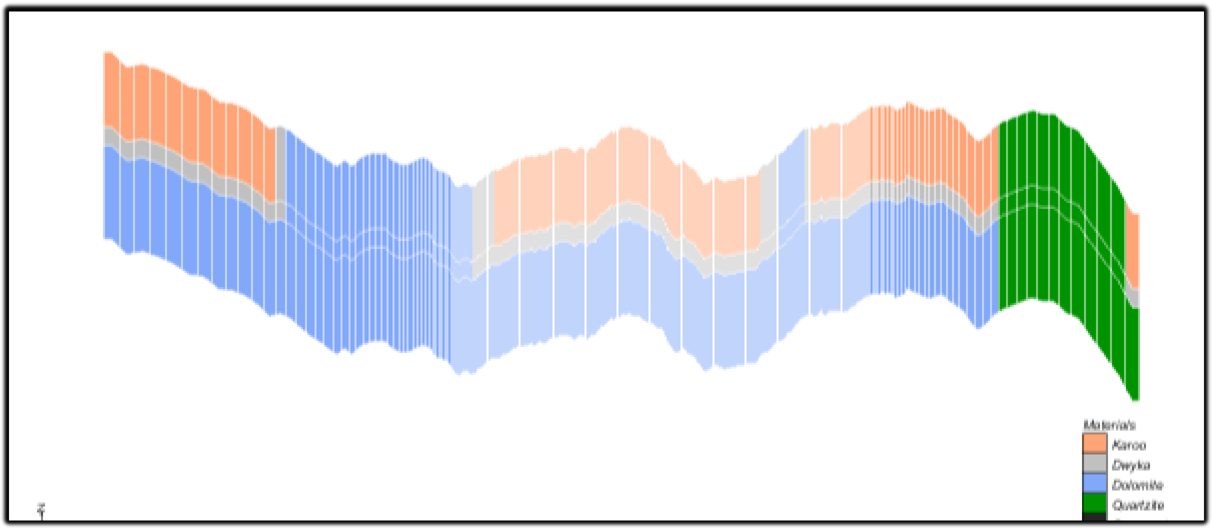


Figure 6-3: Section of Materials – East to West

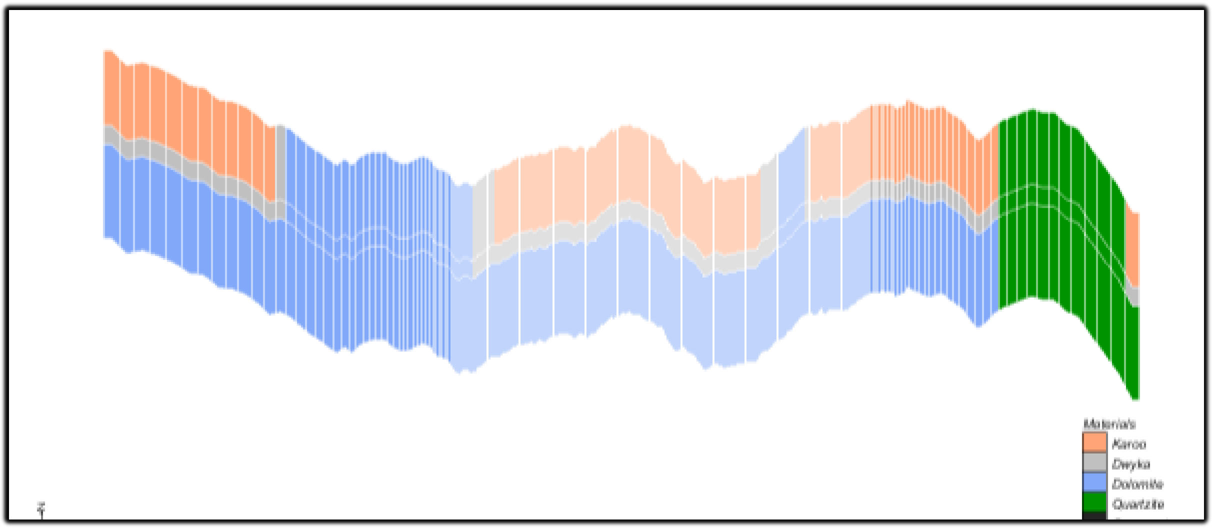


Figure 6-4: Section of Materials – South to North

6.2.8 Mine scheduling

The opencast schedules, particularly OI and OL and as provided by the client, were used as input for the model for the purpose of scenario modelling. The mining operations were simulated by means of drain cells. Drains were assigned to cells using polygons based on the proposed mine schedules. The drain boundary condition is then switched 'on' in the appropriate time step. A drain conductance was assigned using the following equation:

$$C = \frac{k}{t}$$ **Equation 6-1**

where:

- C is the drain conductance (1/T);
- k is the hydraulic conductivity of the cell the drain is assigned to; (L/T); t is the thickness of the cell the drain is assigned to (L).

6.2.9 Model Parameter Assignment (Initial parameters)

Although the most relevant aquifer parameters are optimised by the calibration of the model (Section 6.3), many parameters are calculated or assumed due to experiences in similar environments. The following fixed assumptions and input parameters were used for the numerical model of this area:

6.2.9.1 Initial heads

The initial head conditions, specified in the steady-state model, were estimated from topography. The choice of initial conditions for the steady state model does not influence the model outcome (Barnett et al, 2012). Initial transient model heads were derived from the steady-state calibrated model results.

6.2.9.2 Hydraulic conductivity and storativity

The initial estimates for hydraulic properties were assigned based on the pump testing results as carried out as part of the hydrogeological field program in the GCS (2014) study. The hydraulic conductivity of the weathered and fractured Karoo rock was taken as 0.02 m/day, and the Dwyka tillite was assigned 0.005 m/day. These hydraulic conductivities correlate with the hydraulic conductivity estimated from the aquifer tests and previous studies at the mine. The dolomite was assigned a hydraulic conductivity of 10 m/day and the quartzite 0.01 m/day. The hydraulic conductivity of the rehabilitated opencasts was taken as 10 m/day. This is a typical value derived from pump tests in rehabilitated opencasts;

A specific storage (S) value of $1x10^{-6}$ was used for all layers. This value relates to the compressibility of the aquifer and water and is approximately constant with depth. The specific storage of the dolomite was however estimated as $1x10^{-4}$ and used in the model.

The specific yield (effective porosity) value was taken as 0.05, declining gradually to 0.01 at a depth of 100 mbgl. This value could not be determined directly and were taken as typical of the fractured bedrock.

6.2.9.3 Recharge

The recharge rate was kept constant across the modelled domain. The recharge flux applied to the highest active cell. Recharge was estimated at 20 mm/a. This value relates to a recharge percentage of approximately 2.7%, similar to the previous groundwater studies. A 10% recharge was used for the backfilled opencast areas post closure (GCS, 2014).

6.2.9.4 Other parameters

Other model parameter values used were as follows:

- Evapotranspiration was allocated to the model and a value of 0.0001 m/d was used which is an average for grasslands, an extinction of 1 m was simulated;
- Vertical Hydraulic Anisotropy (KH/KV) of the bedrock = 10. This is an estimate based on the sub-horizontal layering of the Karoo sediments. A Vertical Hydraulic Anisotropy of 100 was however used for the Dwyka tillite layer;
- Longitudinal dispersion was taken as 50 metres, which is approximately 10% of expected plume dimensions, as recommended in various modelling guidelines;
- Transverse and vertical dispersion was taken as 5m and 0.5m respectively, being about 10% and 1% of the longitudinal dispersion respectively, as recommended in various textbooks;
- The effective porosity of the Karoo aquifers usually ranges between 1 and 5%. An effective porosity of 5% was assumed for the first layer, while a value of 25% was used for the opencasts; and
- The drain boundary condition was used to simulate the streams and rivers in the model domain. The drain conductance value used is 0.1 m^2/day.

6.2.10 Solver

The MODFLOW NWT linearization approach generates an asymmetric matrix, which is different from the standard MODFLOW formulation that generates a symmetric matrix. Because all linear solvers presently available for use with MODFLOW-2005 solve only symmetric matrices, MODFLOW-NWT includes two previously developed asymmetric matrix-solver options. The matrix-solver options include a generalized-minimum-residual (GMRES) Solver and an Orthomin / stabilized conjugate-gradient (CGSTAB) Solver. MODFLOW-NWT is described in the documentation report by Niswonger and others (2011).

6.3 Model Calibration

6.3.1 Steady State Model

The numerical model calculated head distribution (hx,y,z) is dependent upon the recharge, hydraulic conductivity and boundary conditions. For a given set of boundary conditions the head distribution across the aquifer can be obtained for a given set of hydraulic conductivity values and specified recharge values. This simulated head distribution can then be compared to the measured head distribution and the hydraulic conductivity or recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained.

For model calibration the following parameters were included:

- Recharge; and
- Hydraulic conductivity for all hydrostratigraphic units.

Steady state calibration of the model area was accomplished by refining the horizontal hydraulic conductivity relative to average fixed recharge values until a reasonable resemblance between the measured piezometric levels and the simulated piezometric levels were obtained. The previous GCS (2014) groundwater model calibration was reassessed. The calibration was done manually in various stages. Since it is apparent that the groundwater level in the dolomitic aquifer dominates groundwater levels in the upstream Karoo aquifer, the hydraulic conductivity in the dolomitic aquifer was firstly adjusted until modelled groundwater levels matched with measured values. Following that, the hydraulic conductivity in the Karoo aquifers were similarly adjusted and fitted to measured values. Lastly, boreholes that obviously do not coincide with the regional groundwater levels were deactivated and minor final adjustments made to improve the overall fit over the modelled area.

The pre-mining simulated groundwater levels and flow directions are depicted in Figure 6-6. However, as the measured groundwater levels used in the calibration are located in the mining area, transient calibration was warranted.

6.3.2 Transient calibration

Model parameter values and hydrologic stresses determined during the steady-state calibration were used to simulate a transient response. The groundwater level data used for calibration was available from 2015 to 2019 whilst mining was active. No groundwater level data was available for the period prior to mining. It was therefore deemed necessary to calibrate the model based on groundwater level measurement periods, as the groundwater levels at certain boreholes could already have been impacted on by mining. The 2017 simulated groundwater levels and error bars are depicted in Figure 6-7.

6.3.2.1 Calibrated Parameters

Hydraulic conductivity values were derived from the transmissivity values and assigned to the hydrostratigraphic units in the model area. The initial estimates were used for a combination of PEST (Doherty and Hunt, 2010) and manual calibration.

The resulting calibrated hydraulic conductivity values for each hydrogeological unit is summarised in section 6.2.9.2.

6.3.2.2 Calibration Targets

The groundwater levels of existing Leeuwpan monitoring boreholes were used for model calibration. A total of 24 boreholes were available (229 groundwater levels between 2015 and 2019), of which 22 boreholes were included in the calibration.

6.3.2.3 Calibration Performance Measures

A number of performance measures have been proposed in the past to indicate whether a model suitably correlates with historical field measurements in order to be acceptable for use in future predictions. These may include Root mean squared error (RMS), mean error (ME) and Mean absolute error (MAE). Predefined performance measures may prevent the best possible calibration to be obtained, based on available data. This may lead to overfitting, which is the process of increasing model parameters until acceptable low performance measures are obtained. However, overfitting should not be preferred relative to large performance measure values with rational relationships between model parameters (Barnett et al, 2012).

Quantitative performance measurements were closely evaluated, keeping in mind the effect that heterogeneity of the aquifers in the mining area may have on these performance measurements. Model acceptance was also based on a number of measures not specifically related to model calibration. This will demonstrate that the baseline model is robust, simulates the water balance as required, and is consistent with the conceptual model.

The following performance measurements were evaluated during the calibration of the baseline model:

- Model convergence: Model convergence was obtained during calibration and a maximum change in heads between iterations was set to 1.0 x 10^{-5} m.
- Water Balance: The model demonstrated an accurate water balance during steady state calibration. A water balance error (all flows into the model minus all flows out of the model) of less than 0.5% is regarded as an accurate balance calculation.
- Quantitative measures: The difference in measured compared to calculated head was less than 5 m for 15 target points and less than 10 m for 6 target points of the 2017 measured groundwater levels. In Figure 6-7 the 2017 calibration targets can be observed, with associated error bars. These error bars illustrate the deviation of the simulated groundwater level from those measured. The error tolerance was set at 10m, therefore all the green error bars indicated that the measured and simulated groundwater levels measured for the targets where within the 5 m tolerance. The transient calibration was regarded as sufficient at ME= 1.5m, MAE = 4.93 m and RMS = 6.46 m, which takes into account the variations on simulated versus observed water levels for the entire modelled period. If only 2017 groundwater levels are considered, the calibration error is ME= 1.15m, MAE = 4.00.m and RMS = 5.47 m.

- The graph in Figure 6-5 presents the relation between the measured and simulated heads at the end of the calibration process. In case of absolute conformity, the points should create a 45-degree straight line (Line of perfect fit). As it can be seen, the level of conformity is tolerable especially when the uncertainty in spatial variation of hydraulic properties is considered.
- Qualitative measures: The steady state water level contours are illustrated Figure 6-6 and are consistent with the regional drainage features, which is most often an indicator of regional groundwater levels and flow patterns.

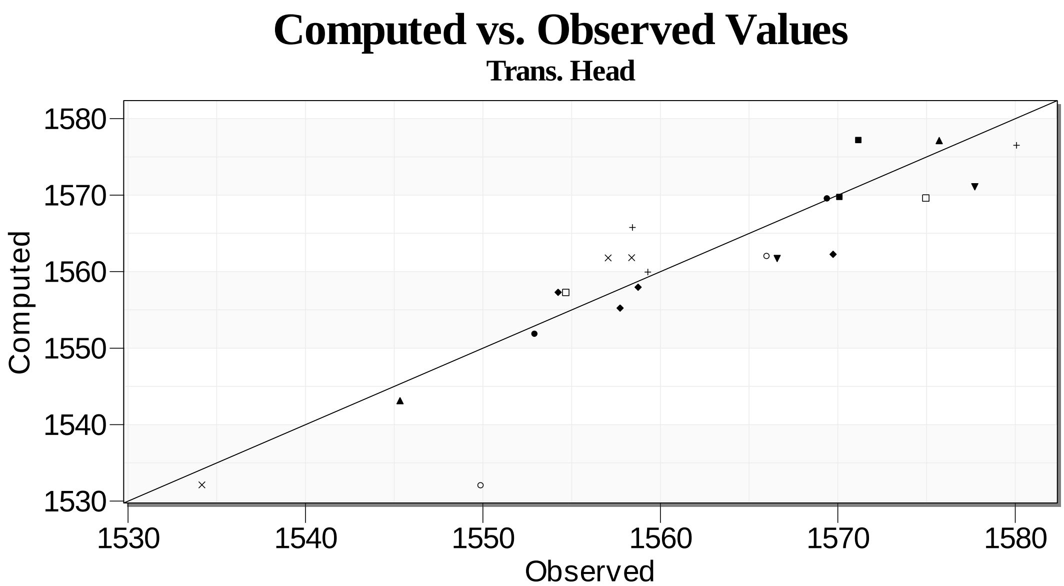


Figure 6-5: Observed versus Computed Water Levels

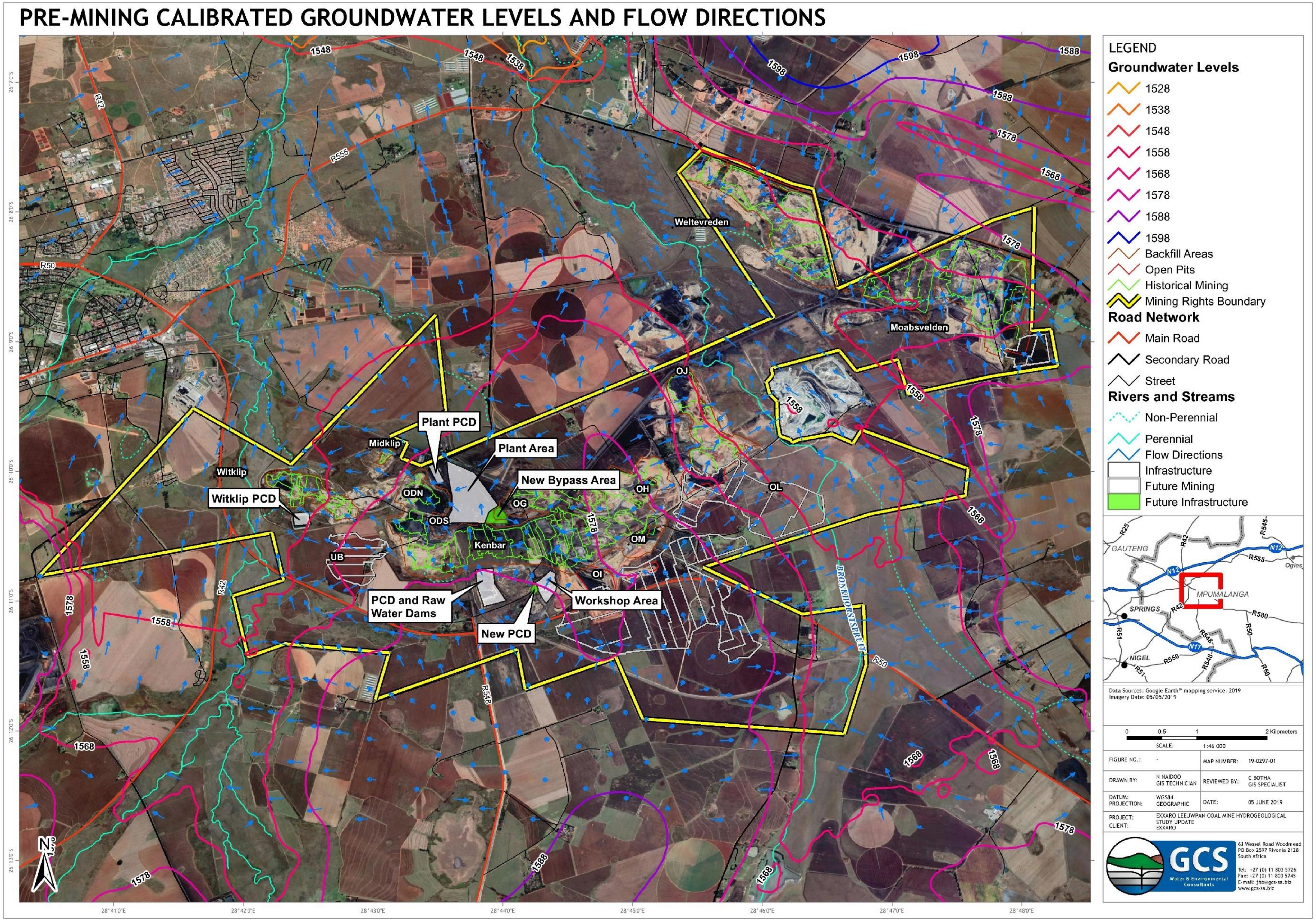


Figure 6-6: Pre-mining Calibrated Groundwater Levels and Flow Directions

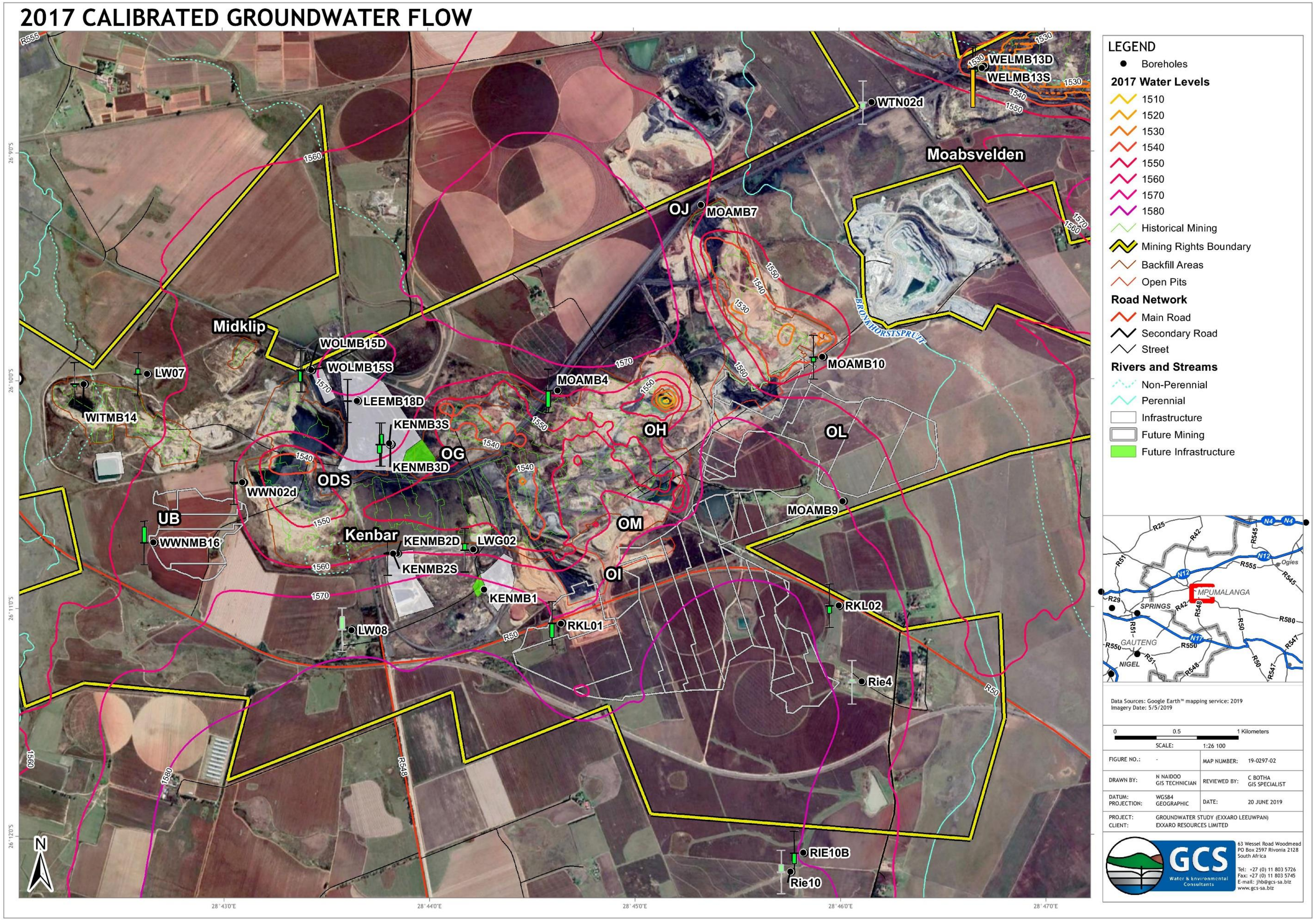


Figure 6-7: 2017 Calibrated Groundwater Flow and Error Bars (5 m tolerance)

6.4 Model Calibration Limitations and Exclusions

An Australian Modelling Guideline Class 1 was assigned to the model due to the available data and the calibration which was achieved against heads. Class 1 models are often used to provide an initial assessment of the problem and it is subsequently refined and improved to higher classes as additional data is gathered (from field test work and long-term monitoring).

Model error and uncertainty are not uniformly distributed. The groundwater levels measured were generally confined to the mining area, however time series data was available for the monitoring boreholes around the mine. Limited hydrogeological data (transmissivity, storativity at depth and in different lithologies/intrusions) was available to characterise the aquifer system (especially the Dwyka tillite and dolomite). Therefore, a level of uncertainty exists regarding the representativeness of the calibrated hydraulic parameters. The heterogeneous subsurface within the relatively large model area, results in hydraulic conductivity being simulated as uniform broad areas and may not reflect the true complexity of the geology. The modelling was performed within the limitations of the scope of work of this study and the amount of water level data available.

Nevertheless, models are a simplified approximation of reality. Efforts have been made to base the model on sound assumptions and the model was calibrated to observed data. The results obtained from this exercise should however be considered in accordance with the assumptions made. Limitations of models are the result of generalisations, interpretations and assumptions made in attempting to simulate the natural environment. The following limitations are applicable to the numerical groundwater model:

- Recharge rates were assumed as constant throughout the simulated period; therefore, no wet-dry cycles are simulated;
- Detailed geology as well as dolerite intrusions and faults were not included;
- The model simulates the fractured rock environment as an equivalent porous medium, which is an overall simplification of the flow process. However, on a large enough scale (bigger than the REV, Representative Elemental Volume) this assumption should be acceptable;
- It is assumed that the opencast pits will be fully rehabilitated post closure;
- It is assumed that there is limited interaction between the dolomitic aquifer and the Karoo aquifers, and that mining does not occur into the Dwyka tillite;
- Groundwater levels prior to the commencement of the mine are assumed to be in equilibrium (steady state); and
- The interpretation of modelled results should be based on the assumptions the model was built on and actual results will vary as unknown aquifer conditions and parameters vary in the natural system.

6.5 Cumulative Impacts of Surrounding Mines

As previously mentioned, a number of operating and defunct mines border the Leeuwpan Colliery. A few mines located adjacent to it may contribute to the impacts posed by Leeuwpan. Stuart Coal is located to the east of the OWN_WTN Block (Weltevreden) opencast, as well as another section to the north of the OJ Block open cast Leeuwpan. Furthermore Samquarz (Silica Mine) is located east of the OJ Block opencast. Samquarz is however exploiting quartzite underlying the coal rich Karoo Ecca Group. The impact of the surrounding mines and vica versa were not assessed during the scenarios.

6.6 Contaminated Transport Model

The calibrated groundwater flow model was used as a basis for developing a contaminant transport model. Sulphate concentration was used to determine the impact of mining on the aquifer. Sulphate is considered to be a water-soluble oxidation product of acid rock drainage (ARD) and is considered to be a representative indicator of the impact of coal mining on groundwater quality. The model is based on the following assumptions:

- Contaminant movement will mostly take place as a result of advection. This assumption is based on the calculation of the Peclet number (Pe) for the aquifer which indicates that advection is the main flow mechanism; and
- Chemical reaction between rock and dissolved species were not taken into consideration during simulations. Therefore, a worst-case scenario is assumed.

Movement of contaminant particles involves advection, dispersion and flux sources. Longitudinal dispersion was taken as 50m, which is about a tenth of the maximum transport distance. Concentrations at different transport distances in the plume also take dilution from natural rainwater recharge and mixing into account (sources).

The results from the contaminant transport model are considered to represent a first approximation of the impact on groundwater quality. Due to the nature of the simulations, the estimated concentrations will reflect expected conditions within an order of magnitude. It is advisable to recalibrate the flow model and transport model once more information regarding water qualities and new mining areas become available.

The sulphate source concentrations in the various opencasts were taken as 2500 mg/l SO_4, as determined during the GCS (2014) geochemical assessment.

7 GROUNDWATER IMPACTS

The impacts of dewatering and coontamination were quantified using the 3D numerical groundwater flow and contaminant transport model. The significance of the potential impacts were asseses using a standard methodology and discussed below.

7.1 Environmental Impact Significance Rating Methodology

To ensure uniformity, the assessment of potential impacts has been addressed in a standard manner so that a wide range of impacts are comparable. The methodology utilised is from the South African Department of Environmental Affairs and Tourism guideline document on EIA Regulations (April 1998). The following descriptive value-added evaluation method will be used to determine the significance of the impacts.

Extent (spatial scale)
Extent is an indication of the physical and spatial scale of the impact.

Low (1)	Low/Medium (2)	Medium (3)	Medium/High (4)	High (5)
Impact is localised within the site boundary: Site only	Impact is beyond the site boundary: Local	Impacts felt within adjacent biophysical and social environments: Regional	Impact widespread far beyond site boundary: Regional	Impact extend National or over international boundaries

Consideration to be given to:

- Access to resources;
- Amenity;
- Threats to lifestyles, traditions and values; and
- Cumulative impacts, including possible changes to land uses around the site.

Duration
Duration refers to the time frame over which the impact is expected to occur, measured in relation to the lifetime of the proposed project.

Low (1)	Low/Medium (2)	Medium (3)	Medium/High (4)	High (5)
Immediate mitigating measures, immediate progress	Impact is quickly reversible, short term impacts (0-5 years)	Reversible over time; medium term (5-15 years)	Impact is long-term	Long term; beyond closure; permanent; irreplaceable or irretrievable commitment of resources

Consideration to be given to:

- Cost-benefit economical and socially (e.g. long- or short-term costs / benefits)

Intensity of magnitude / severity
Intensity refers to the degree or magnitude to which the impact alters the functioning of an element of the environment. The magnitude of alteration can either be positive or negative, as were also taken into consideration during the assessment of severity.

Type of criteria	Negative				
	H-(10)	M/H-(8)	M-(6)	M/L-(4)	L-(2)
Qualitative	Very high deterioration, high quantity of deaths, injury of illness / total loss of habitat, total alteration of ecological processes, extinction of rare species	Substantial deterioration, death, illness or injury, loss of habitat / diversity or resource, severe alteration or disturbance of important processes	Moderate deterioration, discomfort, partial loss of habitat / biodiversity or resource, moderate alteration	Low deterioration, slight noticeable alteration in habitat and biodiversity. Little loss in species numbers	Minor deterioration, nuisance or irritation, minor change in species / habitat / diversity or resource, no or very little quality deterioration.
Quantitative	Level of deterioration is so high that the level thereof is not always measurable	Measurable deterioration. Recommended level will occasionally be violated.	Measurable deterioration. Recommended level will occasionally be violated	Rare violation of recommended level. Very slight measurable deterioration.	No measurable change. Recommended level will never be violated.

Consideration to be given to:

- Cost-benefit economically and socially (e.g. high net cost = substantial deterioration); and
- Impacts on future management (e.g. easy / practical to manage with change or recommendation).

Probability of occurrence

Probability describes the likelihood of the impacts actually occurring. This determination is based on previous experience with similar projects and/or based on professional judgment.

Low (1)	Medium/Low (2)	Medium (3)	Medium/High (4)	High (5)
Improbable; low likelihood; seldom. No known risk or vulnerability to natural or induced hazards.	Likely to occur from time to time. Low risk or vulnerability to natural or induced hazards	Possible, distinct possibility, frequent. Low to medium risk or vulnerability to natural or induced hazards.	Probable if mitigating measures are not implemented. Medium risk of vulnerability to natural or induced hazards.	Definite (regardless of preventative measures), highly likely, continuous. High risk or vulnerability to natural or induced hazards.

Significance

Significance is determined through a synthesis of the above impact characteristics and is an indication of the overall importance of the impact. The significance of the impact “without mitigation:” is the prime determinant of the nature and degree of mitigation required. For this assessment, the significance of the risk without prescribed mitigation actions was measured.

The significance of the identified impacts on components of the affected environment were determined as significance points (SP) = (magnitude + duration + spatial scale) x probability.

The maximum value per aspect is 100 SP. Environmental effects were rated as high, moderate or low significance, based on the following:

- more than 60 significance points indicated high (H) environmental significance;
- between 30 and 60 significance points indicted moderate (M) environmental significance; and
- less than 30 significance points indicated low (L) environmental significance.

7.2 Construction Phase – New Activities

During construction of the new mining blocks (Block OI and OL) minimal additional impacts to the groundwater system are expected. The main activities that could impact on groundwater in this phase include the construction and clearing of footprint areas for construction. Table 7-1 below lists the groundwater impacts expected during this phase, the impacts are expected to have a low significance rating.

Table 7-1: Impacts on groundwater during Construction Phase

ACTIVITY	POTENTIAL ENVIRONMENTAL IMPACT	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
Water quality						
Footprint Clearance / Construction	Clearing topsoil for footprint areas can increase infiltration rates of water to the groundwater system and increase aquifer vulnerability	12	L	Mitigation is not possible. Groundwater monitoring should be used to manage the potential impact	12	L
Waste / hydrocarbon Handling	Handling of waste and transport of building material can cause various types of spills (hydrocarbons) which can infiltrate and contaminate the groundwater system.	15	L	- All vehicles and machinery shall be kept in good working order and inspected on a regular basis for possible leaks and shall be repaired as soon as possible if required; - Repairs shall be carried out in a dedicated repair area only, unless in-situ repair is necessary as a result of a breakdown; - Drip trays shall at all times be placed under vehicles that require in-situ repairs; - Drip trays shall be emptied into designated containers only and the contents disposed of at a licenced hazardous material disposal facility; - Accidental spills (concrete, chemicals, process water, hydrocarbons, waste) need to be reported immediately so that effective remediation and clean-up strategies and procedures can be implemented; - Soil that is contaminated by fuel or oil spills, for example, from vehicles, will be collected to be treated at a pre-determined and dedicated location, or will be treated in situ, using sand, soil or cold coal-ash as absorption medium. - Water quality monitoring of surrounding boreholes and surface water bodies should be conducted on a quarterly basis.	12	L

7.3 Operational Phase

At the time of this investigation, three opencasts were in operation. However, the major purpose of this study is to assess how OI, including OI West Expansion, and OL will impact on the groundwater environment during the operational phase. The environmental impact significance is expected to be moderate to low and is presented in Table 7-2.

7.3.1 Groundwater Quantity (Groundwater level drawdown)

The mine floor elevation is below the general groundwater level thus causing groundwater inflows into the opencast mining areas from the surrounding aquifers during operations. The mining areas require active dewatering to ensure a safe working environment. Pumping water that seeps into the mining areas to the surface will cause dewatering of the surrounding aquifers and an associated decrease in the groundwater level within the zone of influence of the dewatering cone.

The zone of influence of the dewatering cone depends on several factors including the depth of mining below the regional groundwater level, recharge from rainfall to the aquifers, the size of the mining area, and the aquifer transmissivity, amongst others. The 3D numerical groundwater flow model was used to simulate the development of the drawdown cone over time in the study area. The latest mine schedules received in May 2019 (at the time of investigation) were incorporated into the existing predictive model scenario.

During the operational phase, it is expected that the main impact on the groundwater environment will be dewatering of the surrounding aquifer. At the time of the investigation boreholes LWG02, KENM2D, WWN02D, MOAMB7, WTN02D, MOAMB4, MOAMB10, WELMB13D, WELMB13S, LEEMB18D, KENM3D were affected in varying degrees by dewatering activities. Boreholes LEEMB18D and KENMB03D indicate recovering groundwater levels. Dewatering activities at an adjacent mine may be affecting WTN02D. Cumulative dewatering impacts from an adjacent mine and dewatering of Block OJ may have impacted borehole MOAMB7, and dewatering at Block OJ in conjunction with dewatering at an adjacent mine may have impacted borehole MOAMB10.

In order to interpret the changing cone of groundwater depression as mining progresses at the different opencasts, a scenario in 2025 (completion of mining at OL) and 2031 (completion of mining at OI) have been modelled as illustrated in Figure 7-1 and Figure 7-2.

Mining until 2025

By the year 2025, the OI and OL opencast areas will likely result in a lowering of the groundwater level surrounding the opencasts as is evident in Figure 7-1.

It is also observed from model predictions that the extent of groundwater cone of depression around the OD, OH, OM, OJ, OWM_MN (Moabsvelden) and Block OF (Kenbar) is decreasing as the groundwater level rises in the aquifer surrounding these mined-out opencasts.

The OL Block opencast was scheduled to be mined up to the end of 2024 and therefore still has a negative impact on the groundwater levels. More than half of OI will be mined out by 2025. Mining at UB will commence in 2025 based on the schedule. The simulated extent of drawdown extends 100 m to 300m from the active mining area, seen in Figure 7-1.

Mining until 2031

Only the OI and UB are scheduled to be mined between 2025 and 2030. The extent of drawdown around these opencast areas range from 100 to 500m as seen in Figure 7-2. As the mined-out opencasts start filling with water the groundwater levels around the opencast will also rebound.

The following deductions can be made:

- The water levels could be lowered over a relatively large area around the opencasts but recover once dewatering in the pits ceases;
- There are several monitoring boreholes in the potential affected area that might experience a decline in water levels of 5 m or more.
  - Borehole MOAMB9 may experience the greatest groundwater level drawdown (20 m).
  - Monitoring borehole RKL02 is likely to be mined out in the OI 2019 cut.
  - Monitoring borehole WWNM16 is likely to be mined out in the UB 2027 cut.
- The following boreholes identified during the GCS (2014) hydrocensus and older monitoring boreholes that do not form part of the current (2015 to 2019) monitoring network, will likely be impacted by dewatering (their existence should be verified):
  - CBH7B – however, this borehole may no longer exist.
  - Moa1, Moa2 and Moa3 – however these boreholes will likely be mined out during mining of blocks OL and OI.
  - Borehole Moa4 may be exhibit groundwater level drawdown by 25 to 30 mbgl, as it is located between the OI and OL mining blocks.
  - Boreholes Rie5, Rie6 and Rie7 could be impacted by dewatering, however, these boreholes are likely to be mined out in the OI block.
  - Borehole ILB6 may be mined out in Block UB.
  - Dewatering at Block UB may impact original monitoring boreholes WWN01 and WWN02S.

- No other privately-owned borehole is likely to be impacted by the lowering of water levels as a result of the Leeuwpan mining activities, based on the modelling simulations.
- It is important that the boreholes that are to be mined out are comprehensively sealed and grouted before mining commences to prevent potential contamination to the underlying dolomitic aquifer.

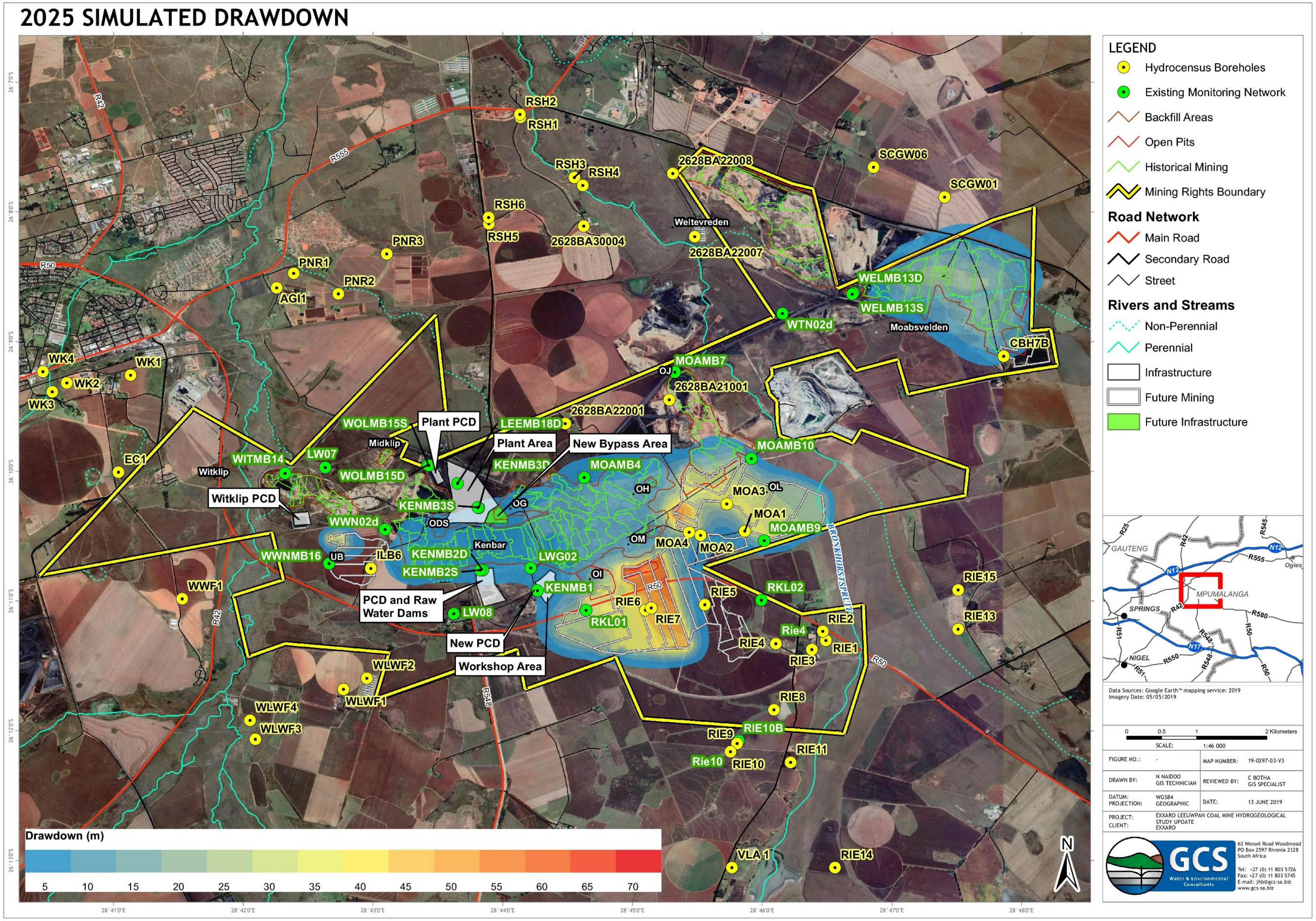


Figure 7-1: Simulated groundwater drawdown in 2025

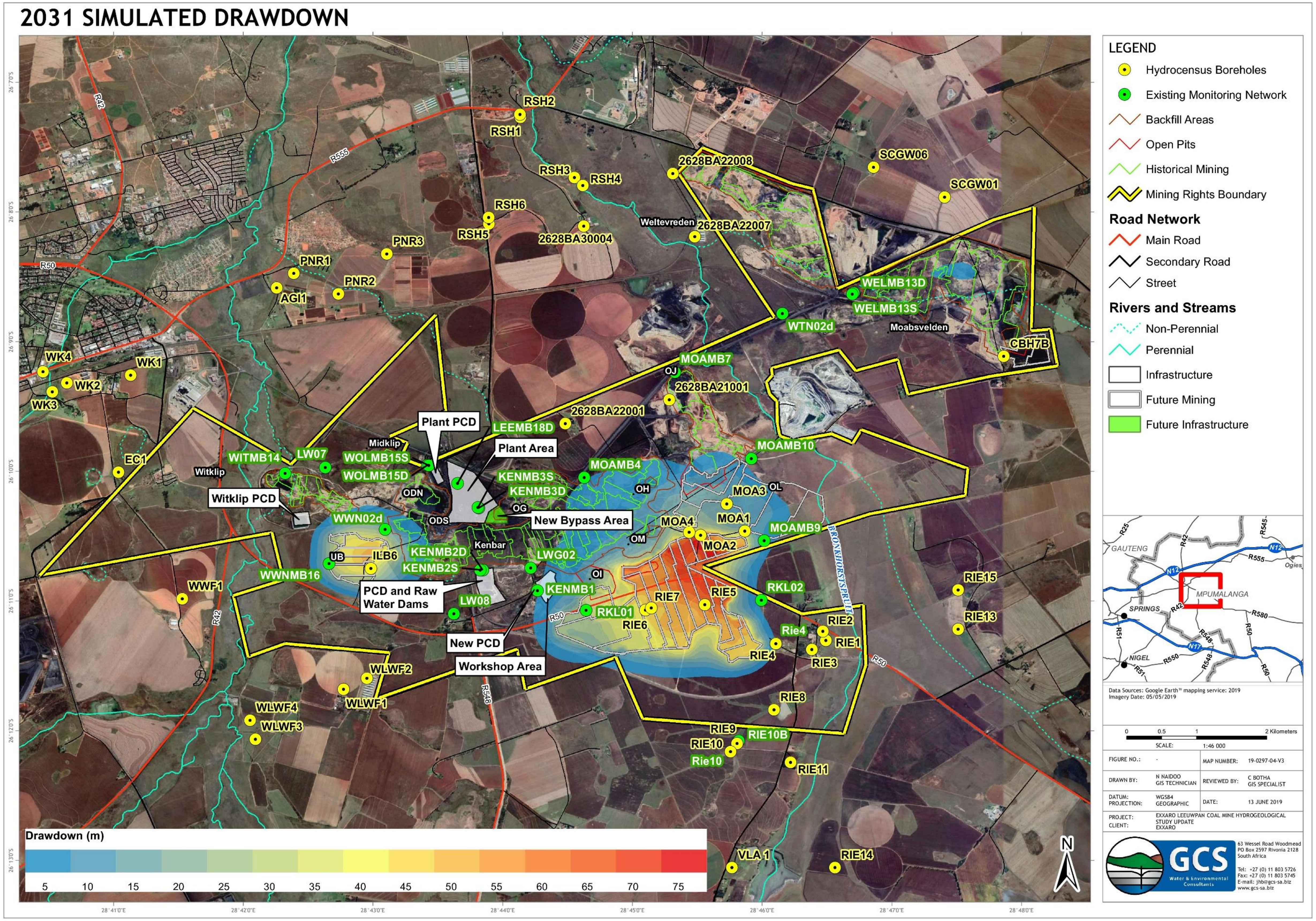


Figure 7-2: Simulated groundwater drawdown in 2031

7.3.2 Mine inflow volumes

It was possible to calculate the inflow into the opencasts for each mining cut, from the numerical model. The computed inflow into each opencast was calculated as shown below in Figure 7-3 to Figure 7-4, based on the mine schedules. Due to several assumptions that had to be made for this model, these numbers must be considered as order of magnitude only, and actual values could deviate considerably from these.

The mine inflows into the proposed Block OI opencast can be seen below in Figure 7-3. The inflows during the first cut is (~360 m^3/day) in the OI west area. The inflow increases at the end of 2030 (~900 m^3/day) as the mining depth increases to 65-78 mbgl.

The proposed Block opencast OL mining depth is shallower than OI and the mine floor depths are envisaged to grade from ~30 mbgl in the north to ~44 mbgl in the south west and 20m in the south east. As a result, the expected groundwater inflows (Figure 7-4) are likely to be less than Block OI. The inflows in 2019 may approach ~270 m^3/day which then increases to ~600 m^3/day at the end of 2022 (as the mining depth increases), and then decreases to ~350 m^3/day at the end of 2024.

It is also important to view these volumes for the water make of the mine in relation to natural evaporation. Evaporation will take place over the whole area of the opencasts, and will remove large amounts of water, particularly in the dry season.

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

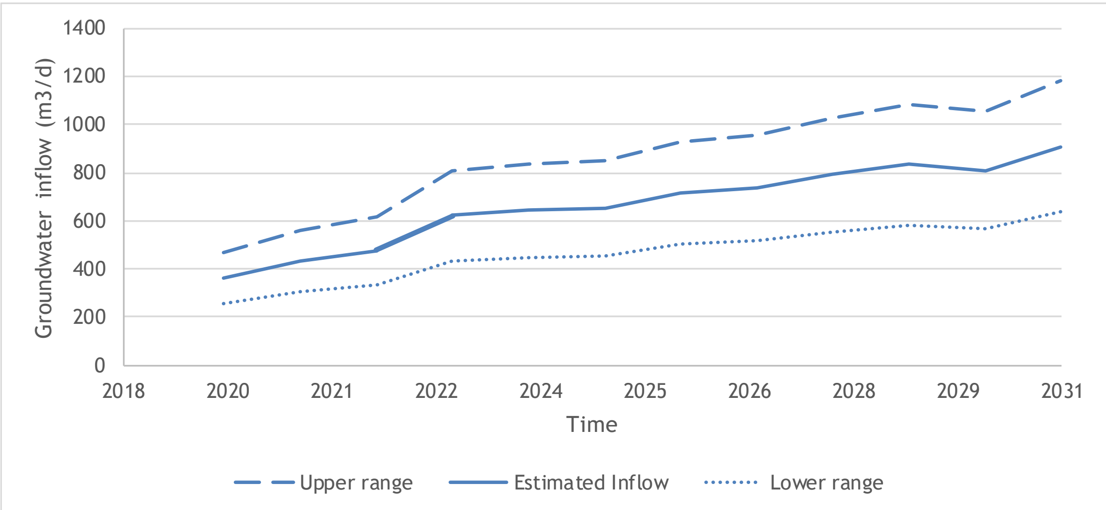


Figure 7-3: Simulated groundwater Inflows into the proposed Block OI opencast

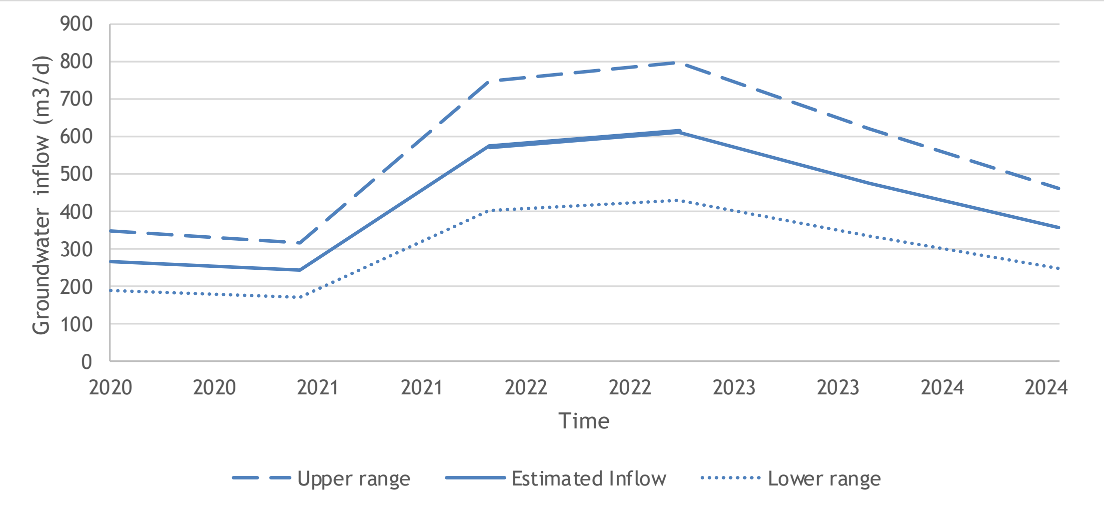


Figure 7-4: Simulated groundwater Inflows into the proposed Block OL opencast

7.3.3 Groundwater Quality (Contamination of the surrounding aquifers)

The life of mine for the existing and proposed mining at Leeuwpan is planned until 2030. This allows sufficient time for chemical reactions to take place in the mined-out areas, overburden dumps and other potential pollution sources to produce ARD conditions. Due to mine dewatering activities, groundwater flow directions will be directed towards the mining areas. Therefore, contamination will be contained within the mining area, and limited contamination will be able to migrate away from the mining area. Effective lining of the water balancing dam and pollution control dams should be ensured, thereby preventing contamination of the underlying aquifers.

The mine residue consisting of overburden, plant residue and fine coal recovered from the slimes dams, was compacted and introduced to the mined-out pits. Thus, no long-term mine residue disposal sites were constructed for the mining operations. Discard material was also placed back into the open pits.

Backfilling efforts at Blocks OJ and OWM_MN are currently underway. Backfilling of Block OI and OL could be conducted in the same manner as the other mined out pits, thus discard and slurry cake could be disposed of as part of the backfilling process.

Contamination from the mining areas is generally contained within the mining right. It is furthermore evident that several monitoring boreholes have been impacted by contaminants at the plant and PCD areas.

- The borehole KENMB02D located down gradient of the No. 5. Emergency overflow dam is potentially impacted by mining related contaminants and exhibits elevated TDS and sulphate concentrations.

- Borehole LEEMB18D located in the plant area has exhibited elevated TDS, sulphate and manganese concentrations.
- Borehole LWG02 located south east of Block OF (Kenbar), has exhibited elevated TDS, sulphate and manganese concentrations, which could be indicative of contamination from the rehabilitated mining area.
- The borehole MOAMB10 located adjacent to OJ Block opencast has been negatively impacted by mining in term of elevated sulphate, TDS and EC.
- Borehole MOAMB4, located north of block OH, exhibited significantly elevated TDS concentration in 2015 and 2016 and elevated manganese concentrations.
- Shallow and deep boreholes (WELMB13S and WELMB13D) located down gradient of the OWN_MN Block (Moabsvelden) opencast are also potentially impacted by mining related contaminants. WELMB13D exhibits a slightly acidic pH range with elevated iron and manganese. WELMB13S has exhibited elevated TDS, sulphate, iron and manganese concentrations, particularly from mid-2018 onwards.
- Shallow and deep boreholes WOLMB15S and WOLMB15D are also potentially impacted by mining related contaminants, which may be emanating from the plant area, particularly the shallow borehole which exhibits TDS concentrations that significantly exceed the DWA SAWQTV Drinking Water Standards (1996) and SANS 214 Drinking Water Standards (2015).
- Borehole WWN02D is located adjacent to a dam west of the ODS block opencast which is also potentially impacted by mining related contaminants (seepage from this dam). However, potentially contaminated seepage from the decommissioned ODS Block may also be impacting the groundwater in this area.
- Borehole WITMB14 located down gradient of the Witklip pit (Block OA) exhibits a potential impact by mining related contaminants although still compliant with the SANS 241 Drinking Water Standards (2015).
- The impacted monitoring boreholes are mostly affected by contaminants emanating from surface related contaminant sources.

Table 7-2: Impacts on groundwater during Operational Phase

ACTIVITY	POTENTIAL ENVIRONMENTAL IMPACT	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
Water quantity						
Opencast Mining	Opencast mining will result in groundwater inflows into the workings which need to be pumped out for mine safety and the resultant dewatering (water level decrease) of the groundwater system in the immediate vicinity of the workings. A groundwater cone of depression will result from dewatering of the opencasts and result in the decline of surrounding water levels.	30	L	Keeping the workings dry is necessary for mining and mitigation is not possible. No users are currently likely to be affected. Water quality will be poor and will be used in the process plant.	30	L
Water quality						
Coal (plant) and discard stockpiling	Stockpiling of coal and discard could expose material to water and oxygen, which could result in ARD from roads and stockpiles. Contamination of the groundwater system will occur from these sites, although at a lower significance than the opencast pits.	36	M	Clean water needs to be kept away from the stockpiling area to minimise water infiltrating from the site. Keep stockpiles as small as possible, to minimise their footprint. Discard should be backfilled into mined-out pits as soon as possible. Water quality monitoring of surrounding boreholes and surface water bodies should be conducted on a quarterly basis.	24	L

ACTIVITY	POTENTIAL ENVIRONMENTAL IMPACT	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
Waste Handling	Handling of waste and transport of building material can cause various types of spills (domestic waste, sewage water, hydrocarbons) which can infiltrate and cause contamination of the groundwater system.	32	M	All vehicles and machinery shall be kept in good working order and inspected on a regular basis for possible leaks and shall be repaired as soon as possible if required; Repairs shall be carried out in a dedicated repair area only, unless in-situ repair is necessary as a result of a breakdown; Drip trays shall at all times be placed under vehicles that require in-situ repairs; Drip trays shall be emptied into designated containers only and the contents disposed of at a licenced hazardous material disposal facility; Accidental spills (concrete, chemicals, process water, hydrocarbons, waste, sewage) need to be reported immediately so that effective remediation and clean-up strategies and procedures can be implemented; Soil that is contaminated by fuel or oil spills, for example, from vehicles, will be collected to be treated at a pre-determined and dedicated location, or will be treated in situ, using sand, soil or cold coal-ash as absorption medium. Water quality monitoring of surrounding boreholes and surface water bodies should be conducted on a quarterly basis.	20	L
Pollution Control Dams	Infiltration of contaminated seepage from dams into underlying aquifer and/or surface water bodies	33	M	Lining of all wastewater containing structures should be ensured. Integrity of dam lining should be maintained. Water quality monitoring of surrounding boreholes and surface water bodies should be conducted on a quarterly basis.	20	L
Rehabilitated opencast (Backfilled and capped/re-vegetated)	Contaminated seepage to groundwater environment and streams (salt load) - potential poor quality	44	M	Groundwater levels in the backfilled pits and underground workings will recover. Pollution plumes may migrate to surface water bodies. All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite. The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas.	30	L

ACTIVITY	POTENTIAL ENVIRONMENTAL IMPACT	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
				The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts. Surface water monitoring of the streams will be essential. Quarterly groundwater sampling should be done to establish a database of plume movement trends, to aid eventual mine closure. The drilling of boreholes into mining areas is recommended so that recovery of water in mining areas can be monitored.		

7.4 Decommissioning Phase

During this phase it is assumed that active mining has stopped, and the opencasts will be rehabilitated. The surface contaminant sources (plant areas, dams, and stockpiles) have been decommissioned and no longer acts as a source. No additional impacts on the groundwater of the study area other than the impacts discussed above are expected during the decommissioning phase of the project.

7.5 Post Closure Phase

In the post closure phase, all the opencasts are deemed to be backfilled and vegetated. Table 7-5 also lists the groundwater impacts expected during this phase. Water and oxygen will likely react with the backfilled material and as a result ARD could peak during this phase. The environmental impact significance is expected to be moderate to high if not mitigated.

7.5.1 Groundwater Quality

Once the mining has ceased, ARD is still likely to form given the unsaturated conditions in the facility and contact of water and oxygen through natural process including rainfall. Therefore, groundwater contaminant plumes are likely to migrate from the mining areas once the water level in the rehabilitated pits have reached long term steady state conditions (i.e. each pit water level has reached the equilibrium level, which could be the decant elevation). The contaminant plume emanating from the rehabilitated opencasts will have a cumulative impact on the groundwater quality as seen in the post mining simulations (Figure 7-5 and Figure 7-6). The migration of contaminated water from the opencasts has been simulated for 50 and 95 years after colliery closure (i.e. it is assumed that all opencasts have been rehabilitated and backfilled). Experience has shown that the plume stagnates after about 80-100 years, and no further movement after such time is expected.

The contaminant plume emanating from the Blocks OA, UB, OWM_MN and OWM_WTN opencasts will move in a north westerly direction towards the dolomitic area and the Bronkhorstspruit. The contaminant plume migrating from Blocks ODN, OD, OF, OM, OH, OG and OJ will move in a northerly direction, while the plume from OI and OL will moved in an easterly direction towards the Bronkhorstspruit. The contaminant concentration is likely to increase over time as the plume develops.

Several monitoring boreholes could be located within the long-term sulphate contaminant plume. The following boreholes identified during the GCS (2014) hydrocensus and older monitoring boreholes that do not form part of the current (2015 to 2019) monitoring network, will likely be impacted by the potential sulphate contaminant plume post-closure (their existence should be verified):

- 2628BA22008; WTN01S; CBH7B; WTN02S; 2628BA21001; Moa4; WWN01; WWN02S and EMPR02/E2.

Shallow contaminated seepage may impact on the Bronkhorstspruit. The SO_4 salt load contribution from contaminated groundwater seepage in the stream can be seen in Table 7-3. The Block OA (Witklip), OJ, OI and OWM_WTN opencast are likely to be the main contaminant sources which may impact on the salt load of the Bronkhorstspruit and its tributaries. It must be noted that this does not include any contribution from decant. Without mitigation, the impact is likely to be moderate as seen in Table 7-5.

Table 7-3: Estimated groundwater seepage salt loads on Bronkhorstspruit and its tributaries

Contaminant source	Average baseflow volumes (m^3/s)*	SO_4 salt load (kg/d)	max SO_4 concentration in seepage (mg/l)	SO_4 concentration in stream (mg/l)
Block OA	0.03	6.8	1700	2.6
Block OL and OJ	0.013	24.0	1000	21.4
Block OWM_WTN	0.01	0.6	100	0.7

* - baseflow was average per annum and obtain from the Bronkhorstspruit catchment calculation

Given the significance of the underlying dolomite aquifer, the interaction between the dolomite and the Karoo aquifers should be further investigated. If these aquifers are in hydraulic connection and a flow gradient form the Karoo aquifer exists towards the dolomite aquifer, the dolomitic aquifer may be impacted post closure by contaminants.

The results must be viewed with caution as a layered homogeneous aquifer has been assumed. Heterogeneities in the aquifer are unknown and the effect of this cannot be predicted. Furthermore, no chemical interaction of the sulphate with the minerals in the surrounding bedrock has been assumed. As there may be some interaction and retardation of the plume, it is likely that this prediction will represent a worst-case scenario.

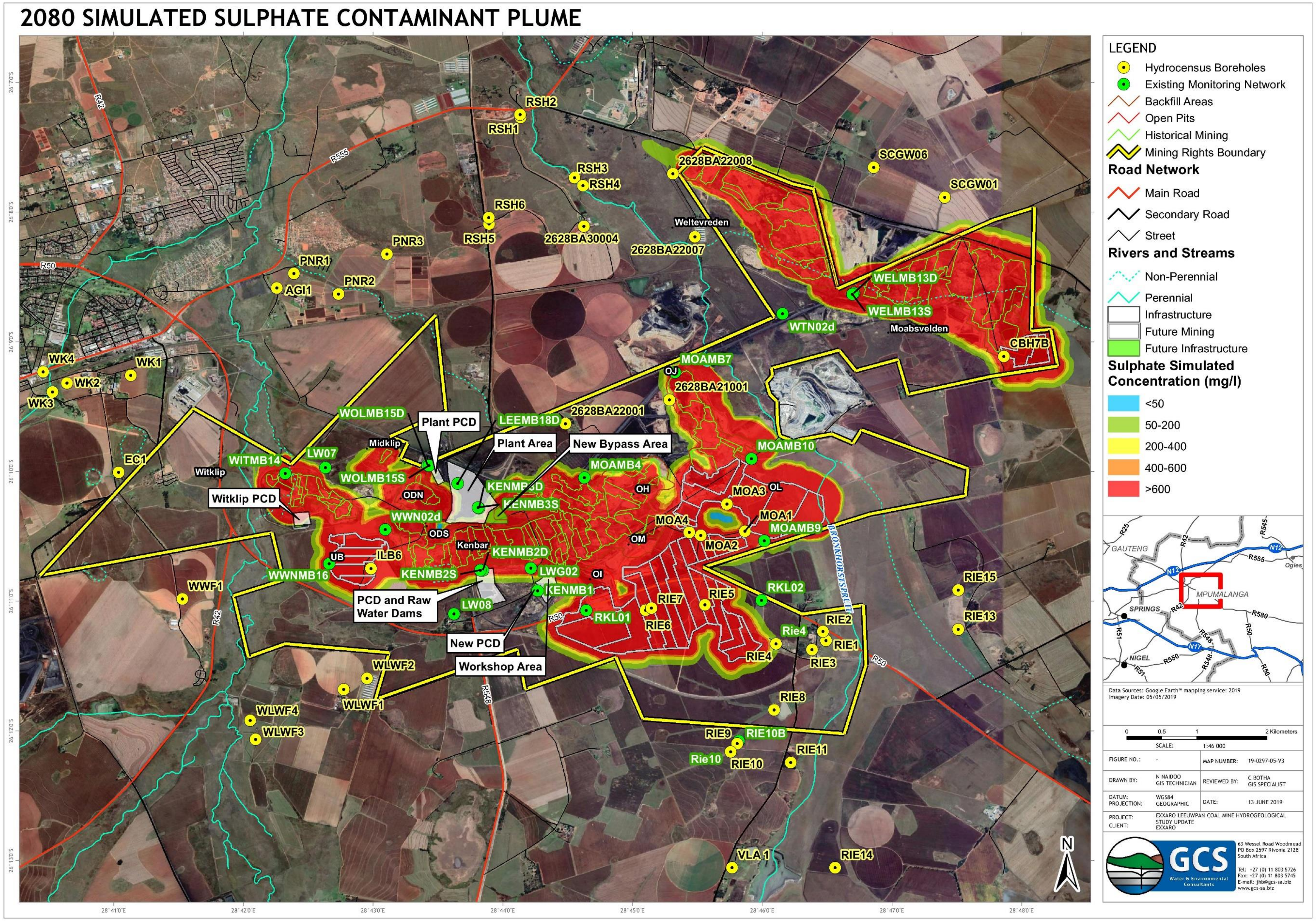


Figure 7-5: Simulated SO_4 Contaminant Plume – 2080 (50 years post closure)

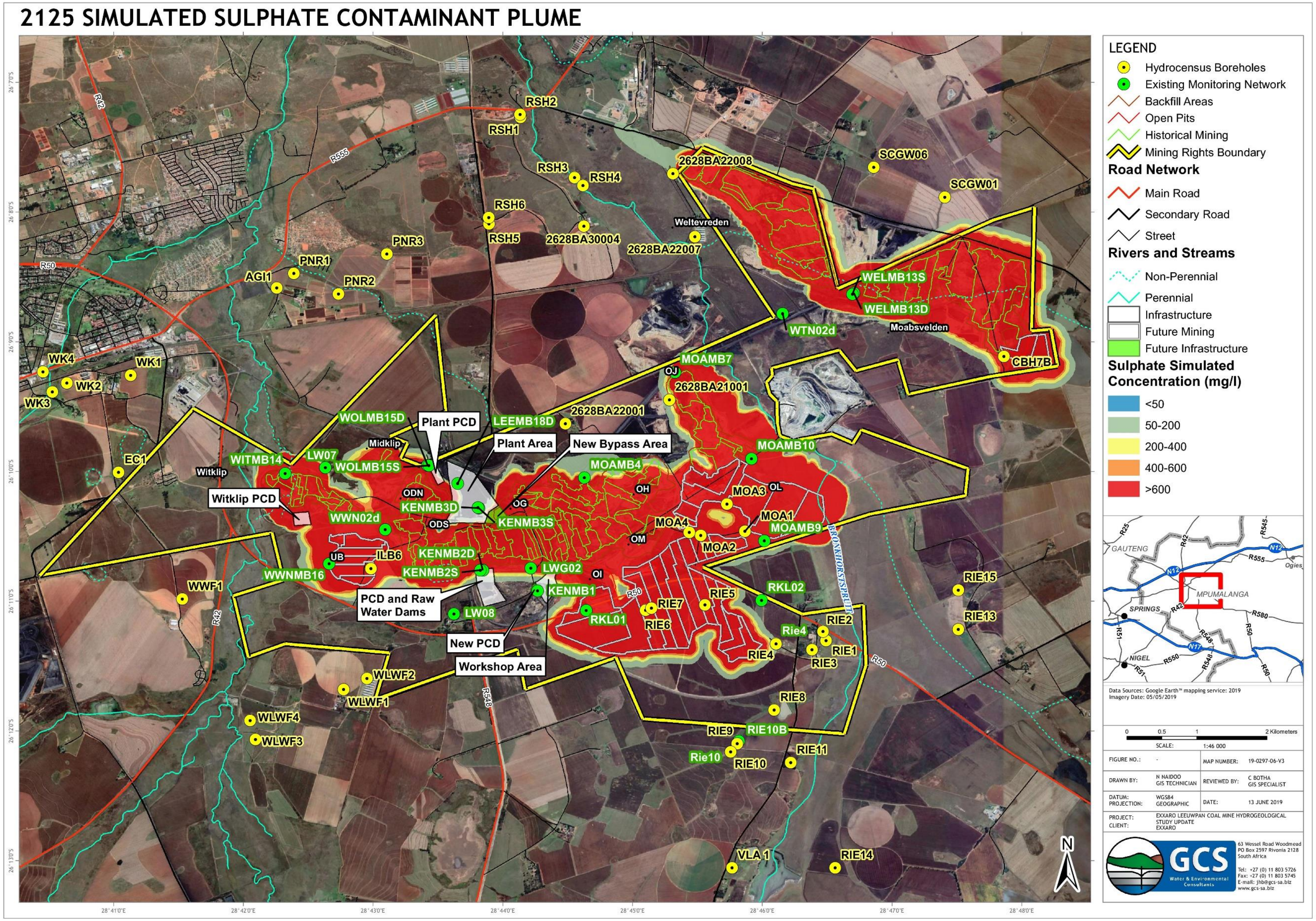


Figure 7-6: Simulated SO_4 Contaminant Plume – 2125 (95 years post closure)

7.5.2 Mine Water Decant

Decanting occurs when the mine water level in the rehabilitated and backfilled workings rebounds to a level above the topographic elevation, resulting in mine water discharging onto surface. Surface decanting refers to direct discharge of mine water to surface through backfilled material, voids, shafts, adits and other direct paths. Decant take place at the lowest topographic level that intersects the flow path and/or opencast. The location of the decant positions can be seen in Figure 7-7. A summary of the decant levels and volume for the opencasts can be seen in Table 7-4. The expected significance of the impact is high as seen in Table 7-5.

The decant volume and period to decant is based on a backfilled opencast with no final void and does not take evapotranspiration into account. Based on the available opencast floor elevations all the opencast floors will be inundated.

It is recommended that boreholes are drilled into the backfilled opencast to determine the inflow rates as the mines flood. Therefore, the active monitoring of the water levels in the mining areas should take place so that more precise decant predictions can be made.

Table 7-4: Summary of the estimated decant status of opencast

Mine Block / Pit	Decant level (mamsl)	Decant volume (m^3/d) (8% recharge)	Decant volume (m^3/d) (10% recharge)	Decant volume (m^3/d) (15% recharge)	Description
Witklip OA	1549	48	60	90	Assuming total backfilling
ODN	1563	42	52	78	Assuming total backfilling
OE Midklip	1561	5	6	8	Assuming total backfilling
OD	1569	106	132	198	Assuming total backfilling
OF (Kenbar)/OG	1569	364	456	683	All pits to decant through OG
OG/OH	1569				
OM	1569				
OJ	1549	59	73	110	Assuming total backfilling
OWM_WTN	1545	199	248	372	Assuming total backfilling
OWM_MN	1550	380	475	713	Assuming total backfilling
OL	1553	172	216	323	Assuming total backfilling
OI	1570	357	447	670	Assuming total backfilling
UB	1561	58	72	108	Assuming total backfilling
Sum		**1789**	**2237**	**3355**	

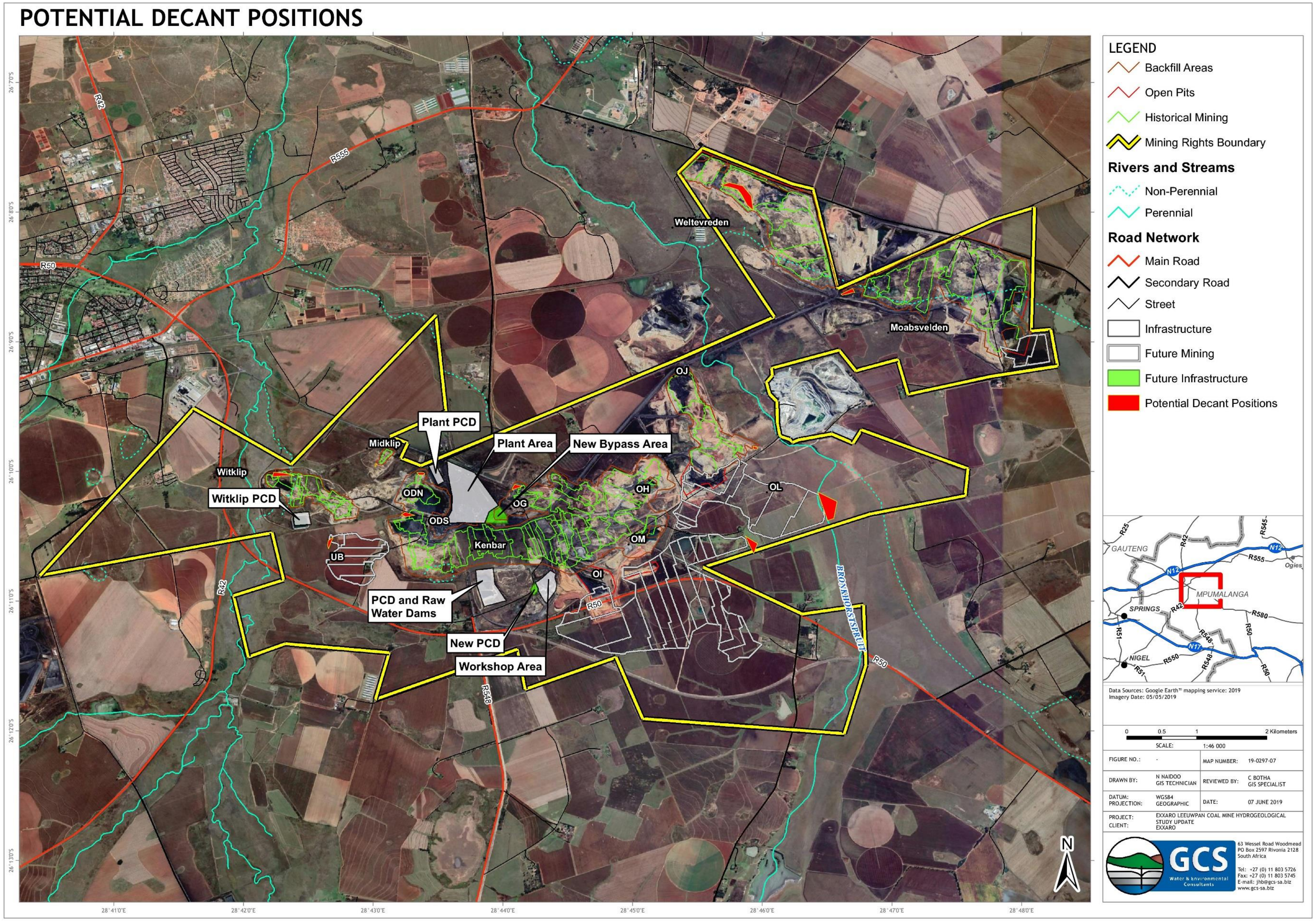


Figure 7-7: Location of potential decant positions

Table 7-5: Impacts on groundwater Post Closure Phase

ACTIVITY	POTENTIAL ENVIRONMENTAL IMPACT	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
Water Quality						
Rehabilitated opencast (Backfilled and capped/re-vegetated)	Contaminated seepage to groundwater environment - groundwater contaminant plume	48	M	Groundwater levels in the backfilled pits and underground workings will recover. Pollution plumes may migrate to surface water bodies. All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite. The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas. The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts. Quarterly groundwater sampling should be done to establish a database of plume movement trends, to aid eventual mine closure. The drilling of boreholes into mining areas is recommended so that recovery of water in mining areas can be monitored. The absence of groundwater users should be assessed bi-annually.	33	M
Rehabilitated opencast (Backfilled and capped/re-vegetated)	Contaminated groundwater seepage to streams (salt load)	36	M	Groundwater levels in the backfilled pits and underground workings will recover. Pollution plumes may migrate to surface water bodies. All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite. The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas. The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts. Surface water monitoring of the streams will be essential. Quarterly groundwater sampling should be done to establish a database of plume movement trends, to aid eventual mine closure. The drilling of boreholes into mining areas is recommended	27	L

ACTIVITY	POTENTIAL ENVIRONMENTAL IMPACT	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION		RECOMMENDED MITIGATION MEASURES/ REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION	
		TOTAL	SP		TOTAL	SP
				so that recovery of water in mining areas can be monitored.		
Residual Impacts Post Closure (All Opencasts)	Decant from opencast operations	60	H	Surface water should be diverted away from the rehabilitated area A dirty water / pollution control dam could be used to intercept and prevent contaminated decant from entering water courses (streams). Proper compaction and rehabilitation may lower recharge to the backfilled area and minimise infiltration, thereby minimising geochemical reactions that will occur. Reduction of the recharge would entail capping the backfill of the opencast with a semi-permeable layer. Leaving a final void in the opencast areas, would potentially facilitate evaporation of the decanting volume on average through the year. Decant can also be treated for reuse or discharge.	33	M

8 GROUNDWATER MANAGEMENT PLAN

8.1 Construction Phase (New Activities)

8.1.1 Actions

- Separate clean and dirty runoff and contain dirty water in adequately sized pollution control dams. Ensure that pollution control dams are adequately sized according to the specifications in DWAF's GN704 or other applicable regulations;
- Prevent dirty water runoff from leaving the general mining area (Storm water management);
- Minimise dirty footprints;
- Compact the base of dirty areas, like the ROM coal stockpile, workshops and oil and diesel storage areas to minimise infiltration of poor-quality water to the underlying aquifers;
- A credible company should remove used oil from the workshops;
- A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills;
- Monitoring boreholes should be monitored to comply with the groundwater monitoring system;
- Contain dirty water in return water dams and re-use dirty water for dust suppression and make up water in the plant. Pollution control dams should be lined, and the lining integrity maintained; and
- The pollution control dams should preferably not be constructed on the Phase 9 opencast footprint. This is done to minimise the risk of increased infiltration through the opencast should the dam leak.

8.2 Operational Phase

Restrict the impact of polluted groundwater to the mining area and mitigate the impact on groundwater levels in the catchment.

8.2.1 Actions

- All boreholes to be mined out should be grouted and sealed to prevent cross contamination of aquifers;
- During the operational phase the mine water must be used or pumped to dirty water dams or pollution control facilities in order to avoid deterioration of the mine water. The longer the mine water resides in the pit the higher it's TDS will be. It is not foreseen that mine water in contact with the pit material will acidify during the operational phase of future mining;
- As much as possible coal must be removed from the opencast mine during the operational phase;

- Carbonaceous rocks (especially shale) and discard could be placed in the deepest part of the pit (as far as practical possible) and below the long-term pit water level in order to ensure that it is flooded, and that pyrite oxidation is minimized;
- Soft overburden and weathered rock could be placed at the top of the backfill in order to minimize oxygen diffusion into the pit;
- The mined-out sections of the pit could be backfilled, compacted and rehabilitated as soon as possible. Rehabilitation can include covering the backfill with a topsoil layer as well as vegetation thereof. Installation of a soil cover could significantly decrease water infiltration and contamination. If less water is infiltrating it will likely not have a negative effect on mine water quality (increasing TDS) as the salt content is controlled by mineral saturation rather than straightforward dilution;
- Adequately sized pollution control facilities should be constructed;
- Minimise the footprint of dirty water areas like the pollution control dam and coal stockpiles, workshops and oil and diesel storage areas;
- Proper storm water management should be implemented. Berms could also be constructed to ensure separation of clean water and dirty water areas;
- Contain poor quality runoff from dirty areas and divert this water to pollution control dam for re-use;
- Static groundwater levels should be monitored as mentioned in 8.4 to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time;
- The numerical model should be updated every two (2) years by using the measured water ingress and water levels to re-calibrate and refine the impact predictive scenario;
- If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, the affected parties can be compensated. This may be done through the installation of additional boreholes for water supply purposes, or an alternative water supply;
- The monitoring results must be interpreted annually by a qualified hydrogeologist and network audited annually as well to ensure compliance with regulations;
- The rehabilitated opencasts should be free draining away from the pit to reduce drainage into the pit;
- All old exploration boreholes must be sealed off after closure;
- Sewage effluent emanating from latrines or ablution blocks should be treated to acceptable levels before discharge into the environment;
- Boreholes could be drilled into the mine workings so that the rate of flooding and water level recovery and quality could be established. Stage curves should be made which would aid in the management of closure phase;

- A detailed mine closure plan should be prepared during the operational phase, including a risk assessment, water resource impact prediction etc. as stipulated in the DWA Best Practice Guidelines. The implementation of the mine closure plan, and the application for the closure certificate can be conducted during the decommissioned phase. Properly engineered decant containment or treatment solutions should be designed; and
- It is recommended that the geochemical assessment is updated during the life of the mine in order to calibrate and validate its results and to construct an effective closure plan. A geochemical model should be performed to assess the effectiveness of potential mitigation measures.

8.3 Groundwater Closure

The following objectives are envisaged for the closure phase:

- Negotiate and obtain groundwater closure objectives approved by Government during the Decommissioning Phase of the project, based on the results of the monitoring information obtained during the construction and operational phases of the project, and through verification of the numerical model constructed for the project;
- Continue with the groundwater quality and groundwater level monitoring for a period of two to four years after mining ceases in order to establish post-closure groundwater level and quality trends. The monitoring information must be used to update, verify and recalibrate the predictive tools used during the study to increase the confidence in the closure objectives and management plans;
- Present the results of the monitoring programme to Government on an annual basis. The post-closure monitoring programme will be re-evaluated on an annual basis in consultation with Government; and
- Negotiate mine closure with Government based on the results of the groundwater monitoring undertaken, after the two- to four-year post-closure monitoring periods.

8.3.1 Actions

- Multiple-level monitoring boreholes must be constructed to monitor base-flow quality within the identified sensitive zones and to monitor groundwater level behaviour in the backfilled pits. The results of the monitoring programme could be used to confirm/validate the predicted impacts on groundwater availability and quality after closure;
- Update existing predictive tools to verify long-term impacts on groundwater, if required;
- Present the results to Government on an annual basis to determine compliance with the closure objectives set during the Decommissioning Phase;

- Reduce recharge, this would entail capping the backfill of the opencast with an impermeable layer, and is encouraged if practical;
- Pollution control dam could be used to intercept polluted seepage water. This should be considered if it is found that the stream is indeed negatively affected by pollution. Regular sampling of the stream is essential;
- Implement as many closure measures during the operational phase, while conducting appropriate monitoring programmes to demonstrate actual performance of the various management actions during the life of mine;
- All mined areas should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite;
- The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas;
- A soil cover design study should be conducted to assess the likely closure cover for the opencasts; and
- Audit the monitoring network annually.

8.4 Groundwater Monitoring Network

The groundwater monitoring network design should comply with the risk-based source-pathway -receptor principle. A groundwater-monitoring network should contain monitoring positions which can assess the groundwater status at certain areas. Both the impact on water quality and water quantity should be catered for in the monitoring system. The boreholes in the network should cover the following: contaminant sources, receptors and potential contaminant plumes. Furthermore, monitoring of the background water quality and levels are also required.

Groundwater monitoring should be conducted to assess the following:

- The impact of mine dewatering on the surrounding aquifers. This will be achieved through monitoring of groundwater levels in the monitoring boreholes. If private boreholes are identified within the zone of impact on groundwater levels, these will be included in the monitoring programme;
- Groundwater inflow into the mine workings. This will be achieved through monitoring of groundwater levels in the monitoring boreholes as well as measuring water volumes pumped from mining areas;
- Groundwater quality trends. This will be achieved through sampling of the groundwater in the boreholes at the prescribed frequency; and
- The rate of groundwater recovery and the potential for decant after mining ceases. This can be achieved through drilling of additional boreholes into the opencast workings for monitoring purposes. These boreholes should be drilled in the deepest

sections of the mine. Stage curves will be drawn to assess the inflow into defunct workings.

Groundwater Monitoring should be undertaken to SANS and DWS requirements according to the schedule presented in Table 8-1 below. The existing Leeuwpan monitoring network and the proposed additional borehole can be seen in Figure 8-1 and tabulated in Table 8-2. It is envisaged that the frequency of monitoring remains on a quarterly basis.

The groundwater monitoring network should however be reviewed and expanded for the all activities at Leeuwpan. An updated and optimised monitoring program should be developed and submitted to DWA should it be required.

Table 8-1: Groundwater Monitoring Programme

Monitoring position	Sampling interval	Analysis	Water Quality Standards
Construction, Operational, Decommissioning and Post Closure Phases			
All monitoring boreholes	Quarterly: measuring the depth of groundwater levels	N/a	N/a
All monitoring boreholes	Quarterly: sampling for water quality analysis	Full analysis in April and October	DWA South African Water Quality Guidelines: Domestic Use South African National Standards 241-1:2015
Rainfall	Daily at the mine	N/a	N/a

8.4.1 Monitoring Parameters

The identification of the monitoring parameters is crucial and depends on the chemistry of possible pollution sources. They comprise a set of physical and/or chemical parameters (e.g. groundwater levels and predetermined organic and inorganic chemical constituents). The parameters should be revised after each sampling event, some metals may be added to the analyses during the operational phase, especially if the pH decreases.

8.4.2 Full Analysis

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements: pH, EC
- Laboratory analyses: Anions and cations (Ca, Mg, Na, K, NO_3, Cl, SO_4, F, Fe, Mn, Al, & Alkalinity); Other parameters (pH, EC, TDS)
- Petroleum hydrocarbon contaminants (where applicable, near workshops and petroleum handling facilities)

- Sewage related contaminants (E.coli, faecal coliforms) in boreholes in proximity to septic tanks or sewage plants.

Laboratory analysis techniques will comply with SABS guidelines. The groundwater monitoring database will be updated on a quarterly basis as information becomes available. The database should be used to analyse the information and evaluate trends noted.

An annual compliance report should be compiled and submitted to the authorities for evaluation and comment. This report should be submitted annually for the construction, operational and decommissioning phases as well as for two (2) years after mining ceases. The mine must develop a monitoring response protocol. This protocol will describe procedures if groundwater monitoring information indicates that action is required.

Table 8-2: Existing Leeuwpan Monitoring Network and proposed OL/OI monitoring

Borehole	Longitude	Latitude
KENMB01	-26210.54	-2897024.26
KENMB2_D	-26915.09	-2896734.43
KENMB2_S	-26946.18	-2896732.5
KENMB3_D	-26967.21	-2895847.87
KENMB3_S	-26977.03	-2895839.03
LEEMB18_D	-27239.58	-2895496.9
LW07	-28940	-2895277
LW08	-27282	-2897355
LWG02	-26296	-2896700
MOAMB10	-23468.44	-2895139.21
MOAMB4	-25613.14	-2895412.71
MOAMB7	-24450.44	-2893907.47
MOAMB9	-23301.68	-2896308.21
RIE10	-23725.82	-2899313
RIE10B	-23620.389	-2899158.569
RIE4	-23148.12	-2897771
RKL01	-25585	-2897302
RKL02	-23333	-2897155
WELMB13_D	-22155.85	-2892777.94
WELMB13_S	-22175.52	-2892795.48
WITMB14	-29453.45	-2895360.47
WOLMB15_D	-27626.03	-2895239.12
WOLMB15_S	-27611.42	-2895244.74
WTN02d	-23069	-2893073
WWN02d	-28169	-2896156
WWNMB16	28.71102	-26.1785
Proposed Monitoring borehole – OL1	28.77483	-26.1687

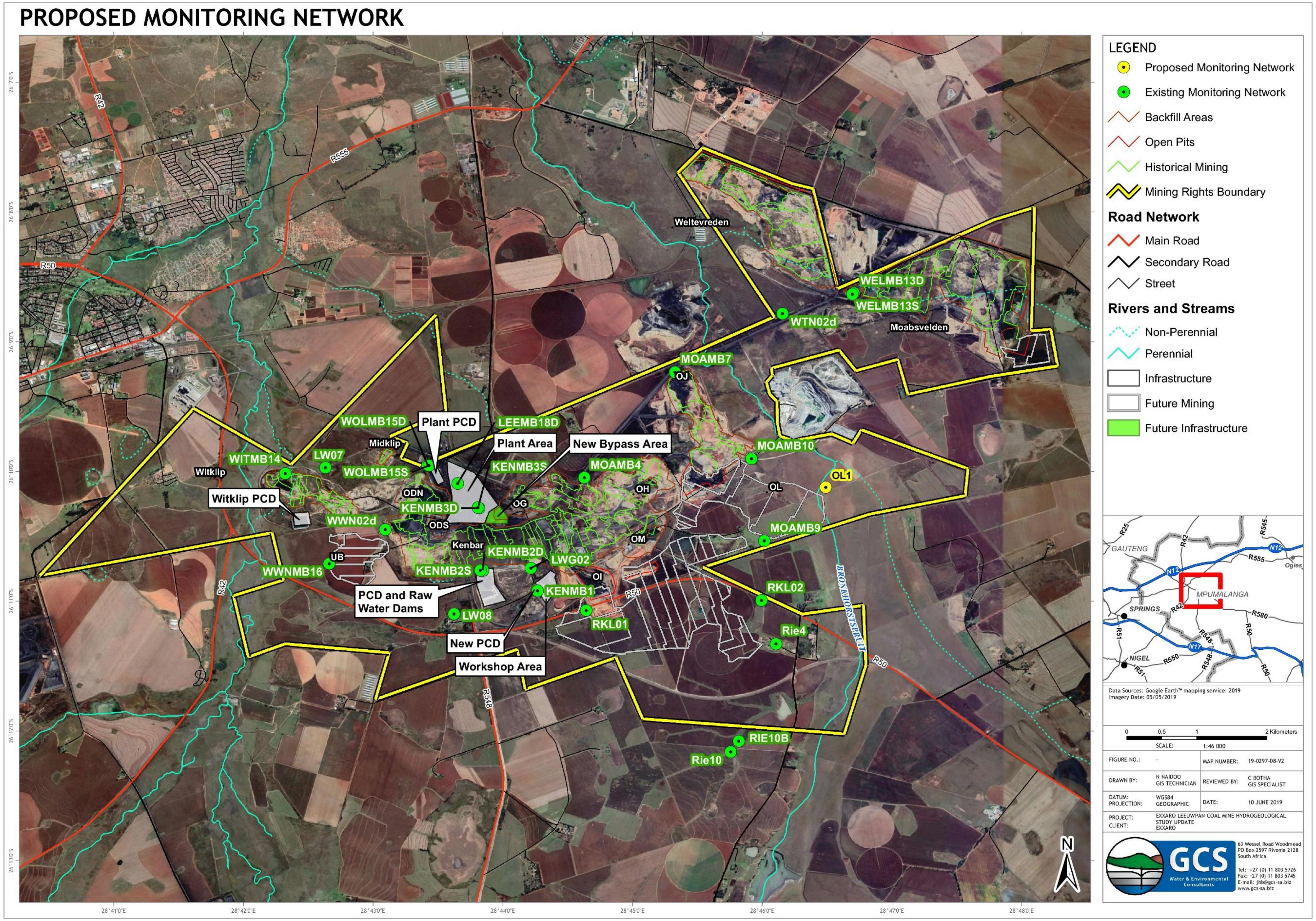


Figure 8-1: Proposed Monitoring Network

9 CONCLUSIONS AND RECOMMENDATIONS

GCS Water and Environmental Consultants (Pty) Ltd ("GCS") was appointed by Exxaro Resources Ltd ("Exxaro") to undertake an update of the hydrogeological study conducted by GCS in 2014 at the Exxaro Leeuwpan Colliery ("Leeuwpan"), located south-east of Delmas in Mpumalanga, South Africa.

The following conclusions have been made:

- Leeuwpan coal mine falls under a summer rainfall region, receiving the highest rainfall reading in January and lowest in July with average mid-day temperatures of 26oC in January and 17oC in July. Based on rainfall measurements taken at the South African Weather Service (SAWS) Delmas rain station (477309) between 1907 and 1999, the station recorded a Mean Annual Precipitation (MAP) of 681 mm. Based on the Leeuwpan Monitoring Station database (2017 to 2019) available on the Africa Weather Website, a total of 602 mm of rainfall was recorded in this region during 2018.
- The topography in the study area is relatively flat with a topographic high in the southern section of the mining right area. The mine is located within quaternary catchment B20A of the Olifants Water Management Area. Drainage across the study area predominantly occurs in a northerly direction and locally towards the Bronkhorstpruit River, which is flowing through the eastern to western sections of the mining right.
- Sedimentary sequences of the Karoo and Transvaal Supergroups outcrop in the regional study area. Jurassic dolerite dykes and sills have intruded the sedimentary rocks of the Karoo Supergroup. The coal measures are up to 16 m thick within the mining right are divided into a Bottom Coal Seam and Top Coal Zone.
- Opencast mining activities at Leeuwpan Colliery of the OF (Kenbar) pit, located to the south of the current plant area, commenced in 1992 and concluded in 2004. Thereafter mining of the OA (Witklip) pit located on the western extent of the mine commenced in 1996 and was decommissioned in March 2005. Mining at Block OE (Midklip) commenced in 1998 and was decommissioned in June 1999. The mining blocks OG, OH, OD and OM were commissioned between 1999 to 2008, and decommissioned between 2010 and 2016. Mining at Block OJ commenced in 2008 and concluded in 2018.

- The Wolvenfontein (UB) reserve is a westward extension of the OD, OF (Kenbar) opencast pits and mining is planned to commence in 2024 and conclude in 2029. The Weltevreden (OWM_WTN) and Moabsvelden (OWM_MN) reserves is situated approximately 4.5 km north-east of the OJ opencast pit. Opencast mining at these reserves commenced in 2011 and 2008, respectively. Block OWM_WTN was decommissioned in 2017, however, mining is currently underway in Block OWM_MN and is planned to continue until 2020.
- The expansion of the mining activities to blocks OL and OI commenced in 2018 and is planned to continue until 2024 and 2030, respectively. Block OI is planned to extend further towards the west and has prompted an update of numerical hydrogeological model. A new PCD has also been constructed west of Block OI, and a new bypass area has been constructed at the plant area.
- The mine residue consists of overburden and plant residue. The slurry fraction recovered from the slime's dams is compacted and backfilled into to the mined-out pits. Thus, no permanent mine residue disposal sites are constructed for the mining operations. The decommissioned mining blocks have been partially to completely backfilled. Backfilling at Block OJ is currently underway.
- Drainage from the opencast backfill will become acidic over the long-term as the ABA results from the 2014 geochemical assessment show that the material has the potential to generate acid-mine drainage. In the opencast the SO_4 will increase roughly to about 2 500 mg/l over the long term.
- Three (3) distinct aquifer types or hydrogeological units are present with the study area. These units vary by aquifer characteristics; however, the aquifers are generally interconnected by fractures and faults:
  - Shallow weathered aquifer: a shallow aquifer formed within the residual and weathered zone of the Karoo Supergroup, locally perched on fresh bedrock;
  - Deeper fractured aquifer: a deeper aquifer formed by fracturing of the Karoo Supergroup and dolerite intrusions; and
  - Fractured karst aquifer: a fractured aquifer hosted within the dolomite- and chert-rich Malmani Subgroup.
- GCS conducted a hydrocensus in the project area during April and July 2012 within a 2 km radius of the proposed mining activities. A total of 59 boreholes were visited of which eleven (11) boreholes formed part of the existing Leeuwpan monitoring network.
- Leeuwpan Colliery has an active groundwater monitoring programme. A total of 26 boreholes were monitored during the 2015 to 2019 monitoring period.

- Seasonal fluctuations in the groundwater levels are evident in most boreholes, with several boreholes exhibiting impacted water levels by either mining activities or abstraction activities. The water levels of mine monitoring boreholes drilled into the shallow weathered Karoo ranged from 1.9 to 9.8 mbgl with an average groundwater level of 7 mbgl. The static water levels of the borehole's representative of the deeper fractured Karoo aquifer ranged between 2.1 and 53 mbgl with the average calculated as 16.6 mbgl.
- Groundwater flows predominantly towards the northwest and northeast, following the topography towards drainage lines. Local groundwater divides are evident around RKL01 and RKL02, as well as MOAMB4 and WOLMB15D/S. Slightly lowered groundwater levels are observed within the Kenbar area. Groundwater depressions, deeper than expected for the natural groundwater table, are evident at boreholes MOAMB7 and MOAMB9, likely attributed to cumulative dewatering impacts from an adjacent mine and Block OJ at MOAMB7, and surrounding abstraction activities at MOAMB9.
- Groundwater quality sampling was conducted in 2012 during a hydrocensus, in 2013 and 2014 after additional monitoring boreholes were drilled for the GCS (2014) study and during the 2015 to 2019 monitoring network. The dominant water type was determined as calcium/magnesium-bicarbonate and it was concluded that water was mostly un-impacted from mining activity. The secondary water type was found to be calcium/magnesium-sulphate-chloride, which is indicative of the impact of mining activities on groundwater.
- The groundwater quality results of the 2015 to 2019 monitoring network were made available by Leeuwpan Coal Mine and interpreted during this investigation. The dominant water type across the study area is calcium/magnesium-bicarbonate, however, within close vicinity of mining activities the water type is predominantly calcium/magnesium-sulphate type, which is indicative of the impact of mining activities on groundwater. Sulphate concentrations are predominantly elevated in the plant area, north of the Kenbar (OF) Block, and south of the mining block at the PCD and raw water dams. Slightly elevated sulphate concentrations are also observed down gradient of the OWM_MN Block (Moabsvelden) opencast.
- The hydraulic conductivity ranges from 0.01-0.60 m/day with a harmonic mean of ~0.05 m/day. The transmissivity ranges from 0.20 to 20 m^2/day with a harmonic mean of ~0.7 m^2/day. These values are typical of the Karoo type aquifers and correspond with the values identified in previous studies.
- The Leeuwpan conceptual model describes the hydrogeological environment and is used to design and construct the numerical model to represent simplified, but relevant conditions of the groundwater system.

- Leeuwpan Colliery is an existing operation and as a result there are numerous contaminant sources present within the mining rights area.
- During the operational phase of the opencast mining, the mined-out areas are backfilled with waste rock material as well as coal discard and slurry cake. The groundwater levels in the rehabilitated backfilled areas will rebound upon the cessation of dewatering and recover to a new equilibrium level, which could be the decant elevation. Above the equilibrated groundwater level, the backfilled material will be unsaturated, and the potential oxidation of sulphur minerals within the pit backfill or exposed along the pit walls could likely impact the overall mine water quality.
- The recharge in the area within which rocks of the Karoo Supergroup outcrop, is estimated between 1 and 3% (7 mm to 20 mm/annum) of mean annual precipitation (MAP). Where dolomite outcrops occur, the effective recharge percentage is likely to be higher and is estimated to be between 2 and 6% (14 mm to 41 mm/annum) of the MAP.
- The unsaturated zone (~5 - 26 mbgl) in the study area consists of colluvial material and clay underlain by weathered sandstone / siltstone / mudstone / shale and coal of the Ecca Group, which become less weathered with depth.
- The surrounding river systems also act as potential pathways for contamination, particularly when decant or contaminated seepage is intercepted.
- Contamination from the mining areas is contained within the mining right. It is furthermore evident that several monitoring boreholes have been impacted by contaminants, particularly at the plant and PCD areas. The dominant water type across the study area is calcium/magnesium-bicarbonate, however, within close vicinity of mining activities the water type is predominantly calcium/magnesium-sulphate type, which is indicative of the impact of mining activities on groundwater. The majority of privately-owned boreholes are associated with the underlying dolomitic aquifer which is unlikely to be impacted by any mining related dewatering activities.
- The objective of the numerical model is to simulate groundwater ingress into the mine and the migration of potential contaminant plumes.
- An Australian Guideline Class 1 model classification was pursued.
- The numerical model used in this modelling study was based on the conceptual model developed from the findings of the desktop and baseline investigations.
- The modelling area was discretised by a 300 x 250 grid in the x and y direction. A refined cell size of 50 m x 50 was used in the mining area with gradual increase to about 400m on a regional scale.
- The subsurface was modelled in three dimensions (three-layer model).

- The opencast schedules, particularly OI and OL and as provided by the client, were used as input for the model for the purpose of scenario modelling. The mining operations were simulated by means of drain cells.
- Steady state calibration of the model area was accomplished by refining the horizontal hydraulic conductivity relative to average fixed recharge values until a reasonable resemblance between the measured piezometric levels and the simulated piezometric levels were obtained. The previous GCS (2014) groundwater model calibration was reassessed.
- Model parameter values and hydrologic stresses determined during the steady-state calibration were used to simulate a transient response. The groundwater level data used for transient calibration was available from 2015 to 2019 whilst mining was active.
- The following performance measurements were evaluated during the calibration of the baseline model:

  - Model convergence: Model convergence was obtained during calibration and a maximum change in heads between iterations was set to 1.0×10^{-5} m.
  - Water Balance: The model demonstrated an accurate water balance during steady state calibration. A water balance error (all flows into the model minus all flows out of the model) of less than 0.5% is regarded as an accurate balance calculation.
  - Quantitative measures: The transient calibration was regarded as sufficient at ME= 1.5m, MAE = 4.93 m and RMS = 6.46 m, which takes into account the variations on simulated versus observed water levels for the entire modelled period. If only 2017 groundwater levels are considered, the calibration error is ME= 1.15m, MAE = 4.00.m and RMS = 5.47 m.
  - Qualitative measures: The steady state water level contours are consistent with the regional drainage features.
- The calibrated groundwater flow model was used as a basis for developing a contaminant transport model.
- Sulphate concentration was used to determine the impact of mining on the aquifer.
- During construction of the new mining blocks (Block OI and OL) minimal additional impacts to the groundwater system are expected.
- The major purpose of this study is to assess how OI, including OI West Expansion, and OL will impact on the groundwater environment during the operational phase. The environmental impact significance is expected to be moderate to low.

- The mine floor elevation is below the general groundwater level thus causing groundwater inflows into the opencast mining areas from the surrounding aquifers during operations. The 3D numerical groundwater flow model was used to simulate the development of the drawdown cone over time in the study area.
- By the year 2025, these opencast areas will a likely result in a lowering of the groundwater level surrounding the opencasts. It is also observed from model predictions that the extent of groundwater cone of depression around the OD, OH, OM, OJ, OWM_MN (Moabsvelden) and Block OF (Kenbar) is decreasing. The simulated extent of drawdown extends 100 m to 300 m from the active mining area.
- Only the OI and UB are scheduled to be mined between 2025 and 2030. The extent of drawdown around these opencast areas range from 100 to 500m. As the mined-out opencasts start filling with water the groundwater levels around the opencast will also rebound.
- The following deductions were made: the water levels could be lowered over a relatively large area around the opencasts but recover once dewatering in the pits ceases; there are several monitoring boreholes in the potential affected area that might experience a decline in water levels of 5 m or more; and that there are a few boreholes identified during the GCS (2014) hydrocensus and older monitoring boreholes that do not form part of the current (2015 to 2019) monitoring network that will likely be impacted by dewatering.
- The inflows into OI Block during the first cut is (~360 m^3/day) in the OI west area. The inflow increases at the end of 2030 (~900 m^3/day) as the mining depth increases to 65-78 mbgl. The proposed Block opencast OL mining depth is shallower than OI. As a result, the expected groundwater inflows are likely to be less than Block OI. The inflows in 2019 may approach ~270 m^3/day which then increases to ~600 m^3/day at the end of 2022 (as the mining depth increases), and then decreases to ~350 m^3/day at the end of 2024. Evaporation will take place over the whole area of the opencasts, and will remove large amounts of water, particularly in the dry season.
- In the post closure phase, all the opencasts are deemed to be backfilled and vegetated. Water and oxygen will likely react with the backfilled material and as a result ARD could peak during this phase. The environmental impact significance is expected to be moderate to high if not mitigated.

- The migration of contaminated water from the opencasts has been simulated for 50 and 95 years after colliery closure. The contaminant plume emanating from the Blocks OA, UB, OWM_MN and OWM_WTN opencasts will move in a north westerly direction towards the dolomitic area and the Bronkhorstspruit. The contaminant plume migrating from Blocks ODN, OD, OF, OM, OH, OG and OJ will move in a northerly direction, while the plume from OI and OL will moved in an easterly direction towards the Bronkhorstspruit. The contaminant concentration is likely to increase over time as the plume develops.

- Several monitoring boreholes could be located within the long-term sulphate contaminant plume. The following boreholes identified during the GCS (2014) hydrocensus and older monitoring boreholes that do not form part of the current (2015 to 2019) monitoring network, will likely be impacted by the potential sulphate contaminant plume post-closure: 2628BA22008; WTN01S; CBH7B; WTN02S; 2628BA21001; Moa4; WWN01; WWN02S and EMPR02/E2.
- Shallow contaminated seepage may impact on the Bronkhorstspruit. Without mitigation, the impact is likely to be moderate.
- Based on the available opencast floor elevations all the opencast floors will be inundated. The expected significance of the impact is high before mitigation, and depending on the mitigation measures, the impact significance could be lowered to moderate.

The following recommendations are made:

- During the construction phase, the following actions should be taken:
  - Clean and dirty runoff should be separated and contained;
  - pollution control dams should be adequately sized;
  - dirty water runoff should be prevented from leaving the general mining area (storm water management);
  - the base of dirty areas, like the ROM coal stockpile, workshops and oil and diesel storage areas should be compacted; and
  - monitoring boreholes should be monitored.
- During the operational phase, the following objective is relevant
  - The impact of polluted groundwater to the mining area should be restricted and the impact on groundwater levels in the catchment mitigated.
- The following actions should be taken in the operational phase:
  - grouting and sealing all mined-out boreholes;
  - using or pumping mine water to dirty water dams or pollution control facilities;

  - removing as much as possible coal from the opencast mine during the operational phase;
  - placing carbonaceous rocks and discard in the deepest part of the pit below the long-term pit water level;
  - backfilling, compacting and rehabilitating mined-out pits as soon as possible;
  - constructing adequately sized pollution control facilities;
  - implementing storm water management;
  - containing poor quality runoff from dirty areas and diverting this water to pollution control dam for re-use;
  - monitoring groundwater levels; updating the numerical model every two (2) years by using the measured water ingress and water levels to re-calibrate and refine the impact predictive scenario;
  - annually interpreting the monitoring results;
  - ensuring that the rehabilitated opencasts should be free draining away from the pit to reduce drainage into the pit;
  - drilling boreholes into the mine workings;
  - preparing a detailed mine closure plan and
  - updating the geochemical assessment.
- The following objectives are envisaged for the closure phase:
  - negotiate and obtain groundwater closure objectives approved by Government during the Decommissioning Phase of the project;
  - continue with the groundwater quality and groundwater level monitoring for a period of two to four years after mining ceases; and
  - present the results of the monitoring programme to Government on an annual basis and negotiate mine closure with Government based on the results of the groundwater monitoring undertaken.
- The following actions should be taken during the closure phase:
  - multiple-level monitoring boreholes must be constructed to monitor base-flow quality within the identified sensitive zones and to monitor groundwater level behaviour in the backfilled pits;
  - update existing predictive tools;
  - reduce recharge, by capping the backfill of the opencast with an impermeable layer, if practical;
  - flooding mine areas as soon as possible;
  - engineering backfilled opencast topography such that runoff is directed away from the opencast areas and
  - audit the monitoring network annually.

- The groundwater monitoring network design should comply with the risk-based source-pathway -receptor principle.
- Groundwater Monitoring should be undertaken to SANS and DWS (then DWA) requirements. One additional borehole positioned at the OL Block can be drilled and added to the monitoring network.
- It is envisaged that the frequency of monitoring should continue on a quarterly basis.

10 REFERENCES

Africa Weather Website (2019) Leeuwpan – Rainfall

Barnett et al (June 2012) Australian groundwater modelling guideline. Waterlines Report Series No. 82. National Water Commission, Canberra, ACT.

Cleanstream Environmental Services (2007). Leeuwpan Colliery: Report on Geohydrological Investigation as part of the EMPR for the proposed Wolwenfontein, Weltevreden and Rietkuil projects.

Exxaro (2011), Pre-Feasibility Study Report for Leeuwpan O/I Project.

GCS (2014) Leeuwpan Colliery Hydrogeological Investigation. GCS Reference Number: 11-447 GW

GCS (2013) Hydrological Investigation on Leeuwpan Mine. GCS Reference Number: 11-447

Golder (2018/2019) Leeuwpan Coal Mine Quarterly Water Monitoring Reports March 2018 to March 2019

Harbaugh et al (2005) MODFLOW-2005, the U.S. Geological Survey Modular Ground-Water Model – the Ground-Water Flow Process. U.S. geological Survey techniques and Methods 6-A16. U.S. Department of the Interior. U.S. Geological Survey.

Leeuwpan (2019) 2015 to 2019 Leeuwpan Monitoring Data

Leeuwpan (2019) Dolerite Dyke Positions

Leeuwpan (2019) Life of Mine Layout and Schedule

Leeuwpan (2019) Mine Infrastructure Layout

Mahanyele, P.J. (2010), Interpretation of airborne magnetic data over selected areas of the Witbank Coalfield, South Africa: An aid to mine planning, M.Sc. Dissertation

Minimum Requirements for water monitoring at waste management facilities (1998). Department of Water Affairs & Forestry, Waste Management Series, 1998).

Niswonger et al (2011) MODFLOW-NWT, A Newton Formulation for MODFLOW-2005. Groundwater Resources Program. Techniques and Methods 6-A37. U.S. Department of the Interior. U.S. Geological Survey.

Parsons, R. (1995). A South African Aquifer System Management Classification. Water Research Commission Report No. KV 77/95.

South African National Standard for Drinking Water (SANS 241-1: 2015). Part 1: Microbiological, physical, aesthetic and chemical determinants.

South African National Standard for Drinking Water (SANS 241-1: 2011). Part 1: Microbiological, physical, aesthetic and chemical determinants.

South African Water Quality Guidelines for Domestic Use, (1996). Volume 1, Second Edition, Department of Water Affairs & Forestry.

South African Water Quality Guidelines for Agricultural Water Use, (1996). Volume 4, Second Edition, Department of Water Affairs & Forestry.

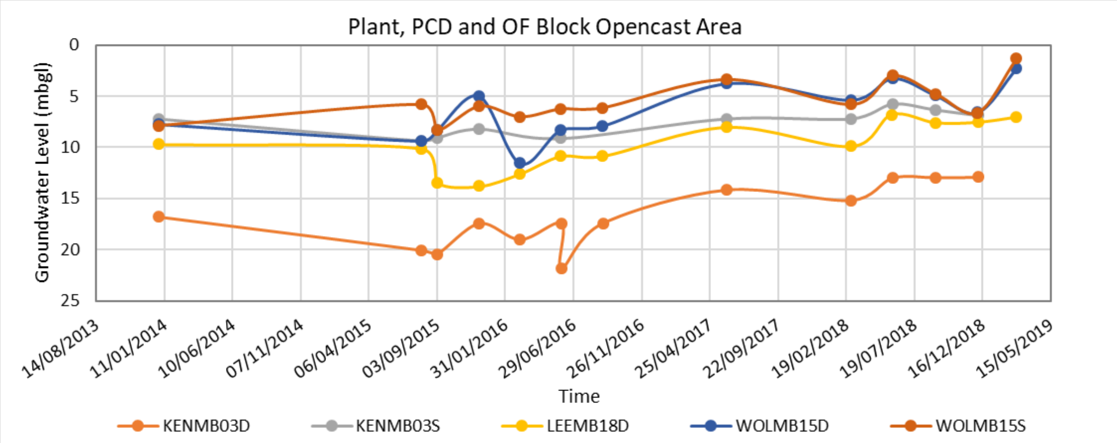
Zheng, C., and Wang, P.P. (1999). *MT3DMS: a modular three-dimensional multispecies transport model for simulation of advection, dispersion, and chemical reactions of contaminants in groundwater systems; documentation and user's guide*. Alabama University.

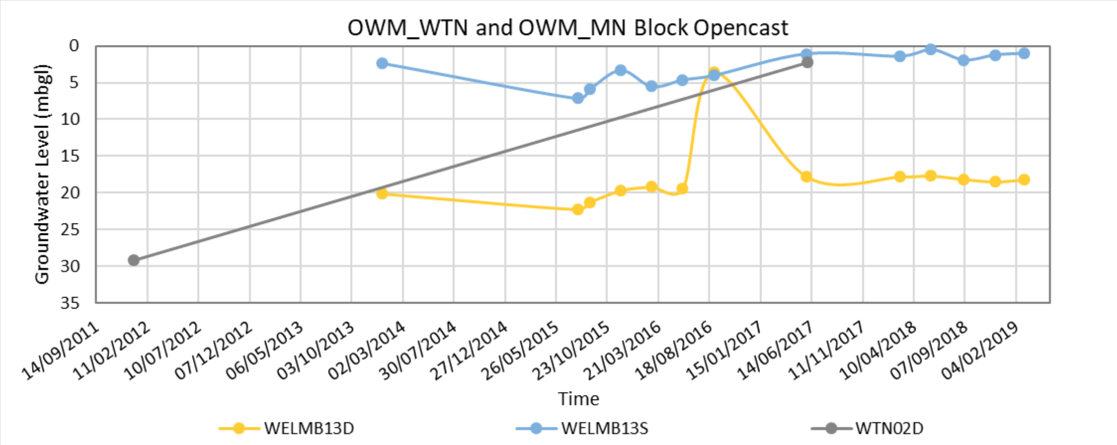
APPENDIX A : 2012 HYDROCENSUS BOREHOLES (GCS, 2014)

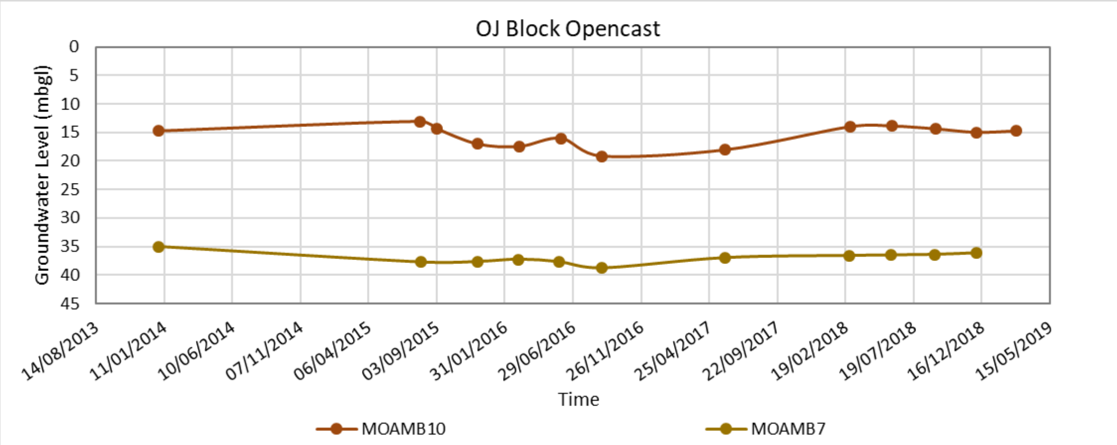
Table 10-1: 2012 Hydrocensus Boreholes (GCS, 2014)

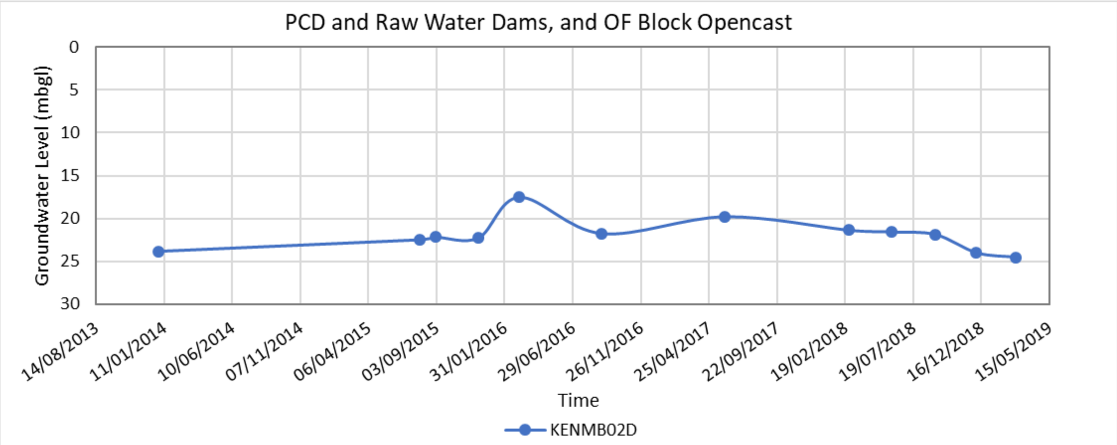
BH ID	Coordinates (WGS84 LO29)		Elev. (DEM)	SWL	Field Measurements			Uses				Farm Name	Contact	Comments
	X	Y	(mamsl)	(mbgl)	pH	EC (mS/m)	Temp. (°C)	Domestic	Livestock water	Irrigation	None			
Moa1	-23548	-2896171	1573	-	8.3	105	21	X				Moabsvelden, 248	Felix Matsenge	Borehole equipped with submersible pump.
Moa2	-24119	-2896232	1583	-	8.6	56	19.2	X				Moabsvelden, 248	Marius v. Heerden	30 m deep borehole equipped with submersible pump
Moa3	-23783	-2895786	1569	-	8.4	57	21.3			X		Moabsvelden, 248	Marius v. Heerden	Borehole yield is approximately 15 000 l/hr
Moa4	-24265	-2896188	1584	-	-	-	-				X	Moabsvelden, 248	Marius v. Heerden	
Vla 1	-23705	-2900964	1593	-	16	44	16.4	X				Vlakplaats, 268	Ferreira	Borehole yield is between 8 000 -10 000 l/hr
Rie1	-22504	-2897727	1564	-	-	-	-			X		Rietkuil, 249	Hannes Potgieter	53 m deep borehole. Borehole yield is approximately 5 000l/hr
Rie2	-22546	-2897595	1565	-	-	-	-			X		Rietkuil, 249	Hannes Potgieter	72 m deep borehole. Borehole yield is approximately 5 000l/hr
Rie3	-22683	-2897855	1571	-	7.7	84	18.6	X	X			Rietkuil, 249	Hannes Potgieter	Supply borehole is equipped with an old pump
RIE4	-23148	-2897771	1578	-	8.1	0.01	19.7	X				Rietkuil, 249	Hannes Potgieter	Supply borehole is equipped with a mono-pump. Borehole yield is approximately 5 000l/hr
Rie5	-24062	-2897221	1589	6.7	-	-	-				X	Rietkuil, 249	Hannes Potgieter	Borehole equipped with a submersible pump and has an estimated yield of approximately 20 000l/hr.
Rie6	-24822	-2897299	1593	48	-	-	-			X		Rietkuil, 249	Hannes Potgieter	Borehole is equipped with a submersible pump and 138 meters deep.
Rie7	-24748	-2897268	1593	19.6	-	-	-			X		Rietkuil, 249	Hannes Potgieter	Borehole is 94 meters deep. Cumulative yield with Rie6 is 110 000 l/hr.
Rie8	-23169	-2898716	1573	9.7	-	-	-			X		Rietkuil, 249	Hannes Potgieter	Borehole yield is approximately 15 000 litres/hr
Rie9	-23642	-2899197	1579	-	-	-	-			X		Rietkuil, 249	Hannes Vermaak	Borehole depth is 146 meters and yield is approximately 20 000 litres/hr
RIE10	-23726	-2899313	1583	-	-	-	-			X		Rietkuil, 249	Hannes Vermaak	Borehole depth is 143 meters and yield is approximately 45 000 litres/hr.
Rie11	-22953	-2899464	1578	-	7	45	17.2	X				Rietkuil, 249	Hannes Vermaak	Borehole yield is between 8 000 -10 000 l/hr
Rie13	-20806	-2897563	1566	14.9	8.3	62	19.7	X				Rietkuil, 249	Sckalekamp	
Rie14	-22383	-2900962	1571	-	8.7	55	21.8	X				Rietkuil, 249	Snyman	Borehole is equipped with a submersible pump
Rie15	-20807	-2897004	1569	-	8.8	47	20.4			X		Rietkuil, 249	Snyman	
2628BA21001	-24524	-2894301	1566	Sealed	-	-	-				X	Moabsvelden 248 PTN12	Leeuwpan Mine	Pipe cut off
ILB6	-28351	-2896710	1575	28	6.81	40	17.7	X	X			Wolvenfontein 244 PTN3	Leeuwpan Mine	
2628BA30004	-25625	-2891833	1555	34.75	-	-	-	X		X		Goedgedacht 225 PTN35	Leeuwpan Mine	
2628BA22008	-24482	-2891083	1549	-	-	-	-				X	Weltevreden 227 PTN35	Leeuwpan Mine	No water @ 60m
2628BA22001	-25859	-2894646	1577	Sealed	-	-	-					Moabsvelden 248 PTN12	Leeuwpan Mine	
2628BA22007	-24200	-2891982	1544	Sealed	7.33	54	17.5		X			Weltevreden 227 PTN35	Leeuwpan Mine	
SCGW06	-21905	-2890988	1575	Blocked	-	-	-				X	Weltevreden 227 PTN29	Leeuwpan Mine	Monitoring Borehole
SCGW01	-20992	-2891411	1580	29	8.24	12	17.9				X	Weltevreden 227 PTN6	Leeuwpan Mine	Monitoring Borehole
CBH7B	-20225	-2893676	1570	30.8	7.22	29	20.7				X	Moabsvelden, 248 PTN6	Leeuwpan Mine	Monitoring Borehole
EC1	-31595	-2895350	1560	Sealed	7.83	18	18.1	X				Eskom Camp	Leeuwpan Mine	Water supply borehole
WWF1	-30771	-2897150	1569	15	6.95	27	18.9	X	X	X		Wolwefontein	Tommie Olkers	
WK1	-31444	-2893968	1555	Sealed	-	-	-			X		Witklip	Tommie Olkers	Used in Planting Season - Everyday all day pumping
WK2	-32264	-2894081	1554	21	-	-	-		X	X		Witklip	Tommie Olkers	
WK3	-32447	-2894207	1554	-	7.15	79	16.1	X	X	X		Witklip	Tommie Olkers	Busy Pumping
WK4	-32569	-2893921	1553	19.2	-	-	-		X	X		Witklip	Tommie Olkers	
WLWF1	-28699	-2898436	1581	6.6	7.56	31	14.2	X	X	X		Wolwefontein	Jaco Oosthuyse	
WLWF2	-28397	-2898276	1581	12.9	7.17	25	17.4		X			Wolwefontein	Jaco Oosthuyse	
WLWF3	-29830	-2899147	1561	-	7.31	57	17.1			X		Wolwefontein	Jaco Oosthuyse	WLWF3 & 4 pumps into same pipe - Busy Pumping
WLWF4	-29898	-2898877	1560	14.2	-	-	-					Wolwefontein	Jaco Oosthuyse	Busy Pumping - Just switched the power off
PNR1	-29351	-2892513	1544	6	7.66	38	18.4	X		X		Pannar Seeds	Le Roux	PNR1 & 2 influence each other; PNR2 was just switched off
PNR2	-28777	-2892806	1549	10.8	7.52	34	19.8			X		Pannar Seeds	Le Roux	
PNR3	-28157	-2892233	1566	8.7	-	-	-				X	Pannar Seeds	Le Roux	
AGI1	-29572	-2892720	1545	5.5	7.99	36	16.4	X		X		Afgri	Brent Parrot	Takes 1h to fill the tanks
RSH1	-26443	-2890285	1536	25.7	-	-	-	X	X	X		Roosenhof	Francois Hoffman	All of the boreholes are connected with a pipeline that feeds >100000l dam
RSH2	-26450	-2890245	1536	24.8	-	-	-	X	X	X		Roosenhof	Francois Hoffman	RSH1, 2, 3, 4 are linked with pipeline
RSH3	-25749	-2891139	1535	27.1	5.44	15	17.5				X	Roosenhof	Francois Hoffman	
RSH4	-25639	-2891252	1535	26	-	-	-	X	X	X		Roosenhof	Francois Hoffman	
RSH5	-26846	-2891802	1564	-	-	-	-			X		Roosenhof	Francois Hoffman	Busy Pumping
RSH6	-26849	-2891712	1565	-	-	-	-				X	Roosenhof	Francois Hoffman	No Water @ 60m

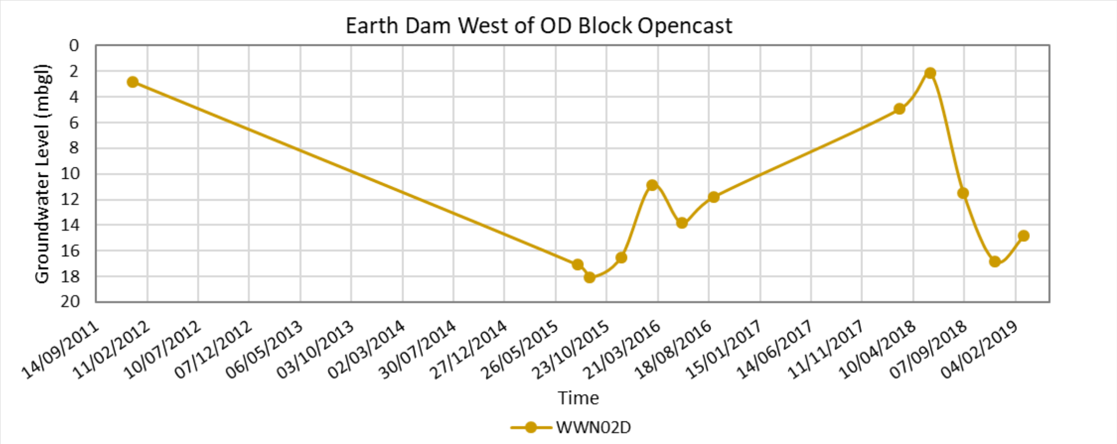
APPENDIX B: 2015 TO 2019 MONITORING NETWORK GROUNDWATER LEVEL GRAPHS

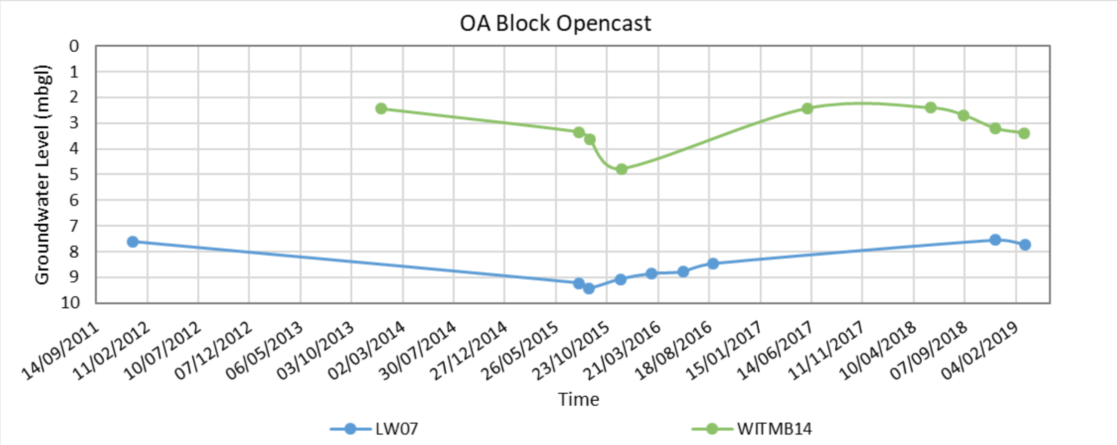

Plant, PCD and OF Block Opencast Area
Groundwater Level (mbgl)
0
5
10
15
20
25
14/08/2013
11/01/2014
10/06/2014
07/11/2014
06/04/2015
03/09/2015
31/01/2016
29/06/2016
26/11/2016
25/04/2017
22/09/2017
19/02/2018
19/07/2018
16/12/2018
15/05/2019
Time
KENMB03D
KENMB03S
LEEMB18D
WOLMB15D
WOLMB15S

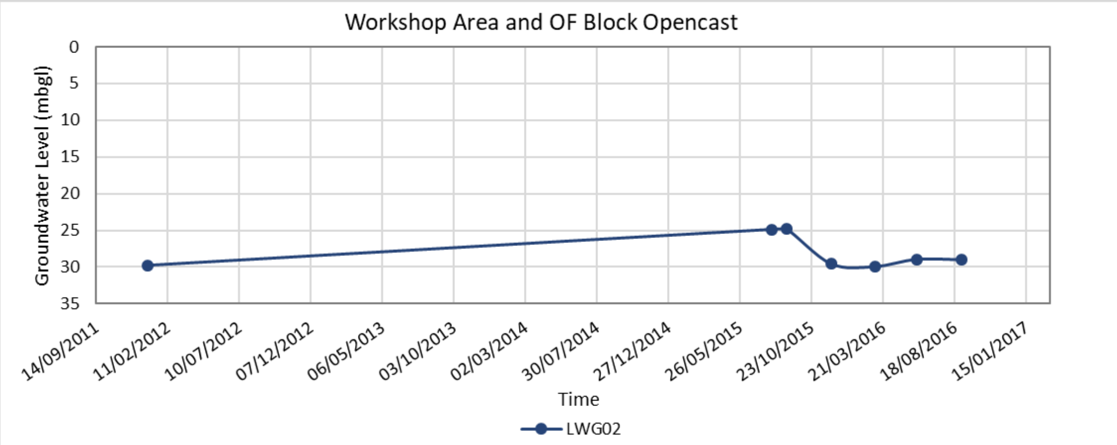

OWM_WTN and OWM_MN Block Opencast
Groundwater Level (mbgl)
0
5
10
15
20
25
30
35
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
14/06/2017
11/11/2017
10/04/2018
07/09/2018
04/02/2019
Time
WELMB13D
WELMB13S
WTN02D

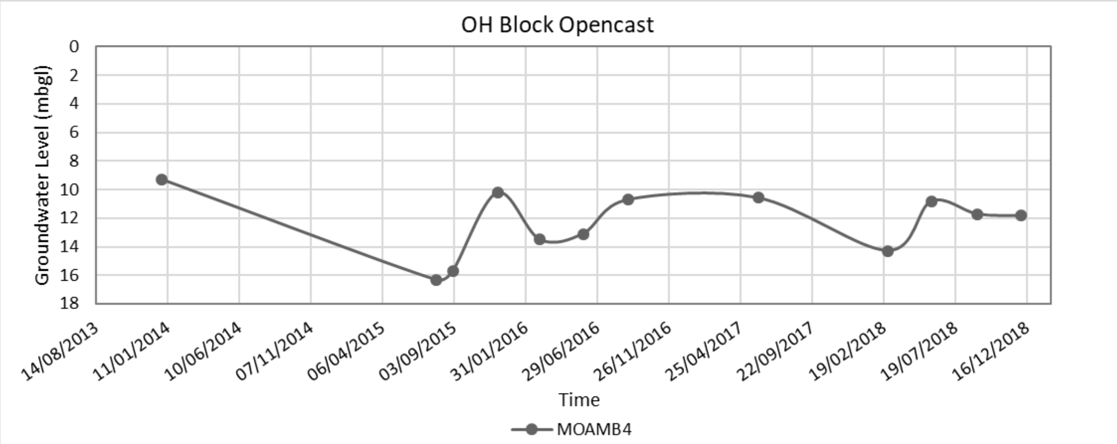

OJ Block Opencast
Groundwater Level (mbgl)
0
5
10
15
20
25
30
35
40
45
14/08/2013
11/01/2014
10/06/2014
07/11/2014
06/04/2015
03/09/2015
31/01/2016
29/06/2016
26/11/2016
25/04/2017
22/09/2017
19/02/2018
19/07/2018
16/12/2018
15/05/2019
Time
MOAMB10
MOAMB7

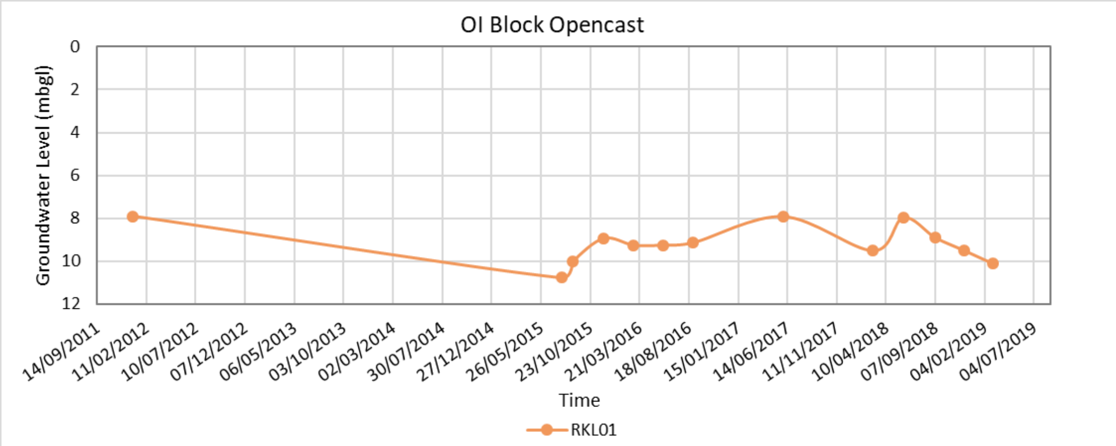

PCD and Raw Water Dams, and OF Block Opencast
Groundwater Level (mbgl)
0
5
10
15
20
25
30
14/08/2013
11/01/2014
10/06/2014
07/11/2014
06/04/2015
03/09/2015
31/01/2016
29/06/2016
26/11/2016
25/04/2017
22/09/2017
19/02/2018
19/07/2018
16/12/2018
15/05/2019
Time
KENMB02D

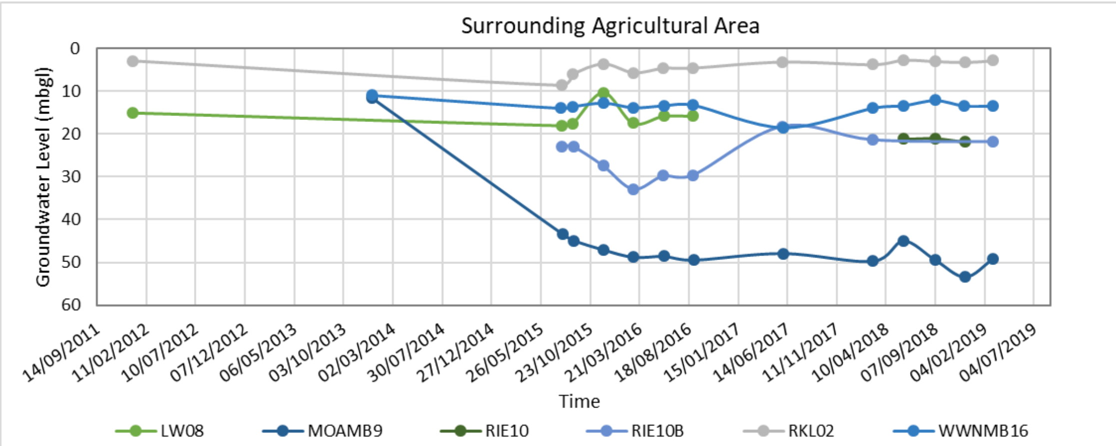

Earth Dam West of OD Block Opencast
Groundwater Level (mbgl)
0
2
4
6
8
10
12
14
16
18
20
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
14/06/2017
11/11/2017
10/04/2018
07/09/2018
04/02/2019
Time
WWN02D


OA Block Opencast
Groundwater Level (mbgl)
0
1
2
3
4
5
6
7
8
9
10
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
14/06/2017
11/11/2017
10/04/2018
07/09/2018
04/02/2019
Time
LW07
WITMB14


Workshop Area and OF Block Opencast
Groundwater Level (mbgl)
0
5
10
15
20
25
30
35
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
Time
LWG02

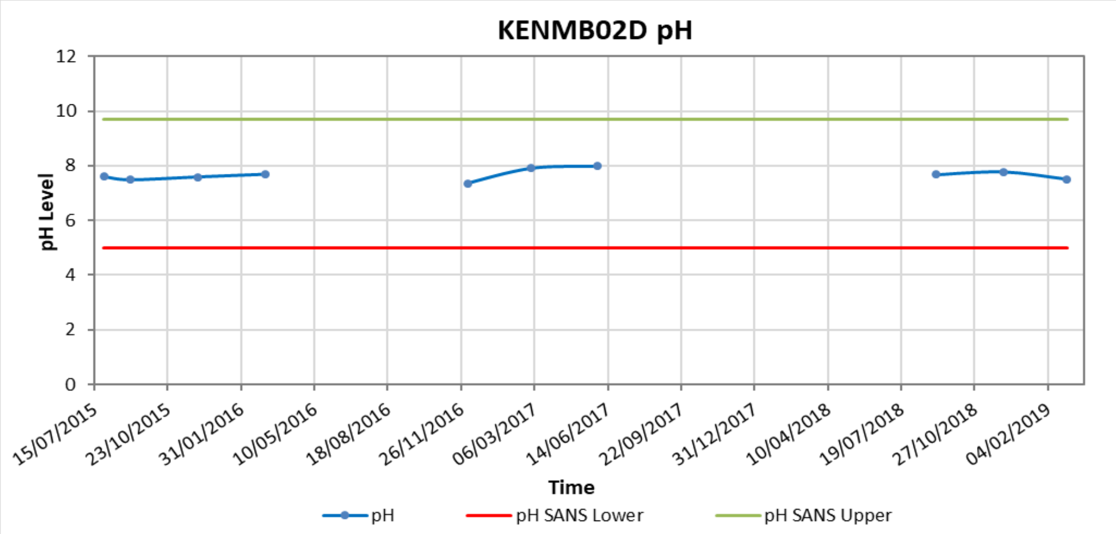

OH Block Opencast
Groundwater Level (mbgl)
0
2
4
6
8
10
12
14
16
18
14/08/2013
11/01/2014
10/06/2014
07/11/2014
06/04/2015
03/09/2015
31/01/2016
29/06/2016
26/11/2016
25/04/2017
22/09/2017
19/02/2018
19/07/2018
16/12/2018
Time
MOAMB4

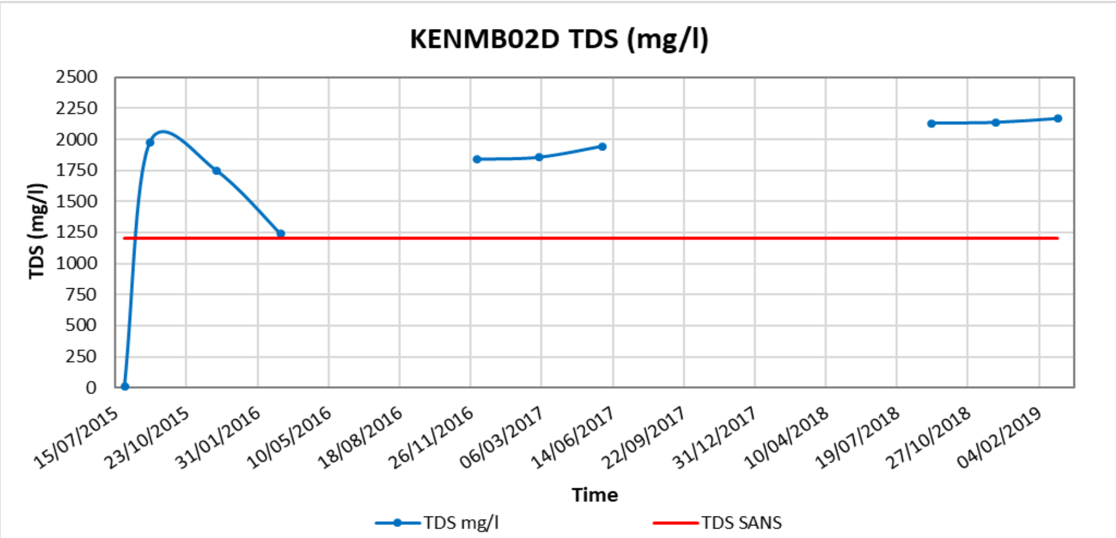

OI Block Opencast
Groundwater Level (mbgl)
0
2
4
6
8
10
12
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
14/06/2017
11/11/2017
10/04/2018
07/09/2018
04/02/2019
04/07/2019
Time
RKL01

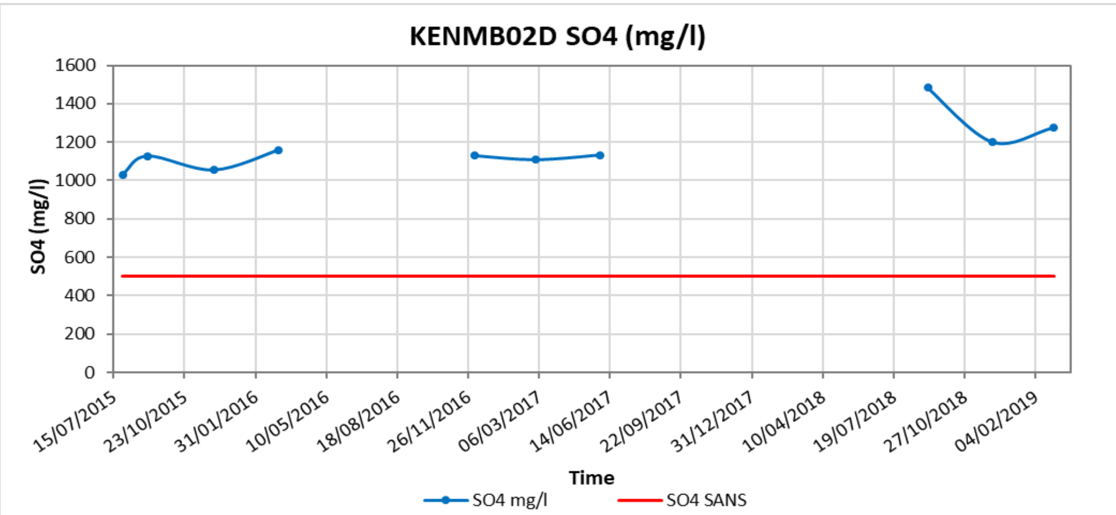

Surrounding Agricultural Area
Groundwater Level (mbgl)
0
10
20
30
40
50
60
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
14/06/2017
11/11/2017
10/04/2018
07/09/2018
04/02/2019
04/07/2019
Time
LW08
MOAMB9
RIE10
RIE10B
RKL02
WWNMB16

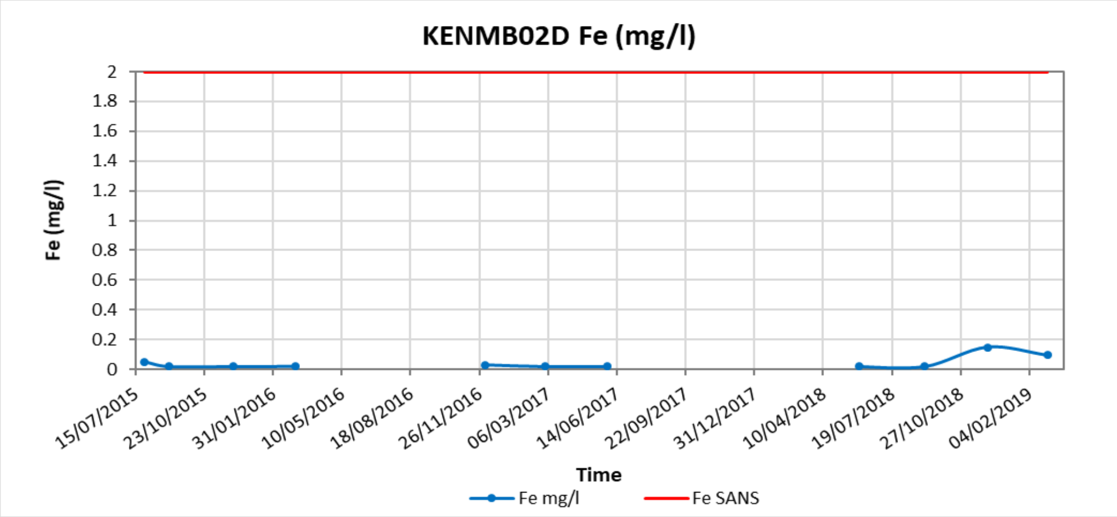
APPENDIX C: 2015 TO 2019 MONITORING NETWORK GROUNDWATER QUALITY GRAPHS

KENMB02D

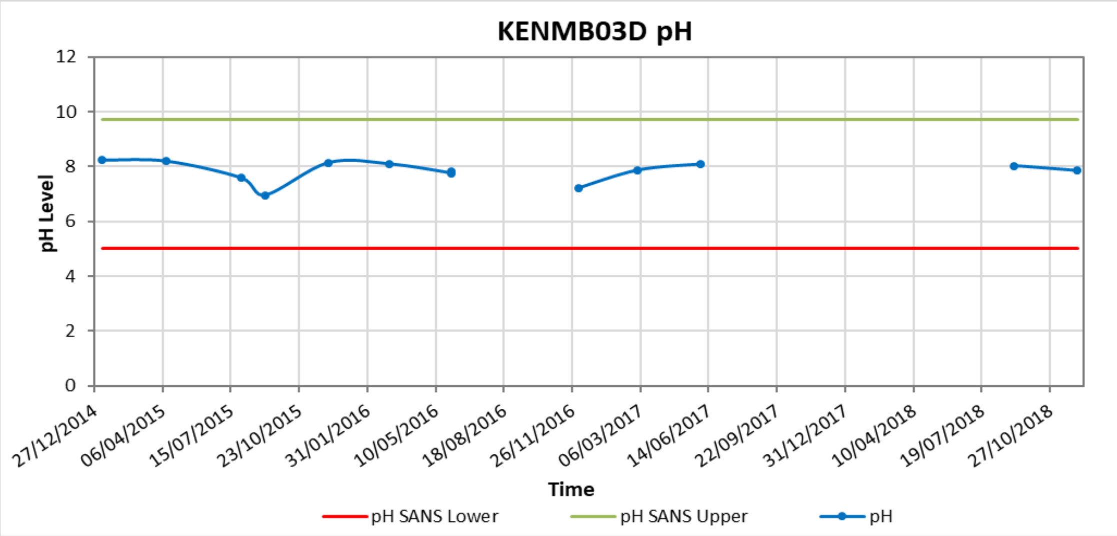

KENMB02D pH
pH Level
12
10
8
6
4
2
0
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
04/02/2019
Time
pH
pH SANS Lower
pH SANS Upper

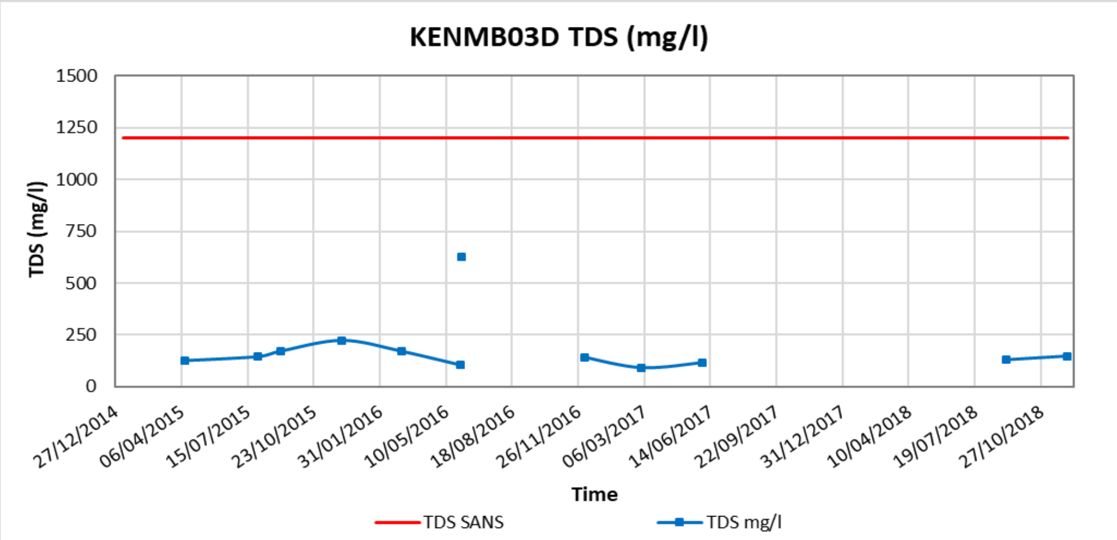

KENMB02D TDS (mg/l)
TDS (mg/l)
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
04/02/2019
Time
TDS mg/l
TDS SANS

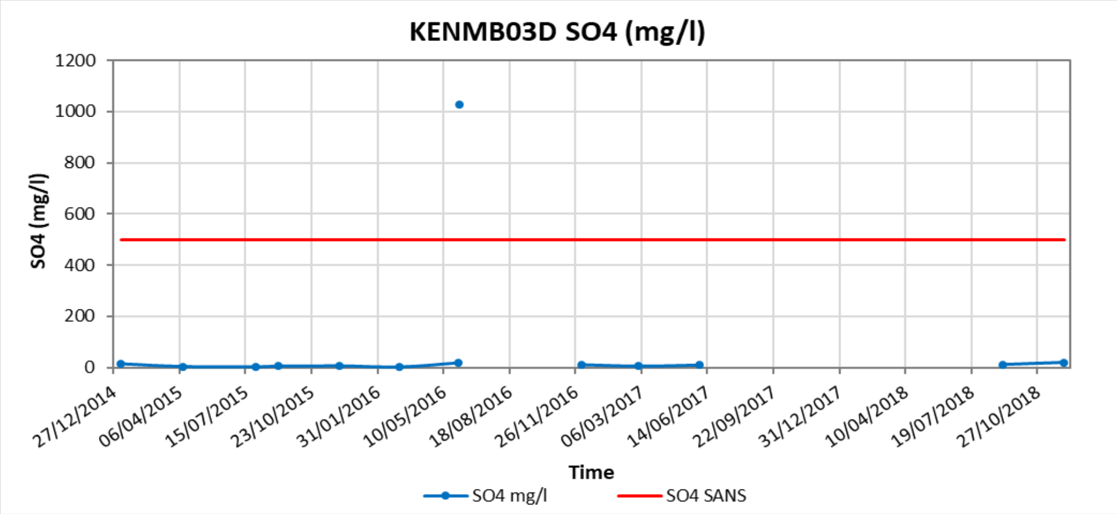

KENMB02D SO4 (mg/l)
SO4 (mg/l)
1600
1400
1200
1000
800
600
400
200
0
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
04/02/2019
Time
SO4 mg/l
SO4 SANS

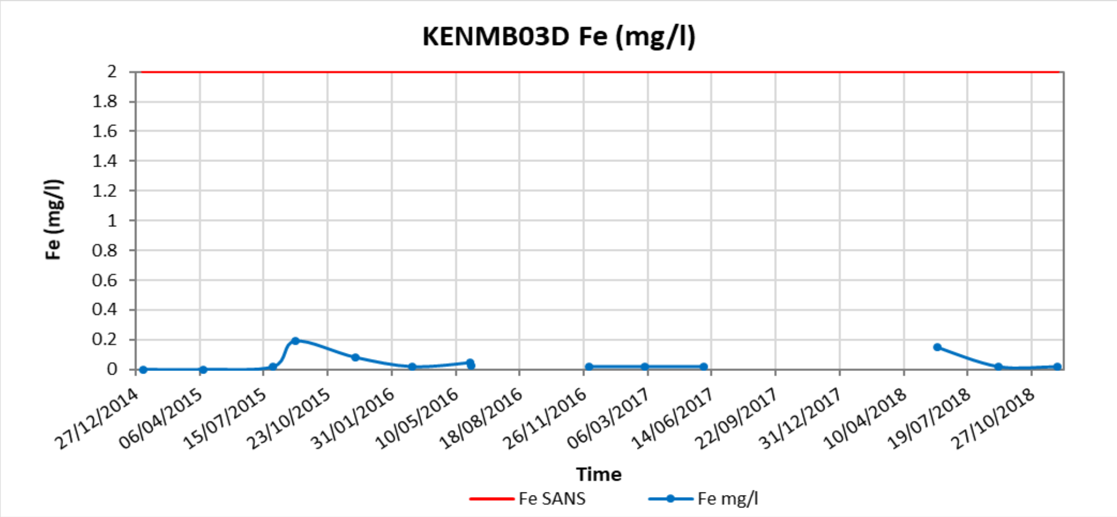

KENMB02D Fe (mg/l)
Fe (mg/l)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
04/02/2019
Time
Fe mg/l
Fe SANS

KENMB03D

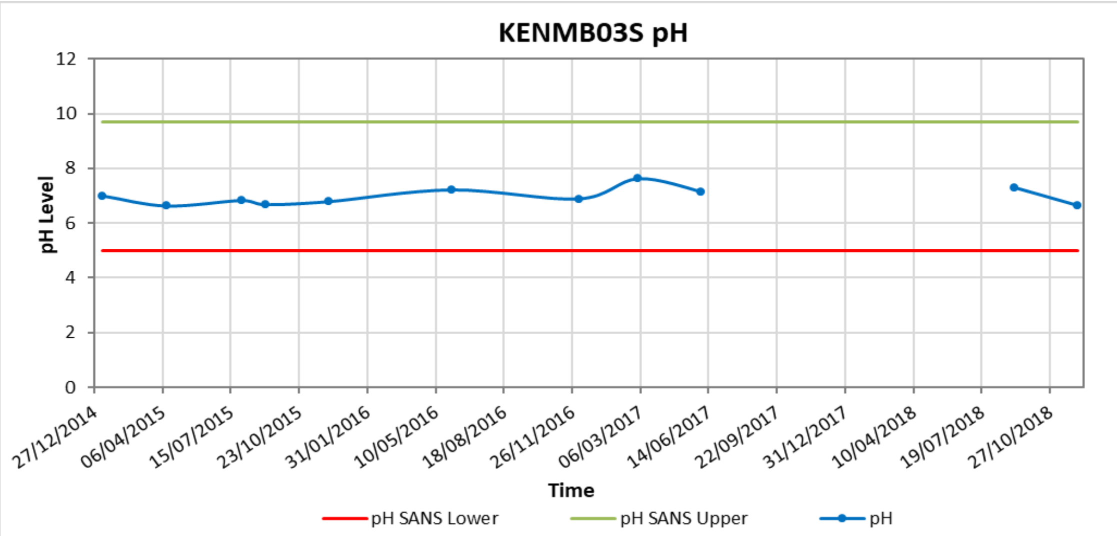

KENMB03D pH
pH Level
12
10
8
6
4
2
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
Time
pH SANS Lower
pH SANS Upper
pH

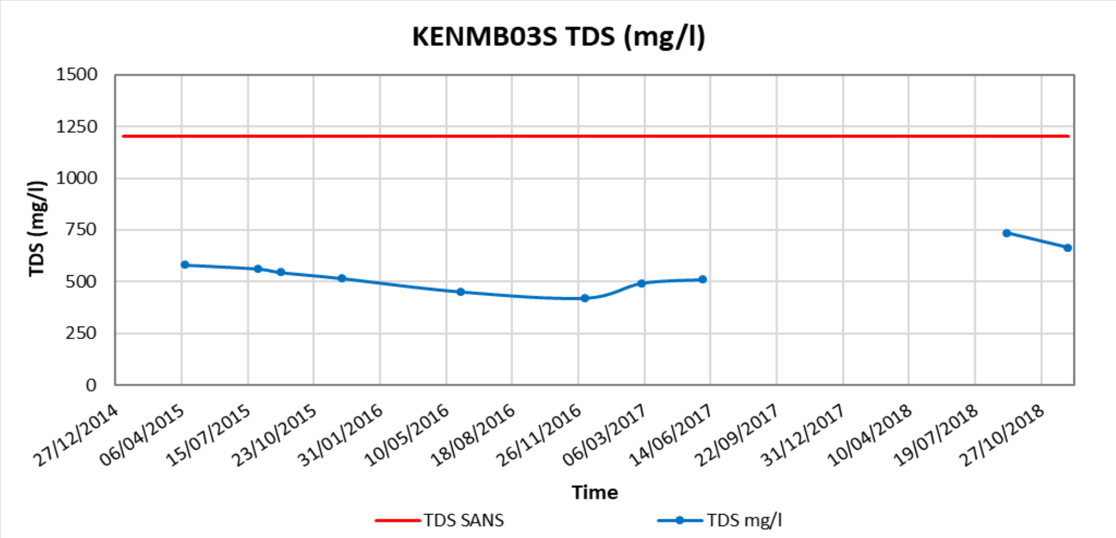

KENMB03D TDS (mg/l)
TDS (mg/l)
1500
1250
1000
750
500
250
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
Time
TDS SANS
TDS mg/l

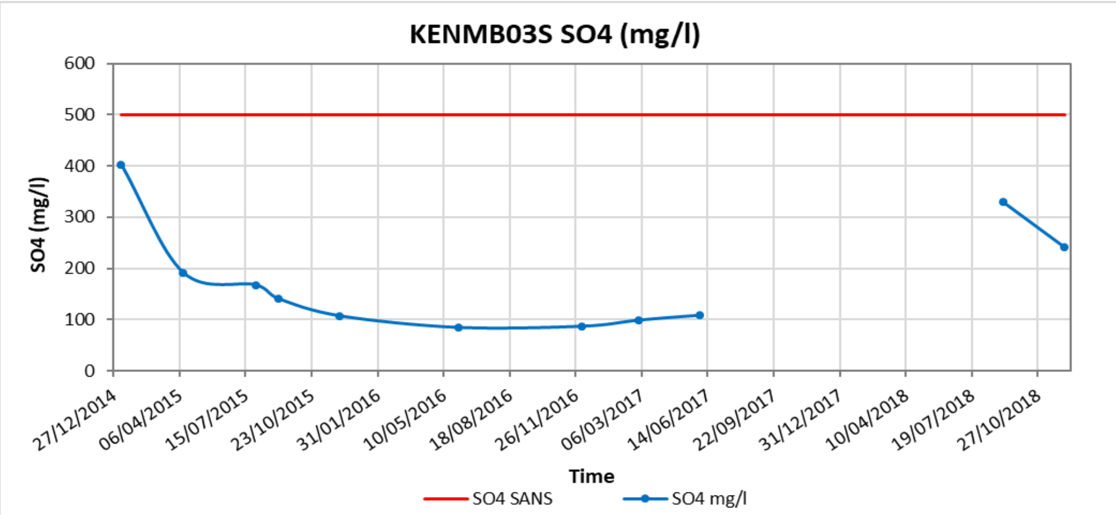

KENMB03D SO4 (mg/l)
SO4 (mg/l)
1200
1000
800
600
400
200
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
Time
SO4 mg/l
SO4 SANS

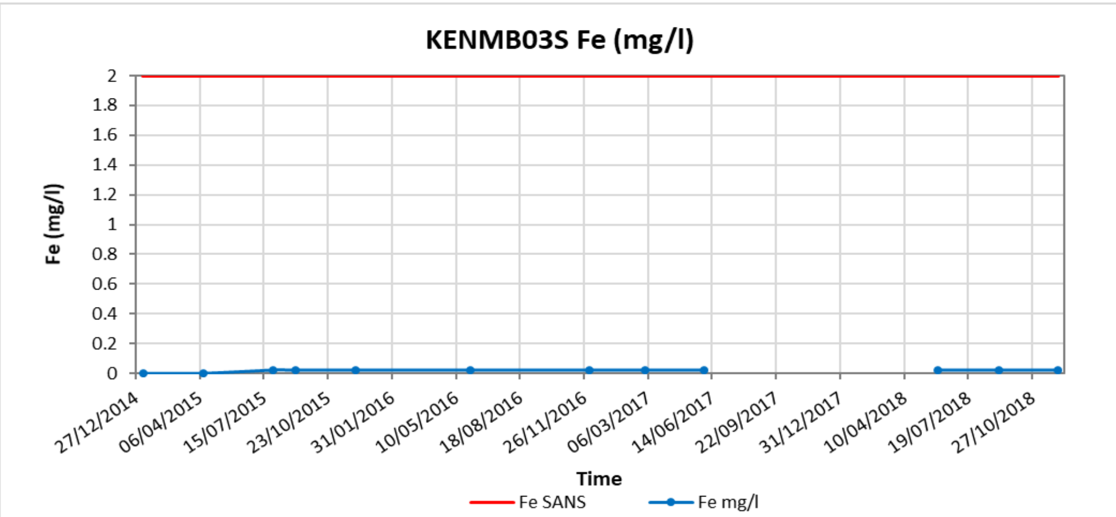

KENMB03D Fe (mg/l)
Fe (mg/l)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
Time
Fe SANS
Fe mg/l

KENMB03S

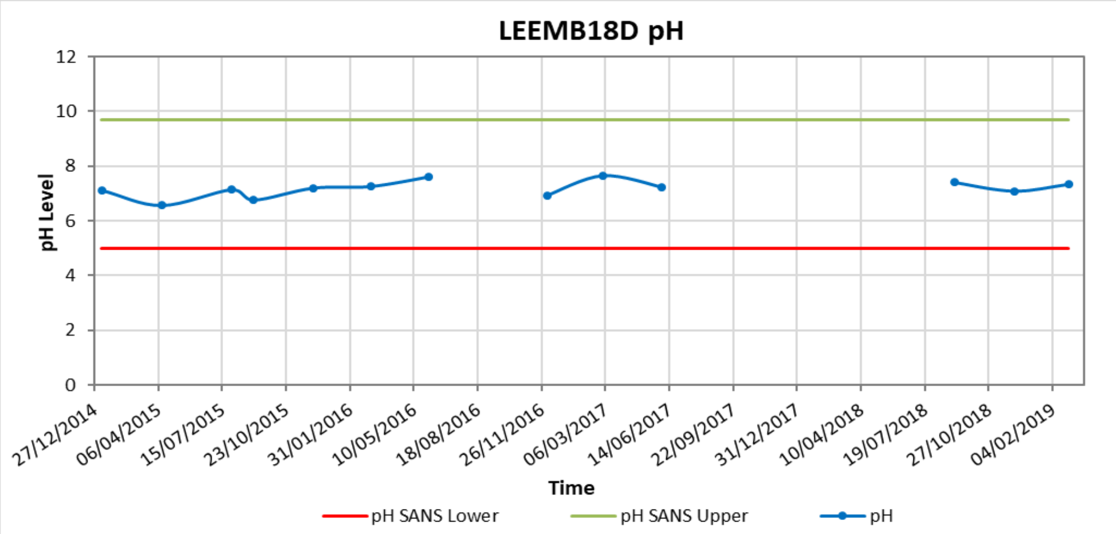

KENMB03S pH
pH Level
12
10
8
6
4
2
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
Time
pH SANS Lower
pH SANS Upper
pH

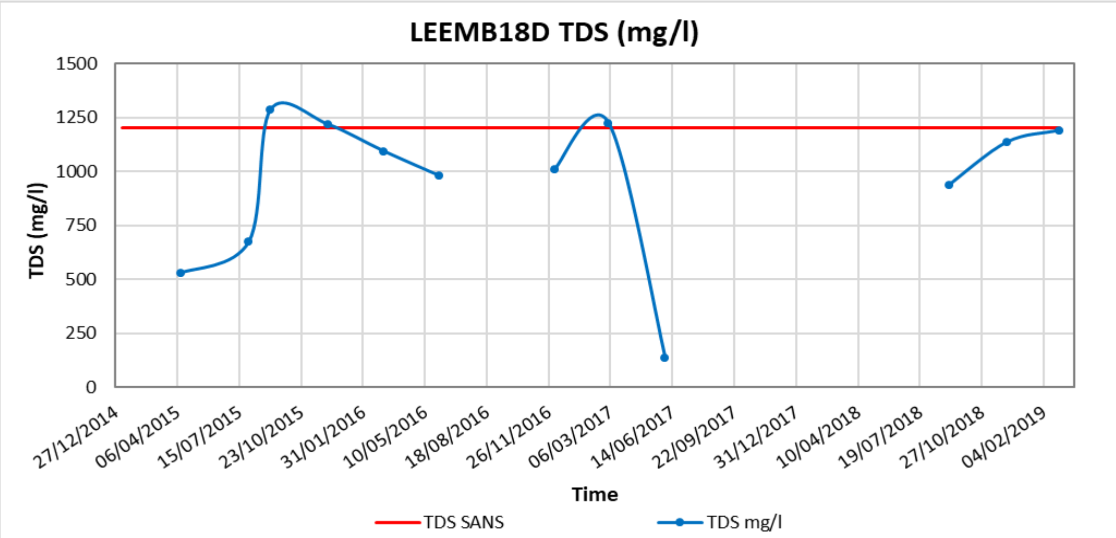

KENMB03S TDS (mg/l)
TDS (mg/l)
1500
1250
1000
750
500
250
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
Time
TDS SANS
TDS mg/l

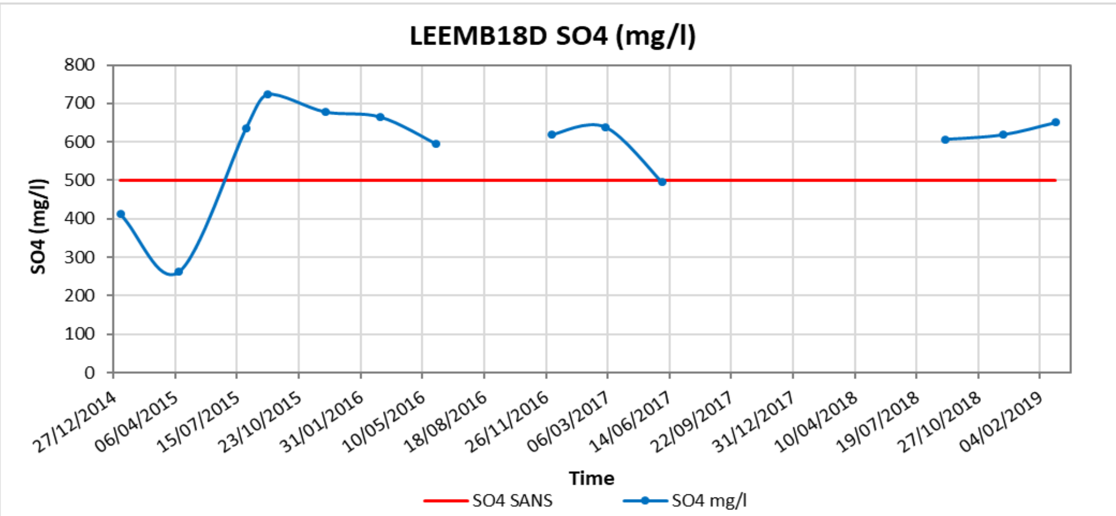

KENMB03S SO4 (mg/l)
SO4 (mg/l)
600
500
400
300
200
100
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
Time
SO4 SANS
SO4 mg/l

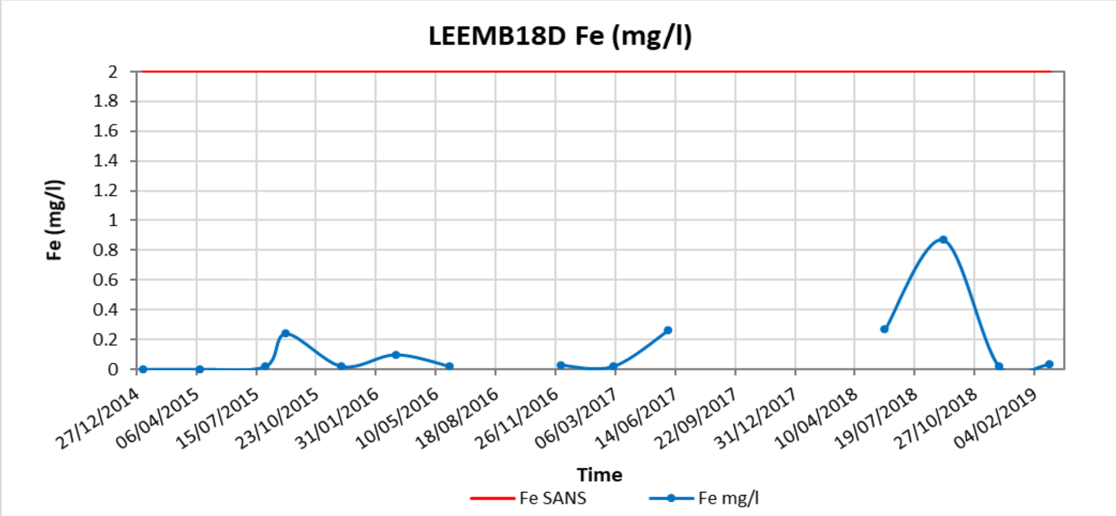

KENMB03S Fe (mg/l)
Fe (mg/l)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
Time
Fe SANS
Fe mg/l

LEEMB18D


LEEMB18D pH
pH Level
12
10
8
6
4
2
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
04/02/2019
Time
pH SANS Lower
pH SANS Upper
pH

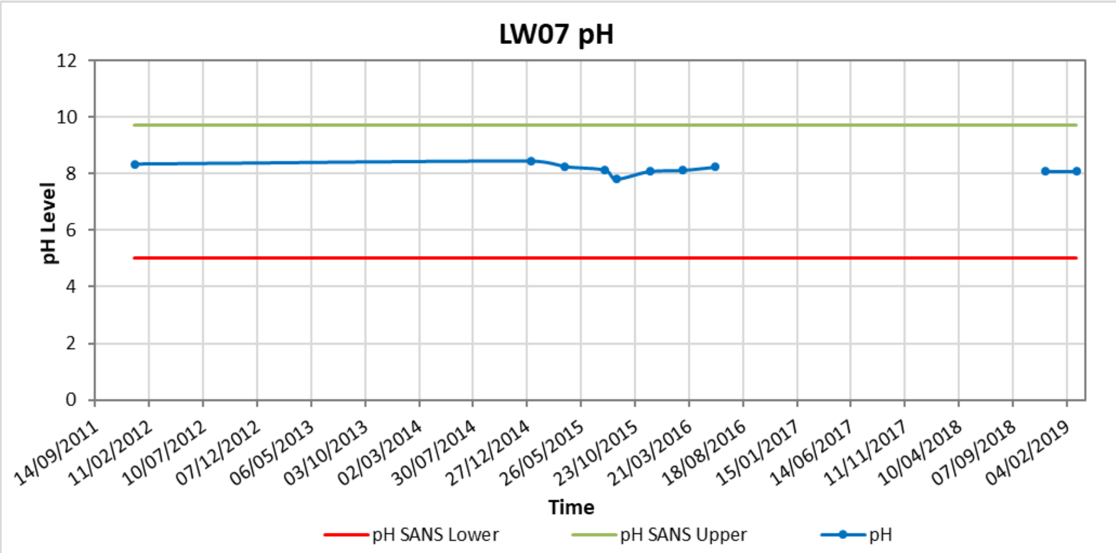

LEEMB18D TDS (mg/l)
TDS (mg/l)
1500
1250
1000
750
500
250
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
04/02/2019
Time
TDS SANS
TDS mg/l


LEEMB18D SO4 (mg/l)
SO4 (mg/l)
800
700
600
500
400
300
200
100
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
04/02/2019
Time
SO4 SANS
SO4 mg/l

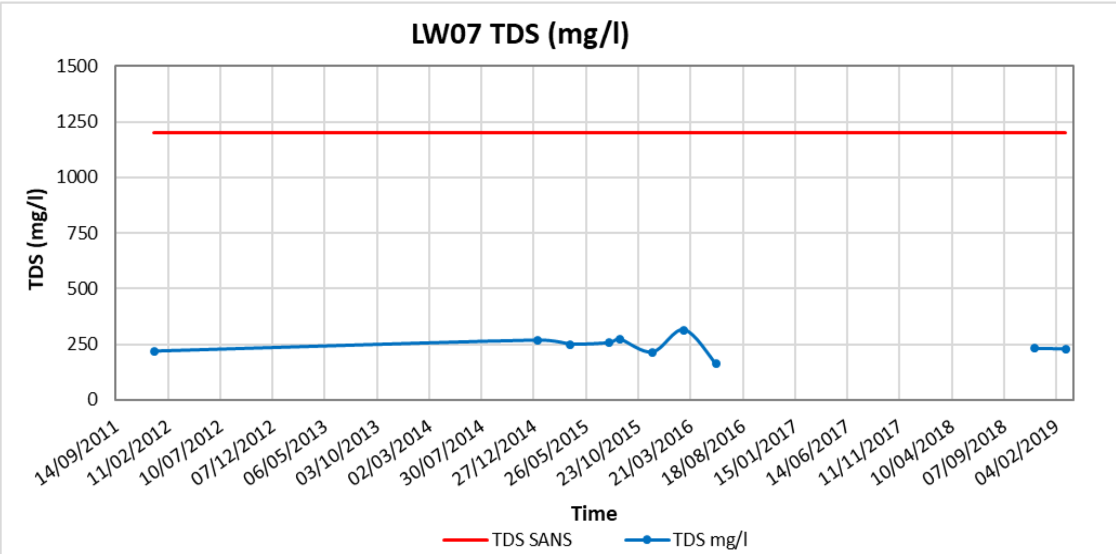


LEEMB18D Fe (mg/l)
Fe (mg/l)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
27/12/2014
06/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
18/08/2016
26/11/2016
06/03/2017
14/06/2017
22/09/2017
31/12/2017
10/04/2018
19/07/2018
27/10/2018
04/02/2019
Time
Fe SANS
Fe mg/l

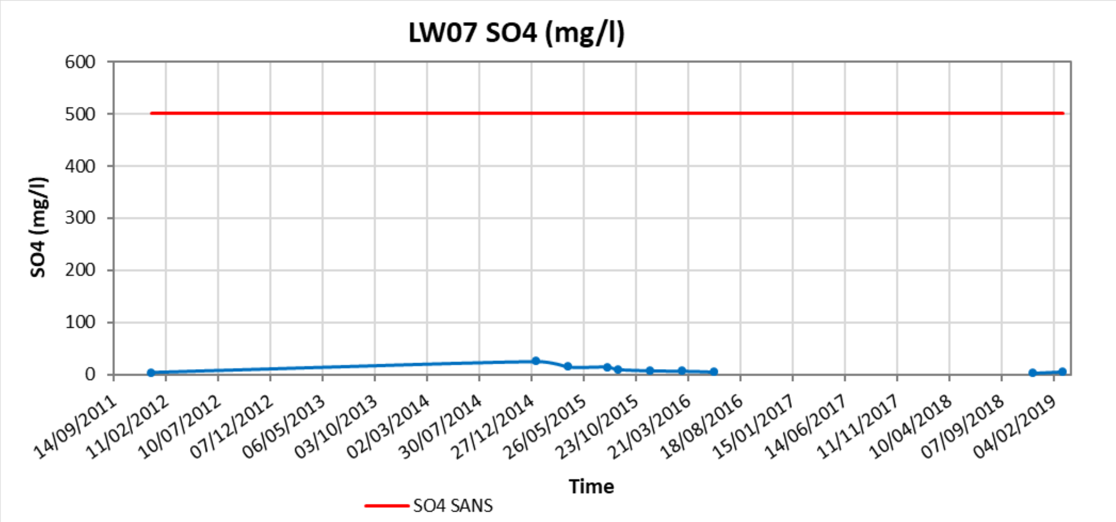
LW07

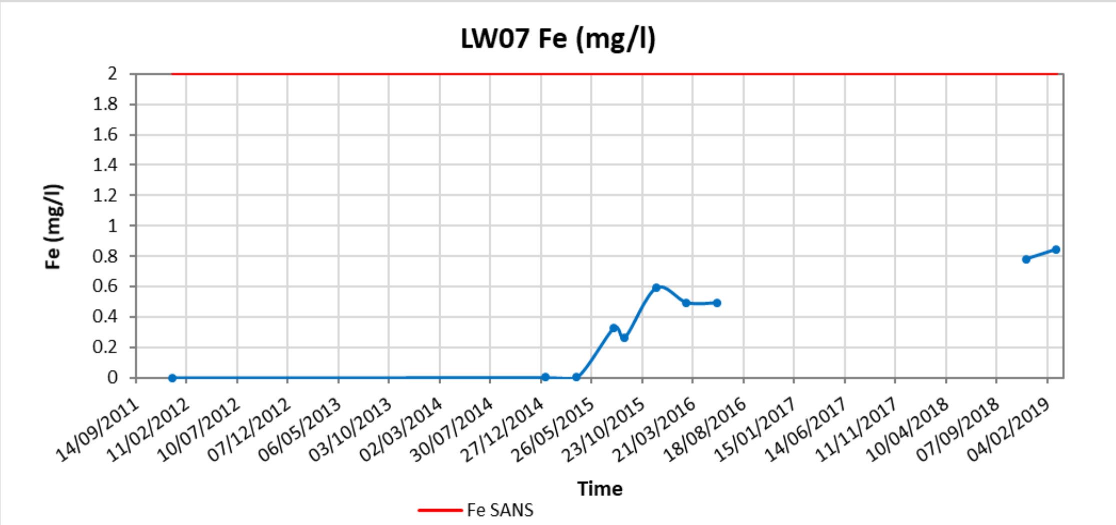


LW07 pH
pH Level
12
10
8
6
4
2
0
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
14/06/2017
11/11/2017
10/04/2018
07/09/2018
04/02/2019
Time
pH SANS Lower
pH SANS Upper
pH

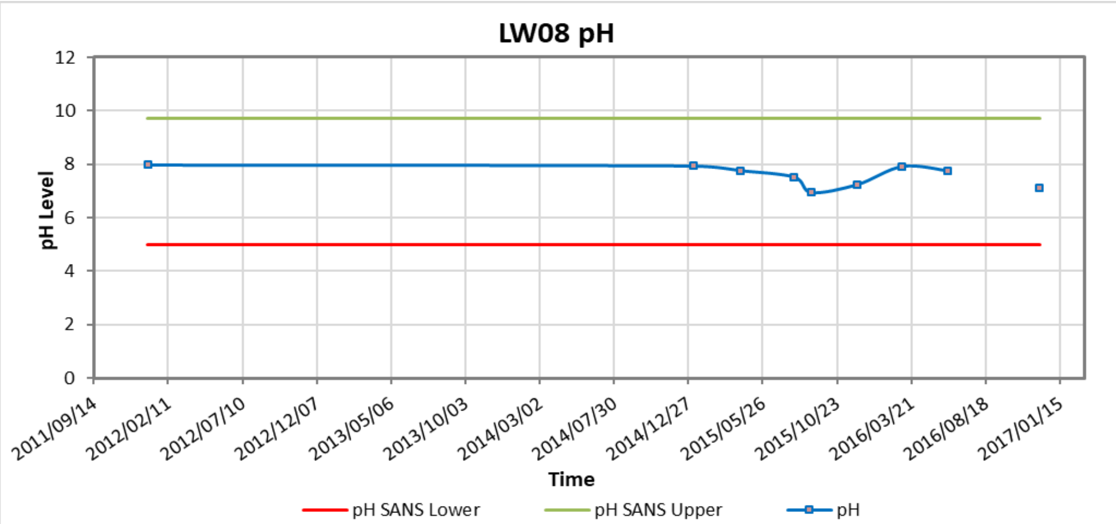


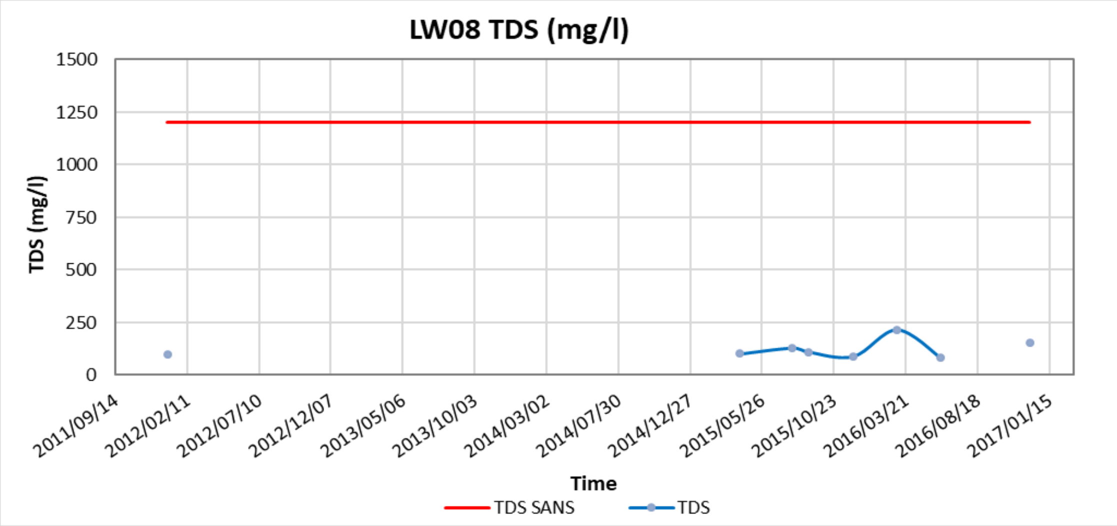
LW07 TDS (mg/l)
TDS (mg/l)
1500
1250
1000
750
500
250
0
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
14/06/2017
11/11/2017
10/04/2018
07/09/2018
04/02/2019
Time
TDS SANS
TDS mg/l

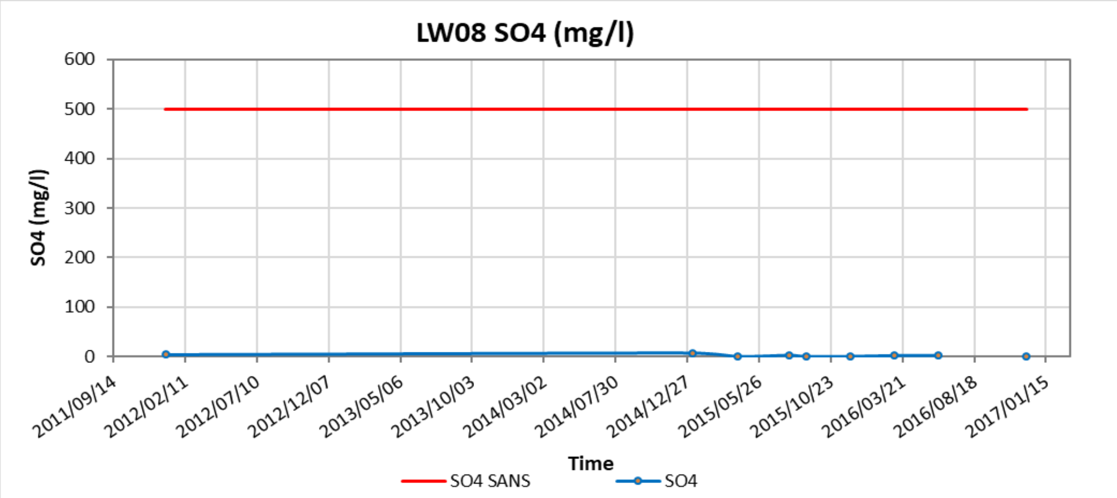

LW07 SO4 (mg/l)
SO4 (mg/l)
600
500
400
300
200
100
0
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
14/06/2017
11/11/2017
10/04/2018
07/09/2018
04/02/2019
Time
SO4 SANS

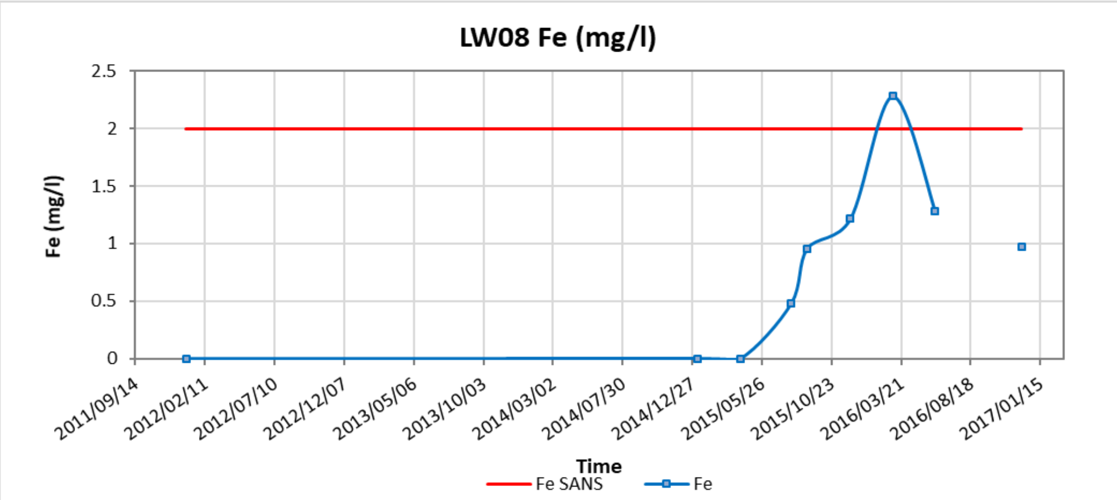

LW07 Fe (mg/l)
Fe (mg/l)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
14/09/2011
11/02/2012
10/07/2012
07/12/2012
06/05/2013
03/10/2013
02/03/2014
30/07/2014
27/12/2014
26/05/2015
23/10/2015
21/03/2016
18/08/2016
15/01/2017
14/06/2017
11/11/2017
10/04/2018
07/09/2018
04/02/2019
Time
Fe SANS

LW08

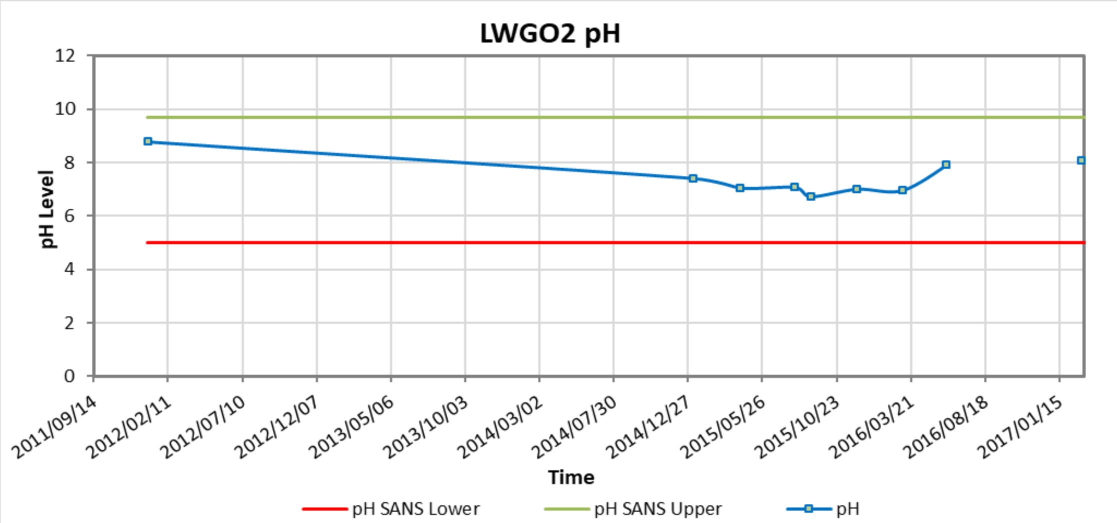

LW08 pH
pH Level
12
10
8
6
4
2
0
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
Time
pH SANS Lower
pH SANS Upper
pH

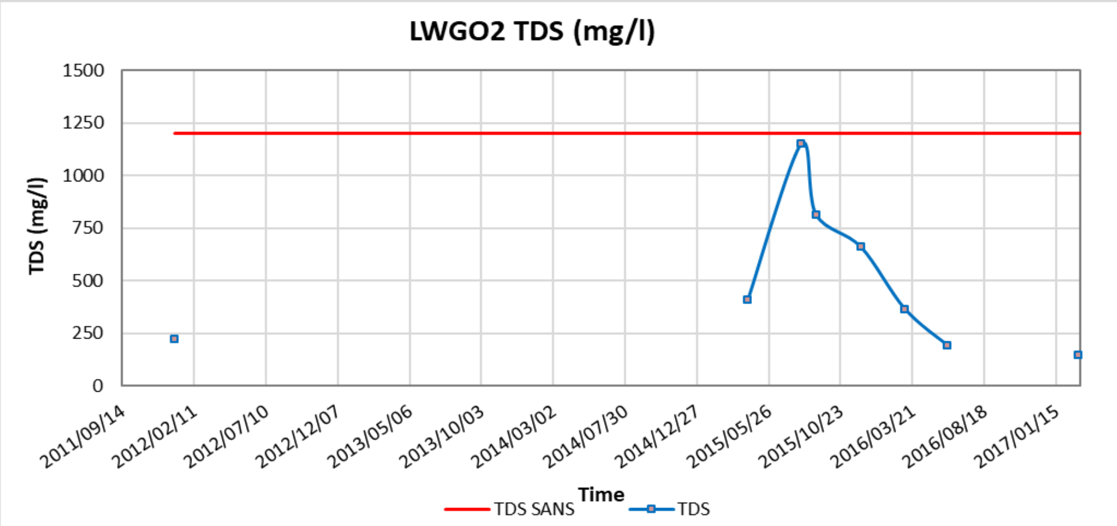

LW08 TDS (mg/l)
TDS (mg/l)
1500
1250
1000
750
500
250
0
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
Time
TDS SANS
TDS

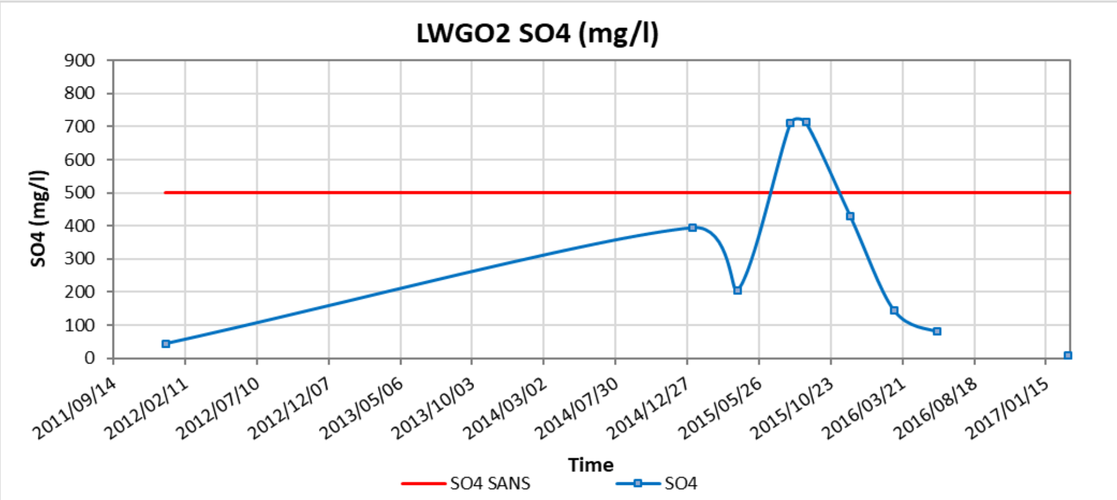

LW08 SO4 (mg/l)
SO4 (mg/l)
600
500
400
300
200
100
0
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
Time
SO4 SANS
SO4

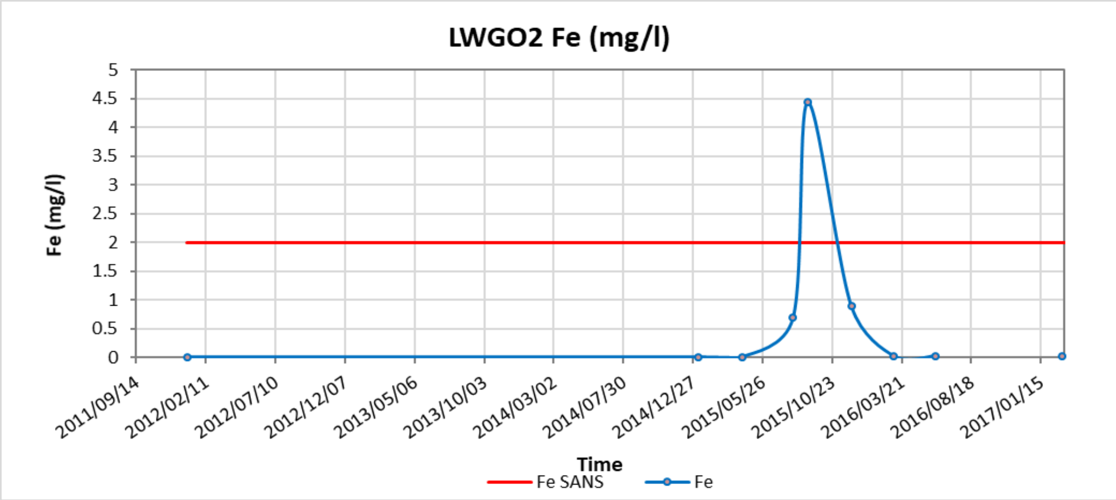

LW08 Fe (mg/l)
Fe (mg/l)
2.5
2
1.5
1
0.5
0
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
Time
Fe SANS
Fe

LWG02

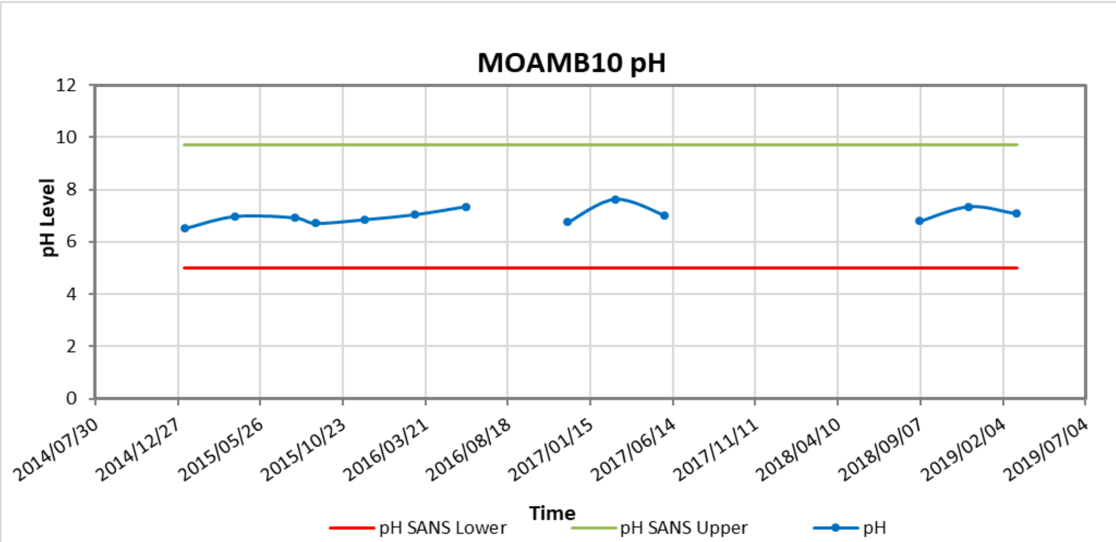

LWGO2 pH
pH Level
12
10
8
6
4
2
0
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
Time
pH SANS Lower
pH SANS Upper
pH

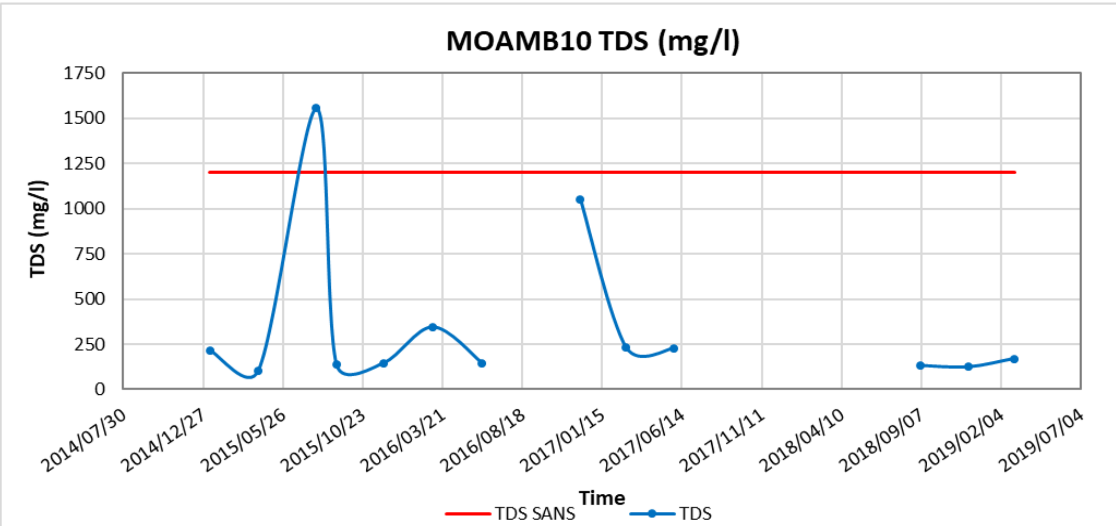

LWGO2 TDS (mg/l)
TDS (mg/l)
1500
1250
1000
750
500
250
0
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
Time
TDS SANS
TDS

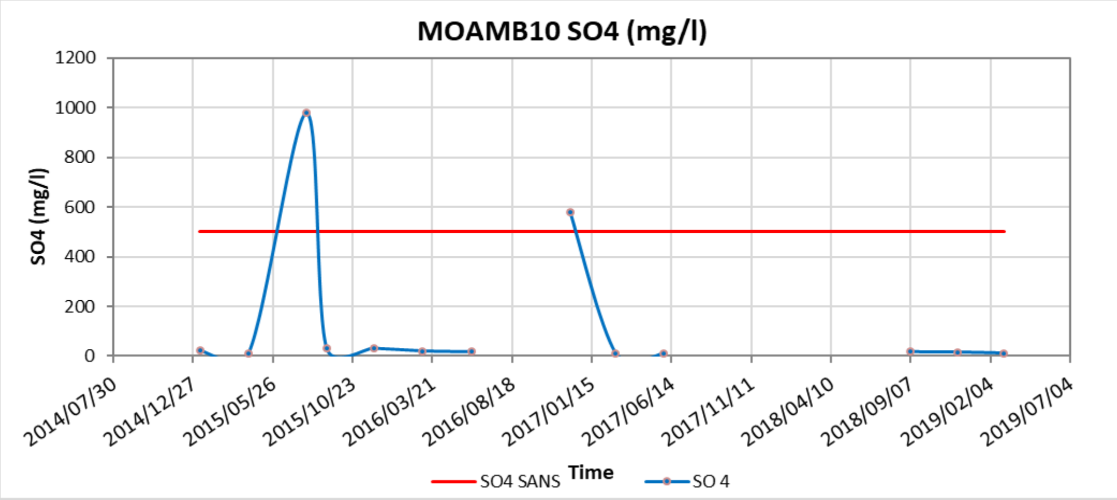

LWGO2 SO4 (mg/l)
SO4 (mg/l)
900
800
700
600
500
400
300
200
100
0
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
Time
SO4 SANS
SO4


LWGO2 Fe (mg/l)
Fe (mg/l)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
Time
Fe SANS
Fe

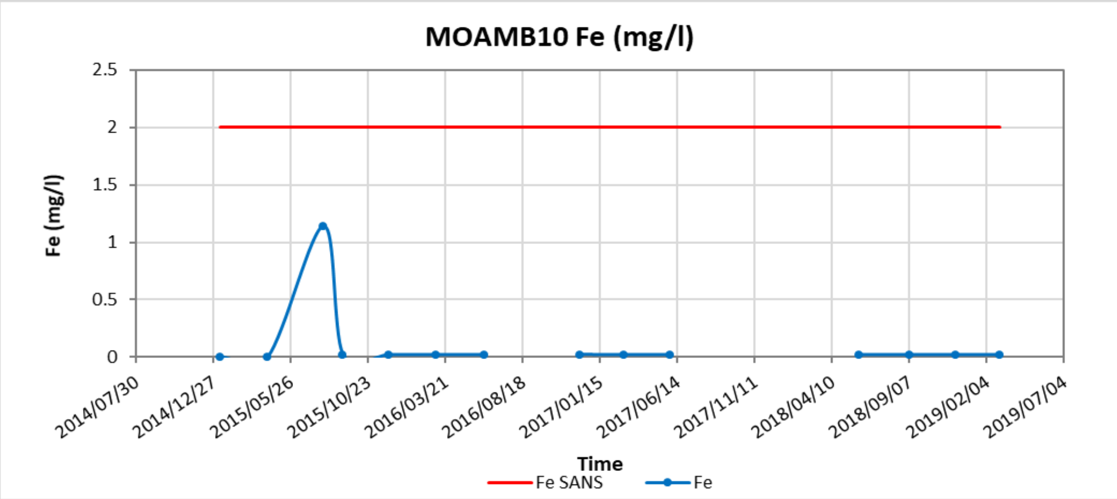
MOAMB10


MOAMB10 pH
pH Level
12
10
8
6
4
2
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
pH SANS Lower
pH SANS Upper
pH


MOAMB10 TDS (mg/l)
TDS (mg/l)
1750
1500
1250
1000
750
500
250
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
TDS SANS
TDS

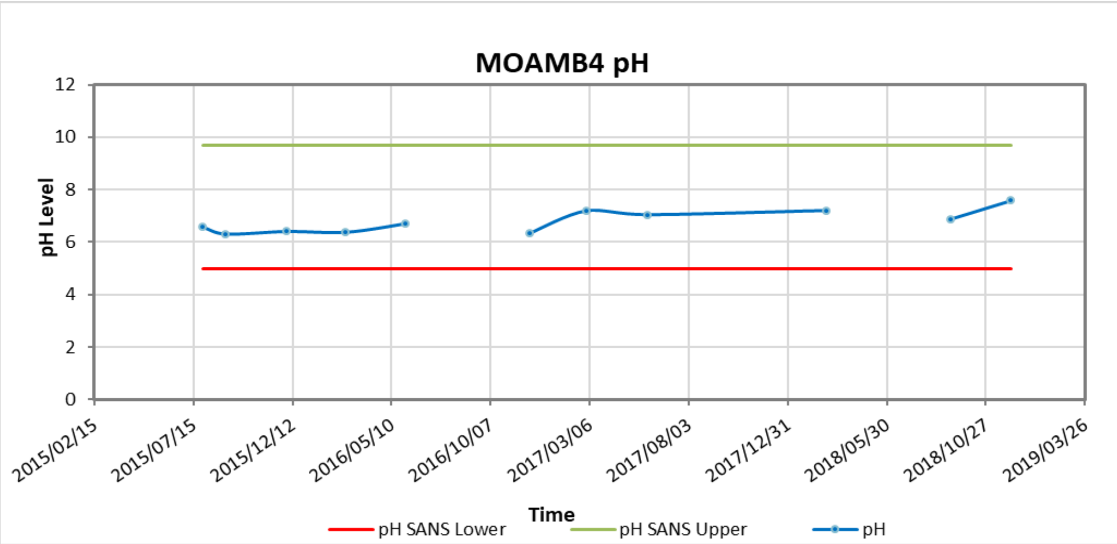


MOAMB10 SO4 (mg/l)
SO4 (mg/l)
1200
1000
800
600
400
200
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
SO4 SANS
SO 4

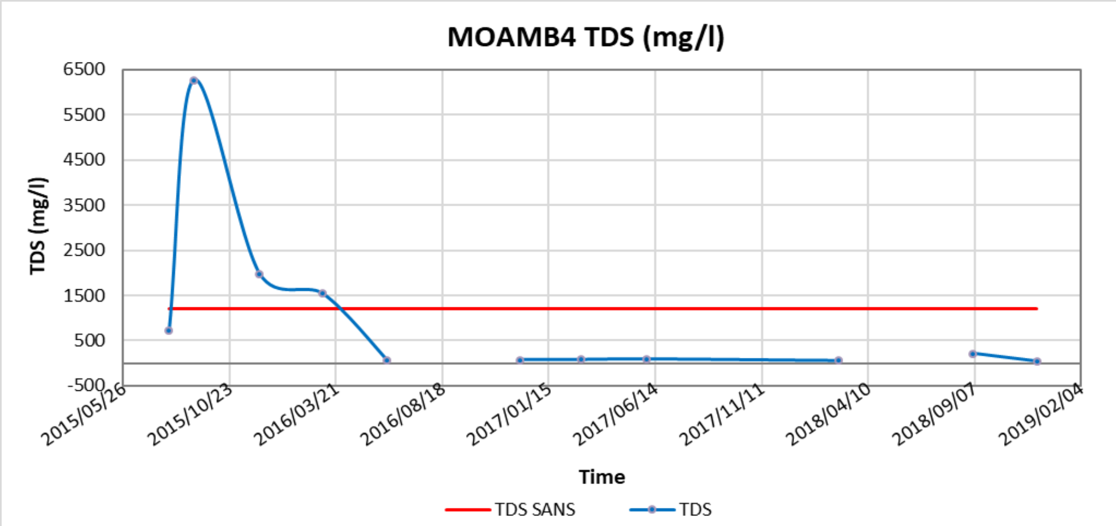


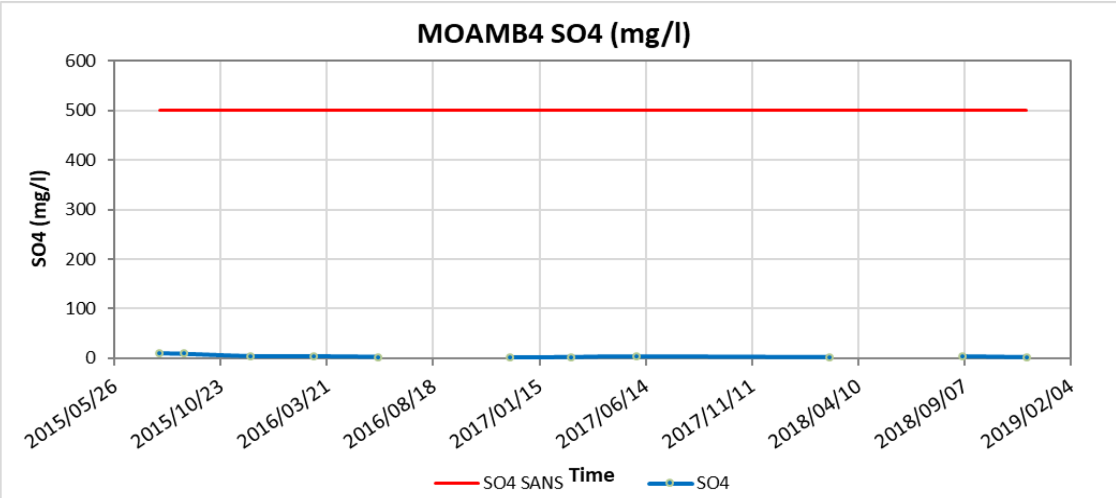
MOAMB10 Fe (mg/l)
Fe (mg/l)
2.5
2
1.5
1
0.5
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
Fe SANS
Fe

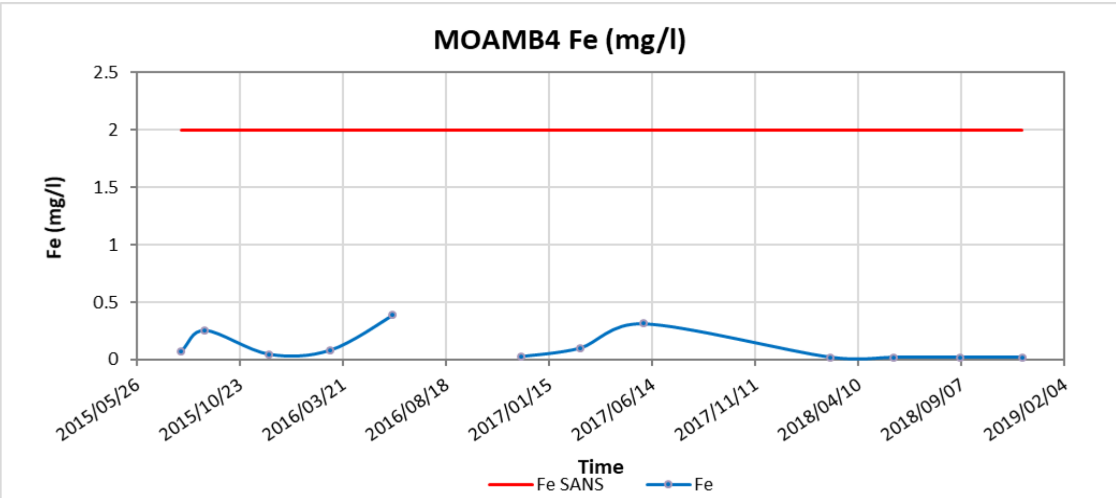
MOAMB4



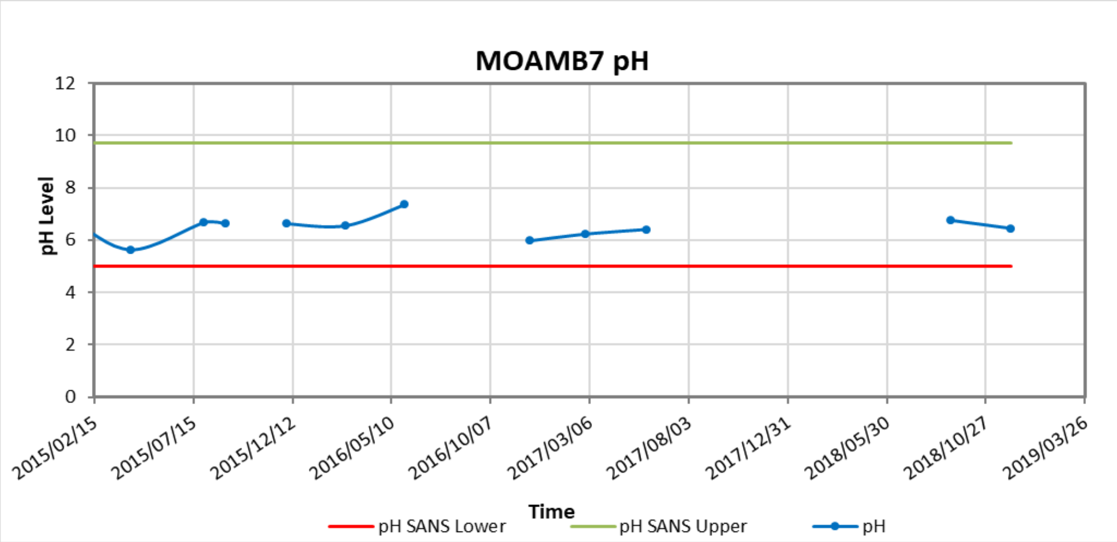
MOAMB4 pH
pH Level
12
10
8
6
4
2
0
2015/02/15
2015/07/15
2015/12/12
2016/05/10
2016/10/07
2017/03/06
2017/08/03
2017/12/31
2018/05/30
2018/10/27
2019/03/26
Time
pH SANS Lower
pH SANS Upper
pH

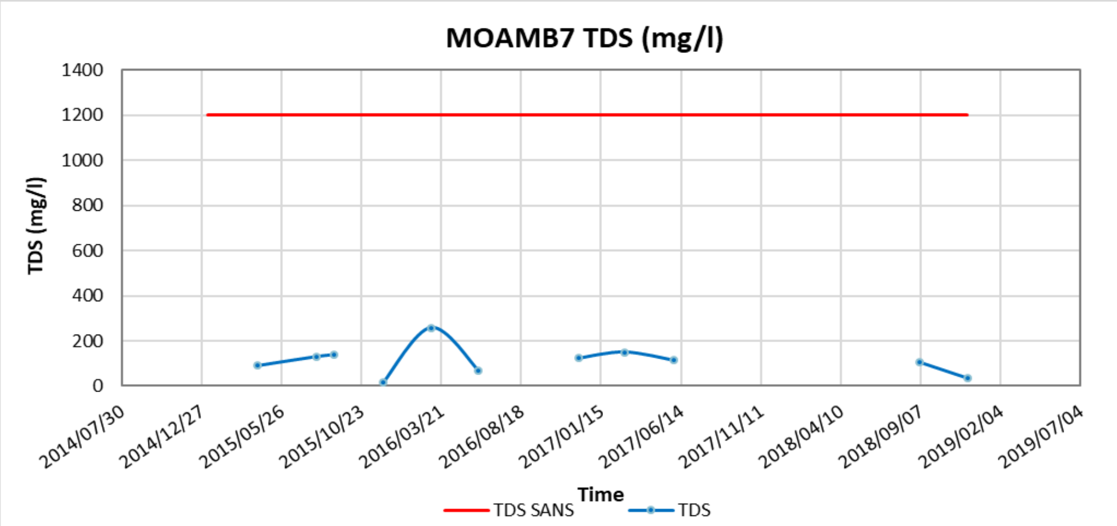

MOAMB4 TDS (mg/l)
TDS (mg/l)
6500
5500
4500
3500
2500
1500
500
-500
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
Time
TDS SANS
TDS

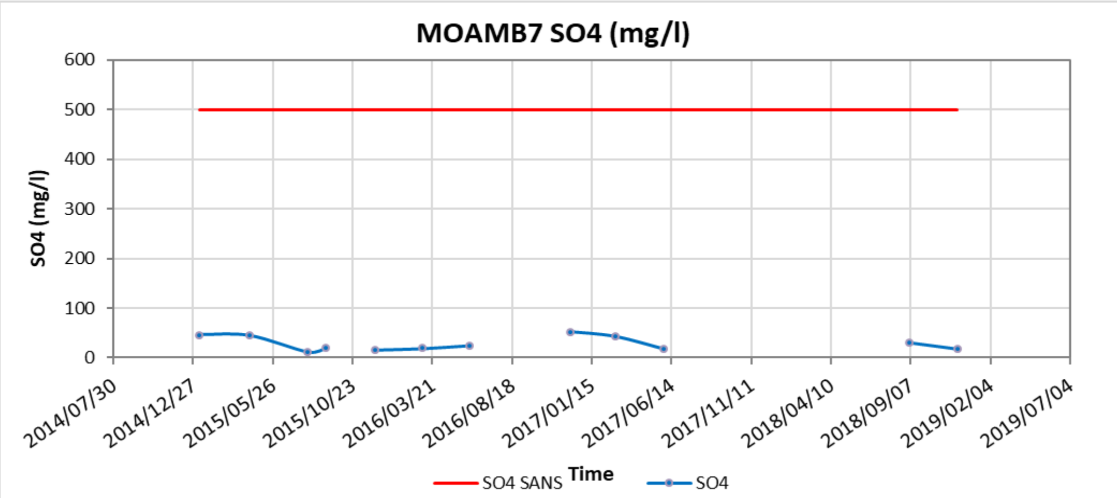

MOAMB4 SO4 (mg/l)
SO4 (mg/l)
600
500
400
300
200
100
0
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
Time
SO4 SANS
SO4

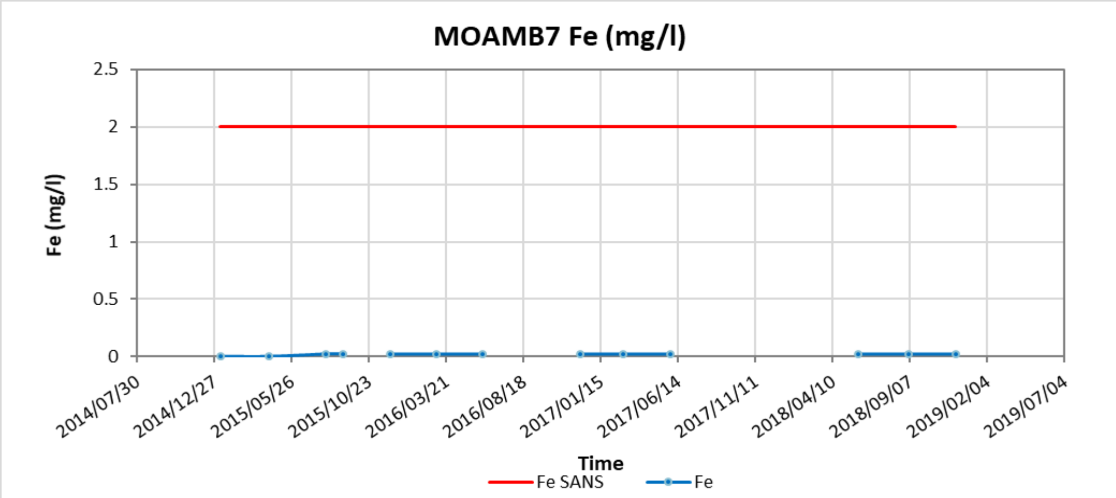

MOAMB4 Fe (mg/l)
Fe (mg/l)
2.5
2
1.5
1
0.5
0
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
Time
Fe SANS
Fe

MOAMB7

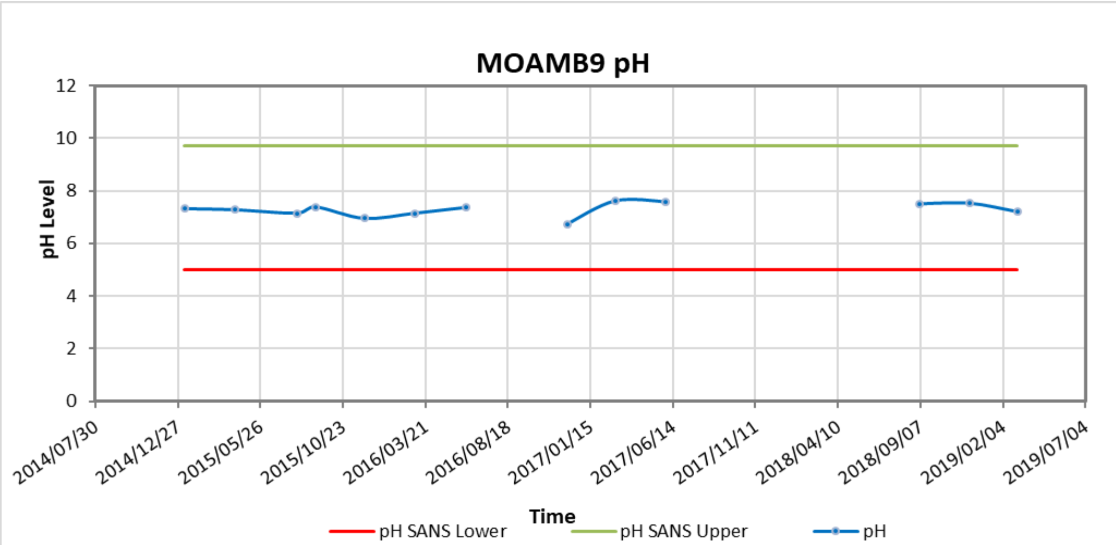

MOAMB7 pH
pH Level
Time
pH SANS Lower
pH SANS Upper
pH

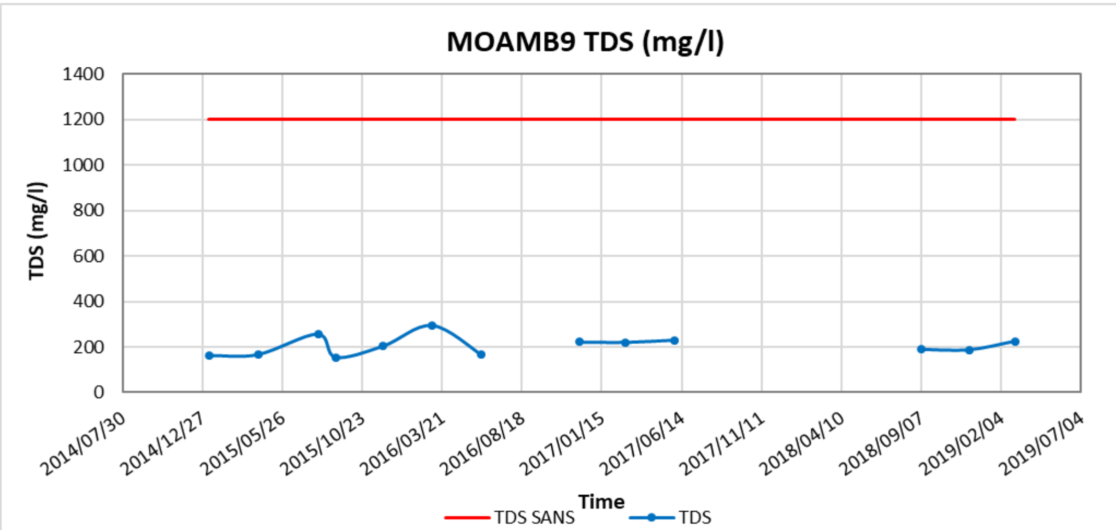

MOAMB7 TDS (mg/l)
TDS (mg/l)
Time
TDS SANS
TDS

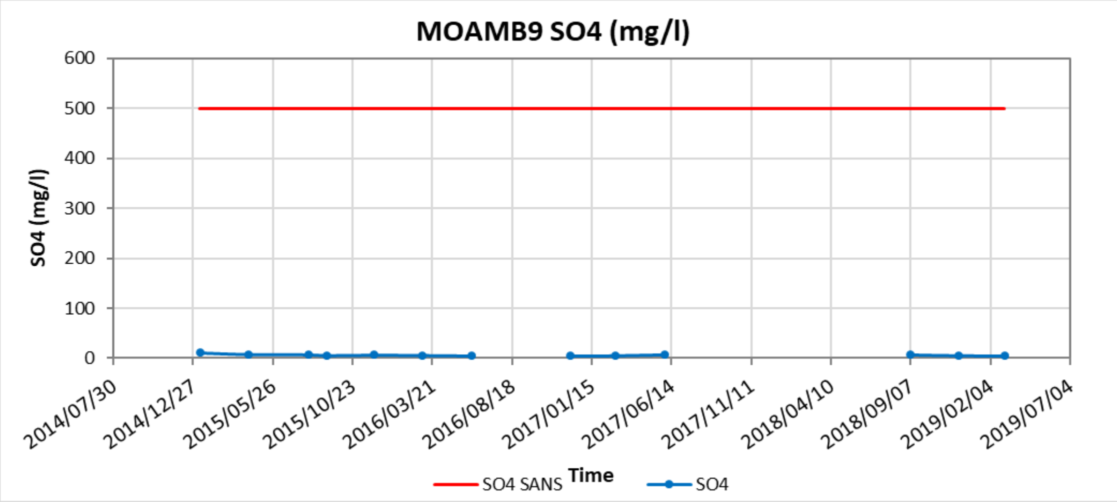

MOAMB7 SO4 (mg/l)
SO4 (mg/l)
Time
SO4 SANS
SO4

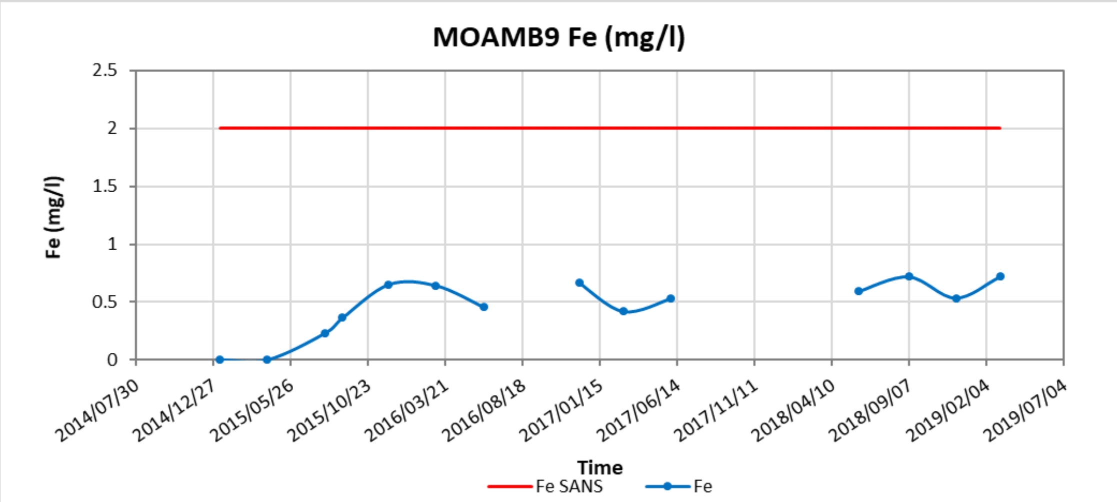

MOAMB7 Fe (mg/l)
Fe (mg/l)
2.5
2
1.5
1
0.5
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
Fe SANS
Fe

MOAMB9

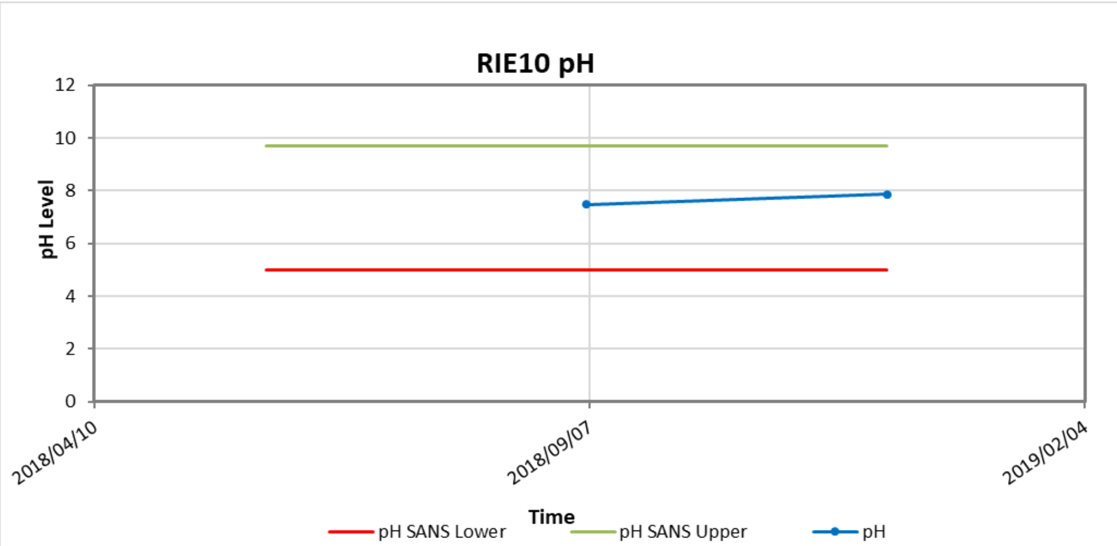

MOAMB9 pH
pH Level
12
10
8
6
4
2
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
pH SANS Lower
pH SANS Upper
pH

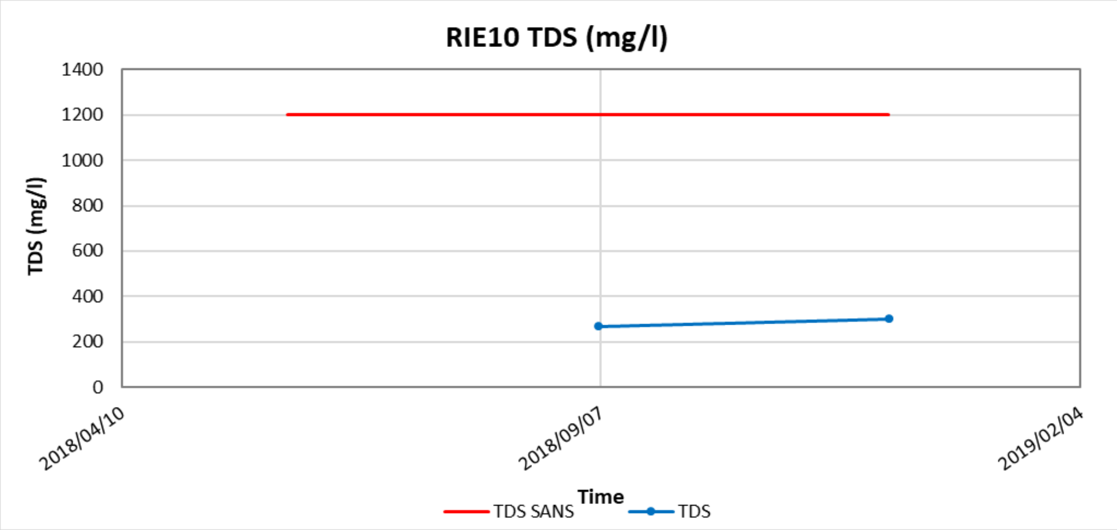

MOAMB9 TDS (mg/l)
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
TDS SANS
TDS

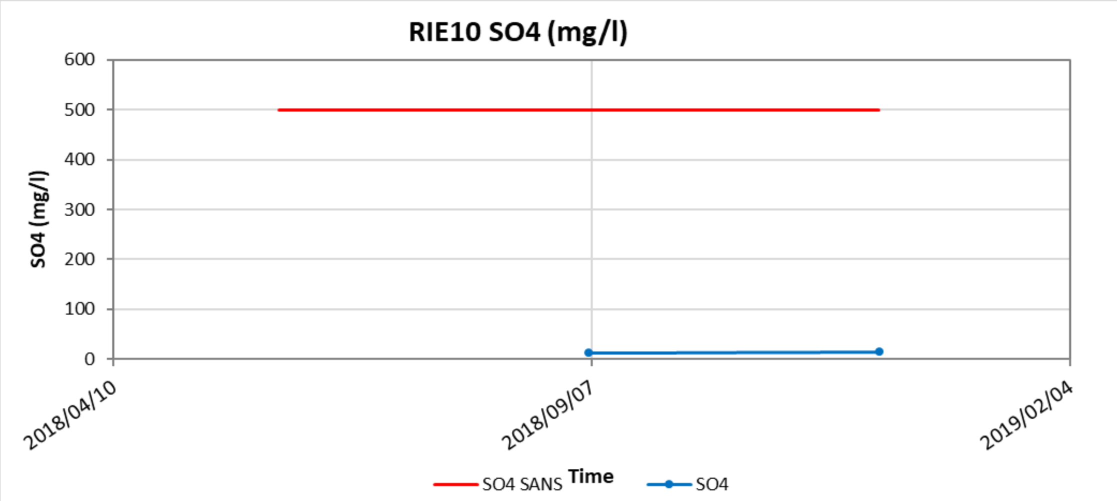

MOAMB9 SO4 (mg/l)
SO4 (mg/l)
600
500
400
300
200
100
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
SO4 SANS
SO4

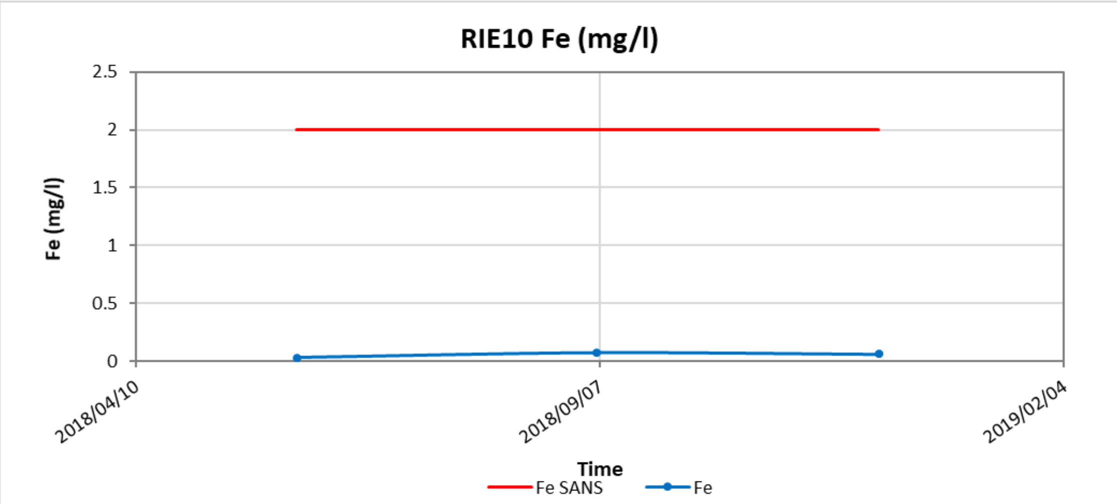

MOAMB9 Fe (mg/l)
Fe (mg/l)
2.5
2
1.5
1
0.5
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
Fe SANS
Fe

RIE10

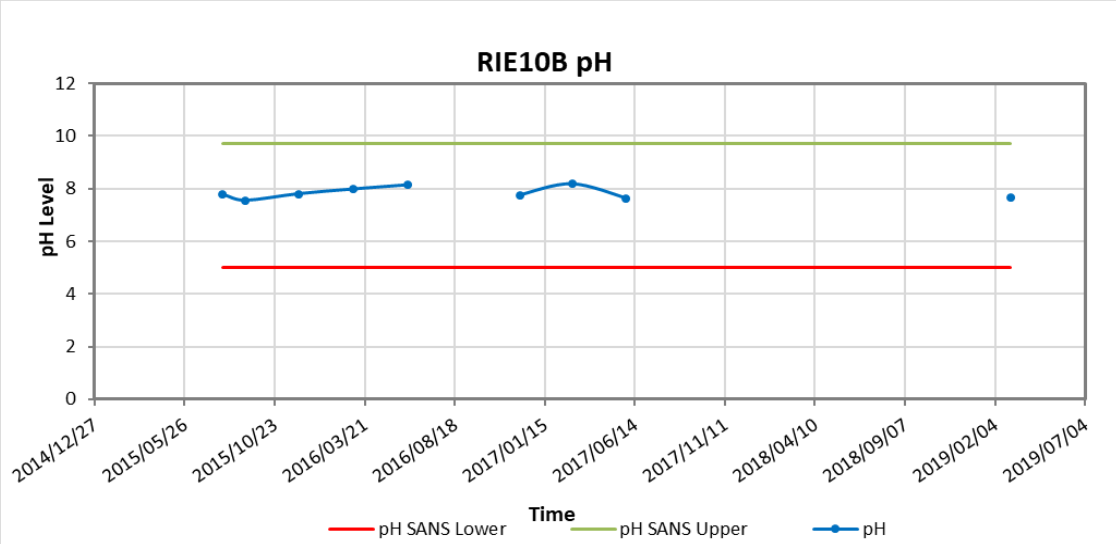

RIE10 pH
pH Level
12
10
8
6
4
2
0
2018/04/10
2018/09/07
2019/02/04
Time
pH SANS Lower
pH SANS Upper
pH

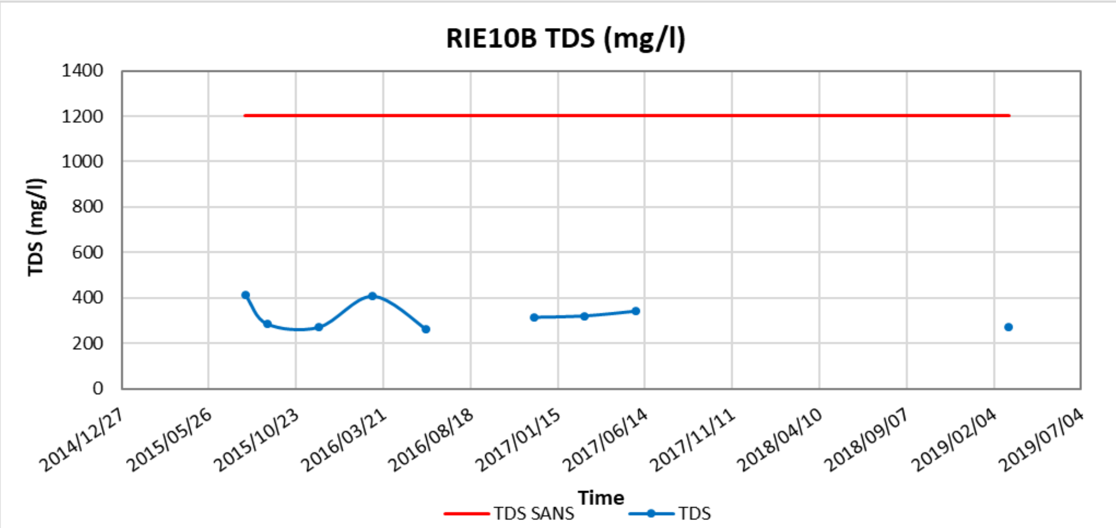

RIE10 TDS (mg/l)
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2018/04/10
2018/09/07
2019/02/04
Time
TDS SANS
TDS

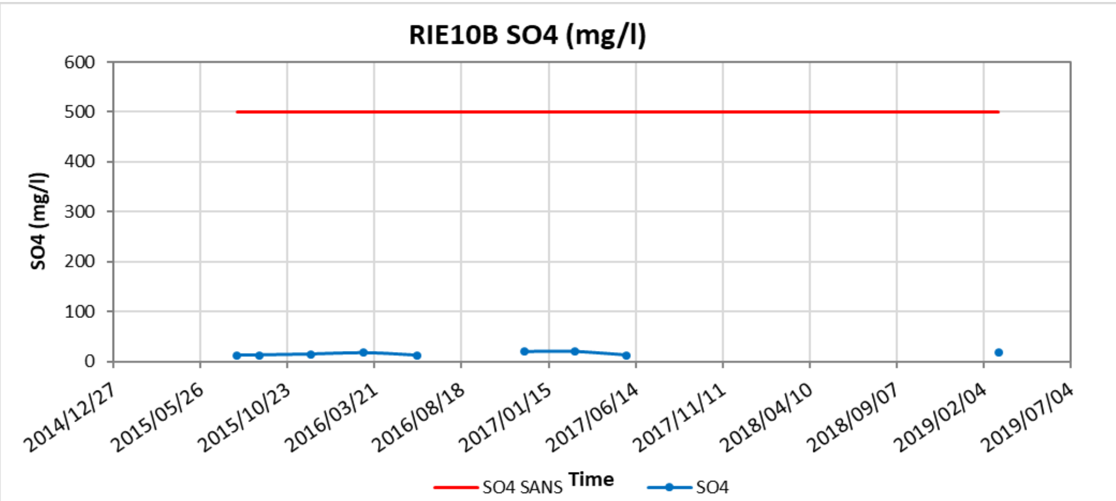

RIE10 SO4 (mg/l)
SO4 (mg/l)
600
500
400
300
200
100
0
2018/04/10
2018/09/07
2019/02/04
Time
SO4 SANS
SO4

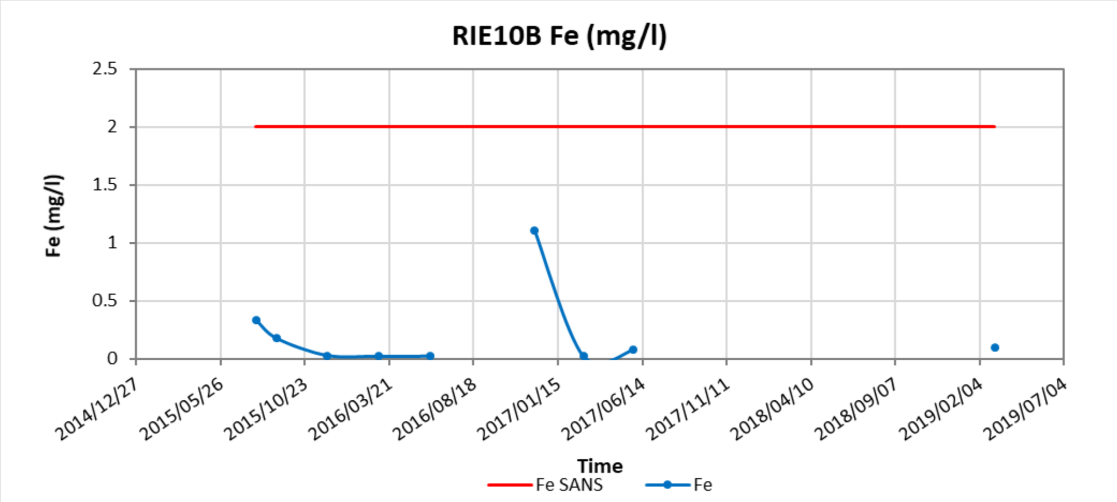

RIE10 Fe (mg/l)
Fe (mg/l)
2.5
2
1.5
1
0.5
0
2018/04/10
2018/09/07
2019/02/04
Time
Fe SANS
Fe

RIE10B

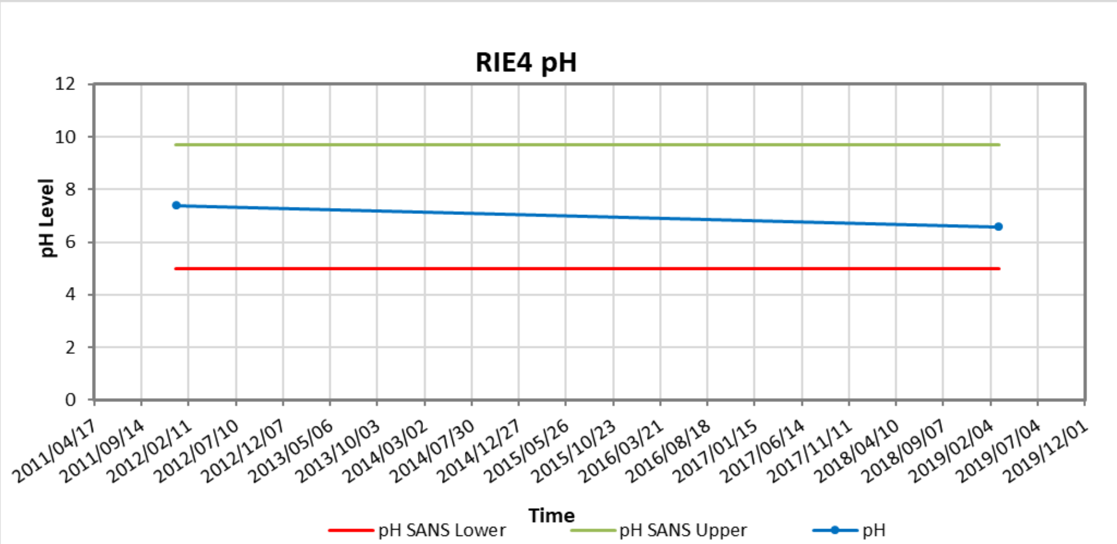

RIE10B pH
pH Level
12
10
8
6
4
2
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
pH SANS Lower
pH SANS Upper
pH

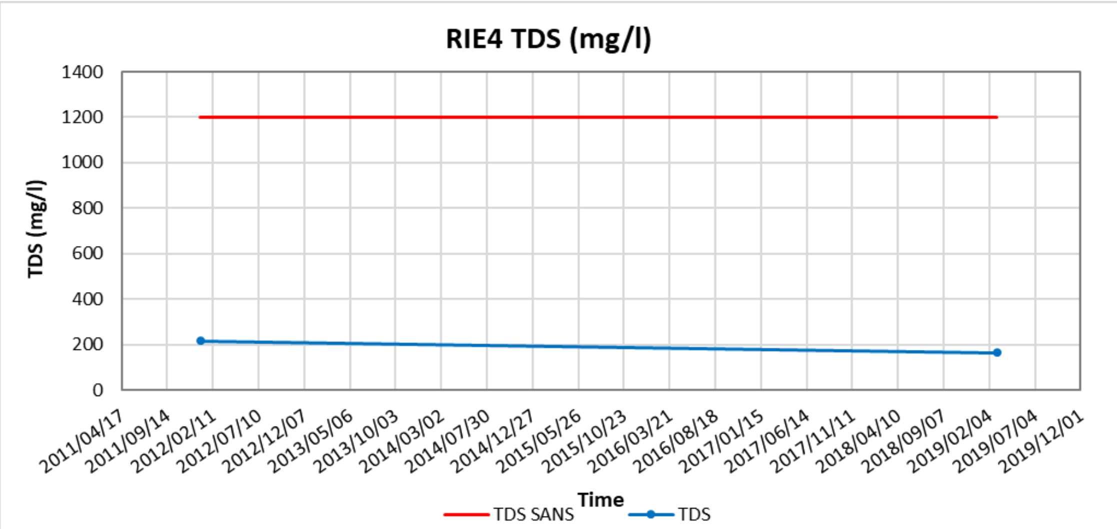

RIE10B TDS (mg/l)
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
TDS SANS
TDS

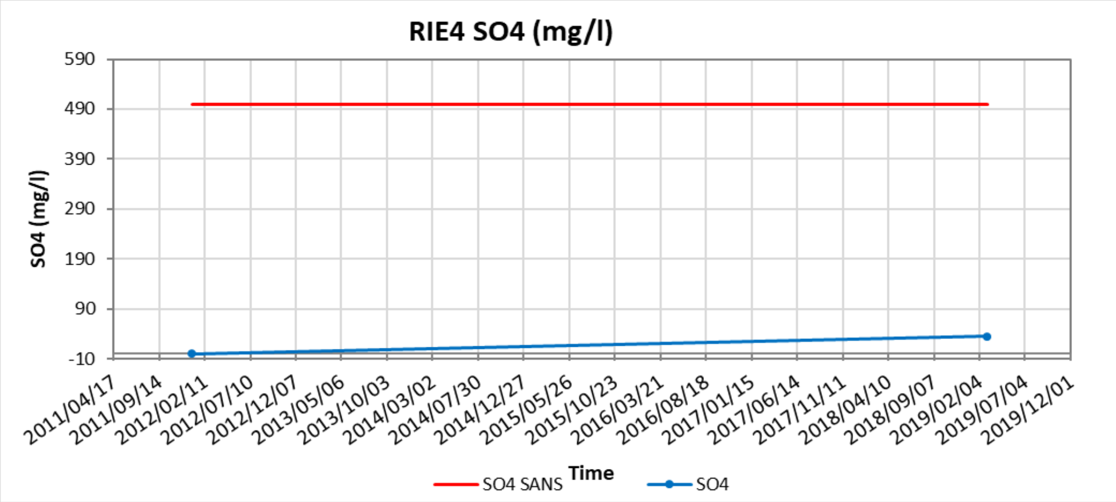

RIE10B SO4 (mg/l)
SO4 (mg/l)
600
500
400
300
200
100
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
SO4 SANS
SO4

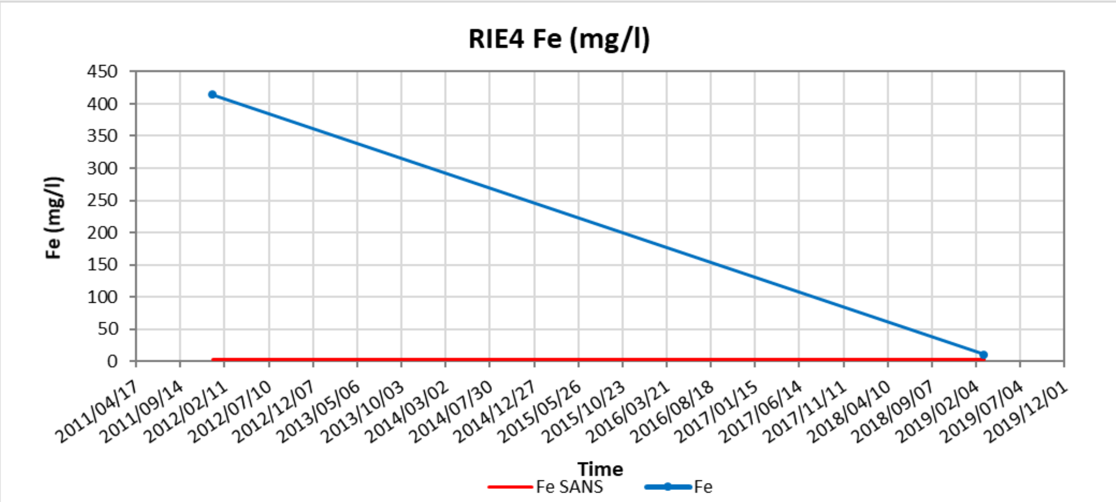

RIE10B Fe (mg/l)
Fe (mg/l)
2.5
2
1.5
1
0.5
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
Fe SANS
Fe

RIE4

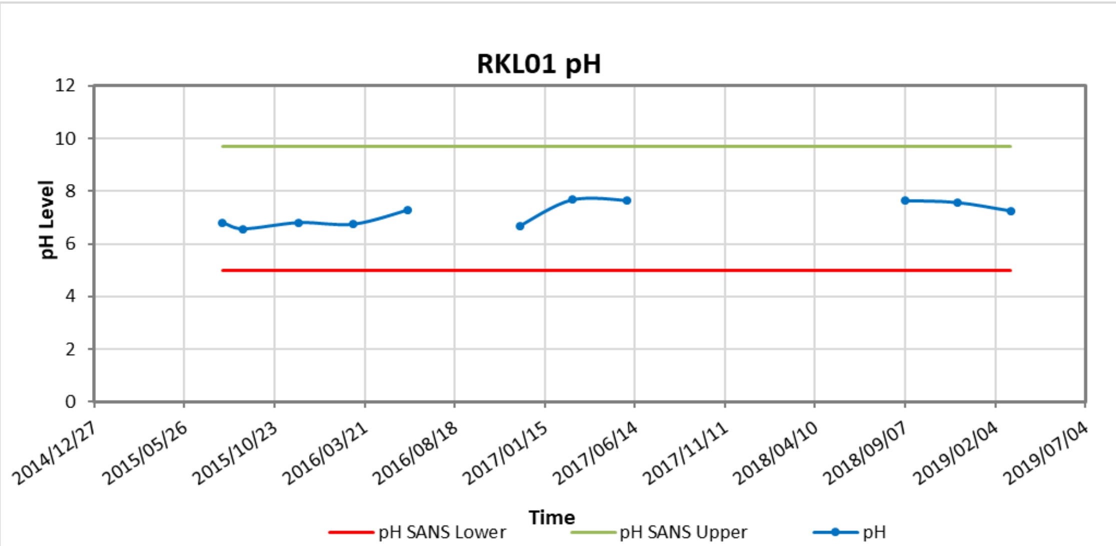

RIE4 pH
pH Level
12
10
8
6
4
2
0
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
pH SANS Lower
pH SANS Upper
pH

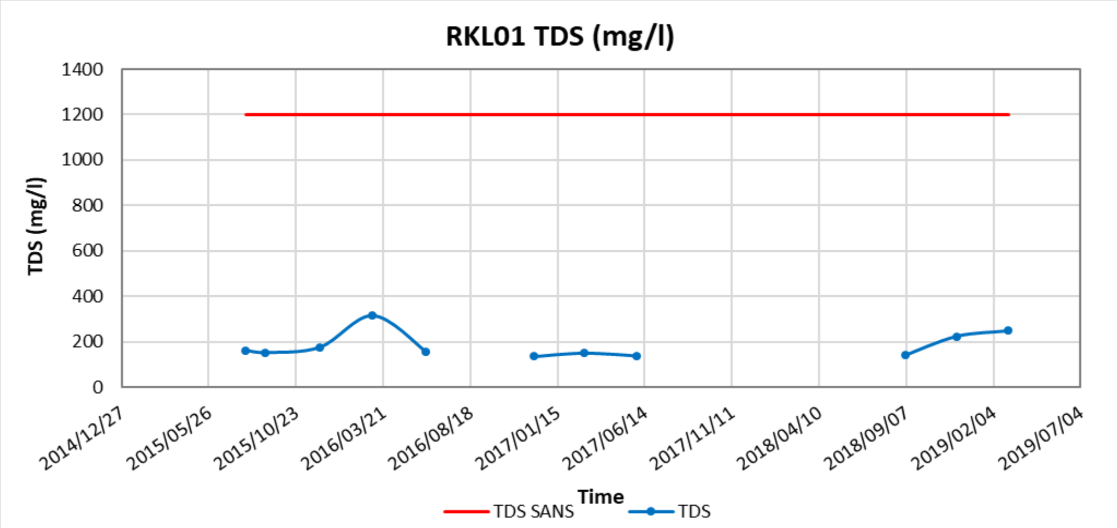

RIE4 TDS (mg/l)
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
TDS SANS
TDS

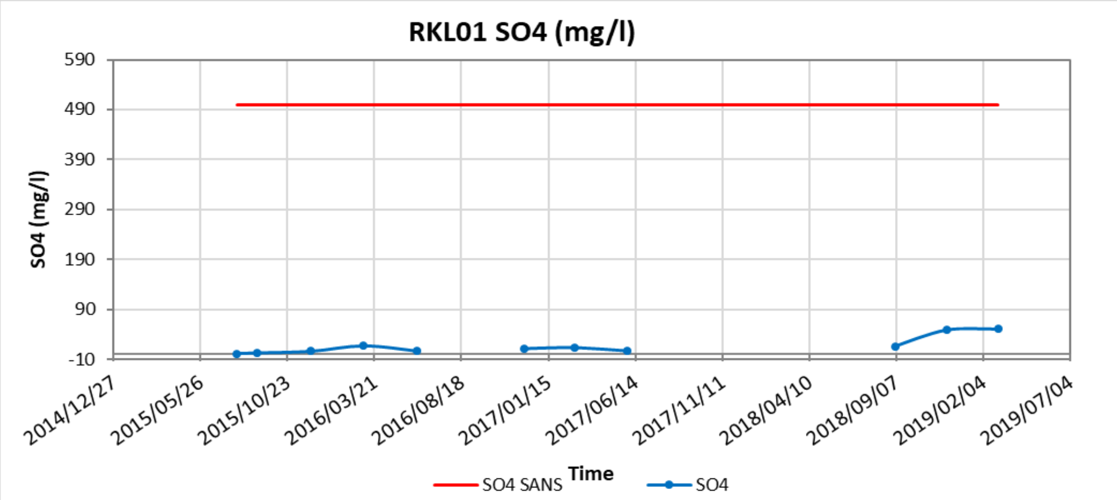

RIE4 SO4 (mg/l)
SO4 (mg/l)
590
490
390
290
190
90
-10
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
SO4 SANS
SO4

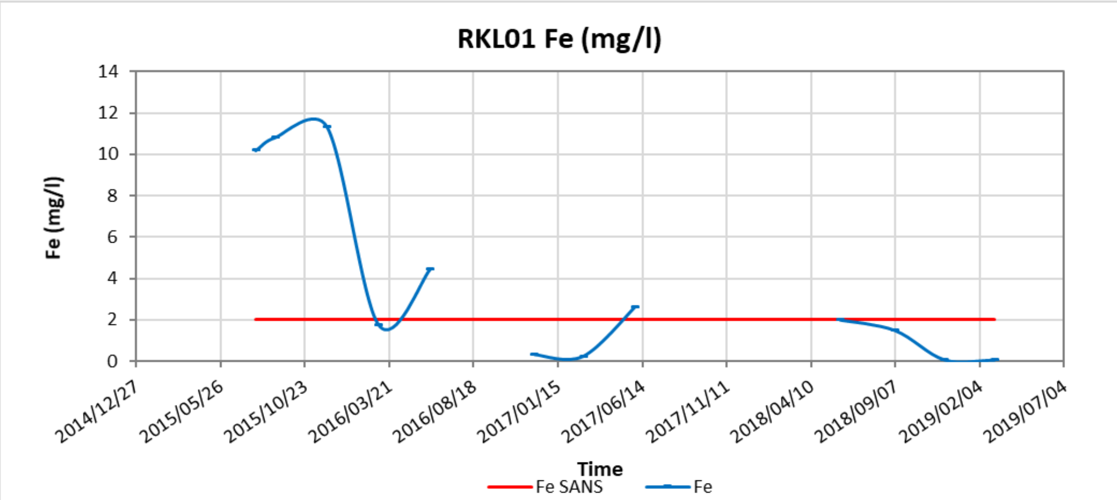

RIE4 Fe (mg/l)
Fe (mg/l)
450
400
350
300
250
200
150
100
50
0
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
Fe SANS
Fe

RKL01

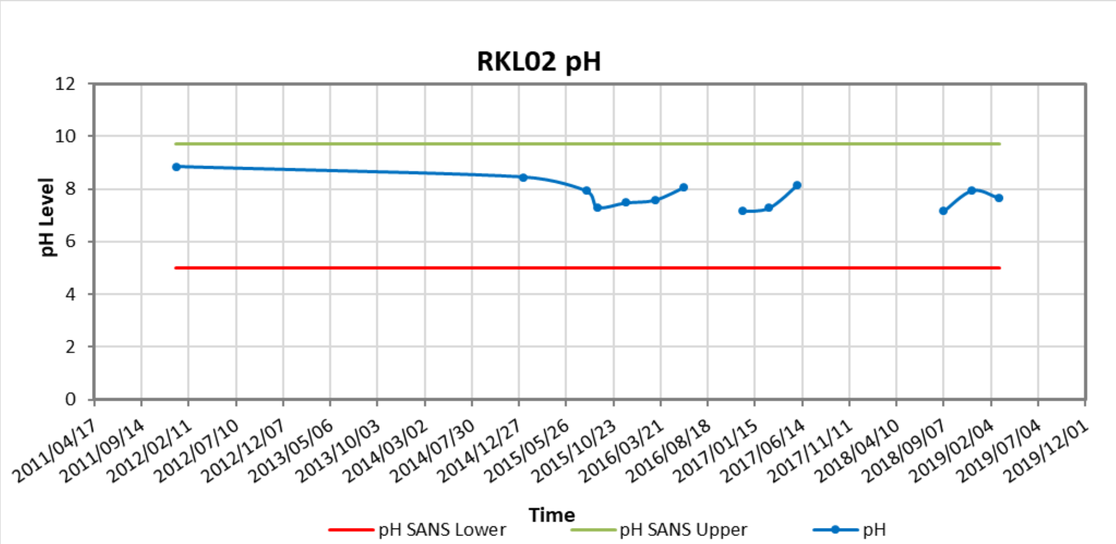

RKL01 pH
pH Level
12
10
8
6
4
2
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
pH SANS Lower
pH SANS Upper
pH

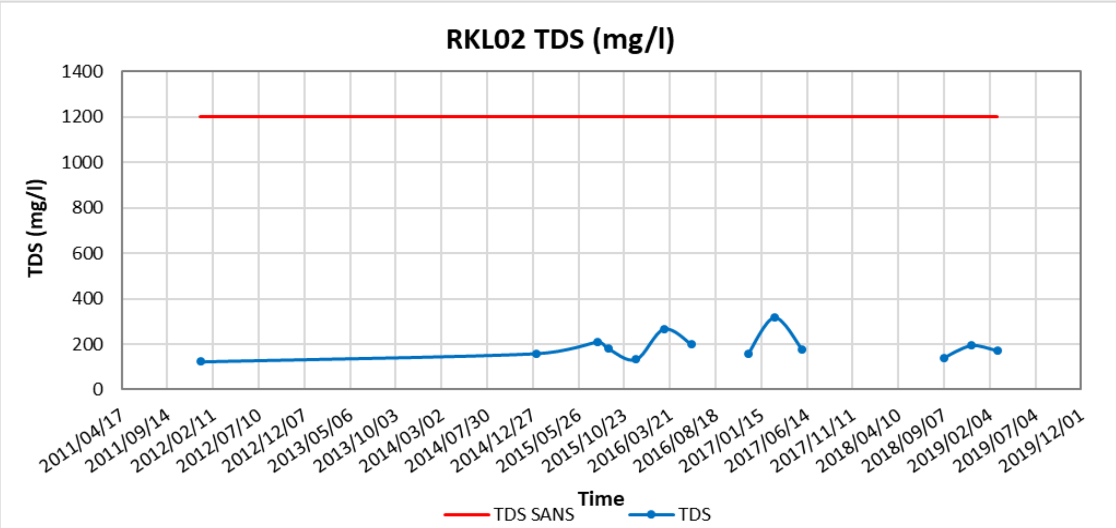

RKL01 TDS (mg/l)
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
TDS SANS
TDS

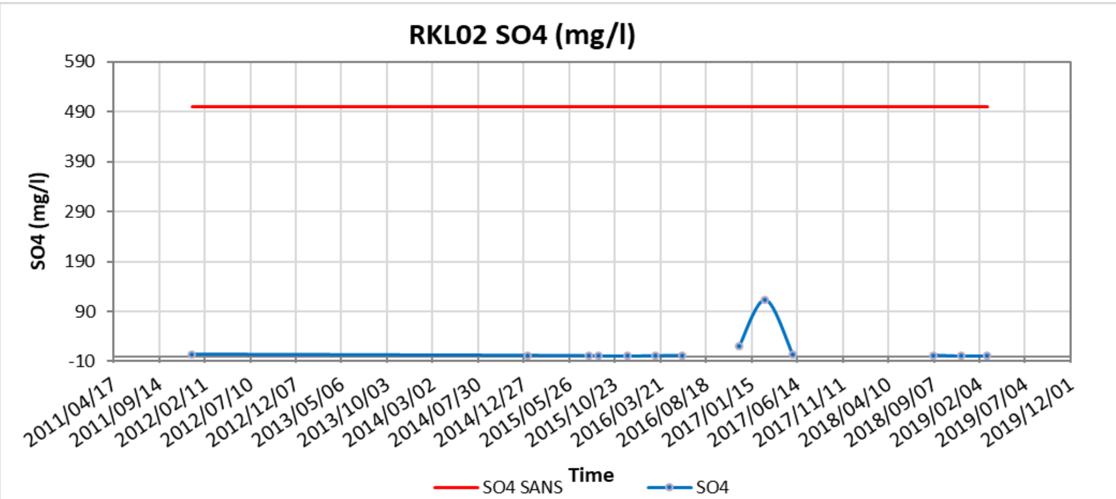

RKL01 SO4 (mg/l)
SO4 (mg/l)
590
490
390
290
190
90
-10
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
SO4 SANS
SO4

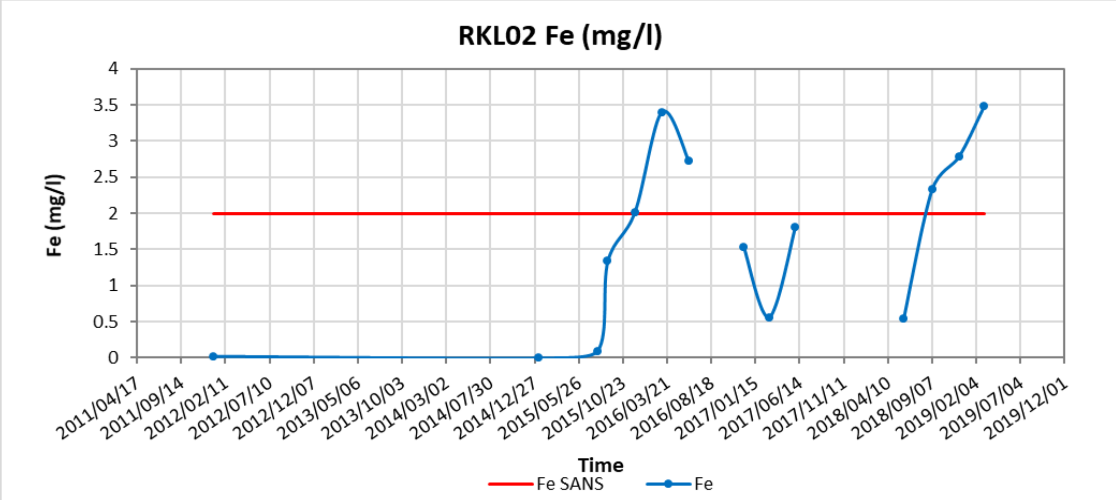

RKL01 Fe (mg/l)
Fe (mg/l)
14
12
10
8
6
4
2
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
Fe SANS
Fe

RKL02

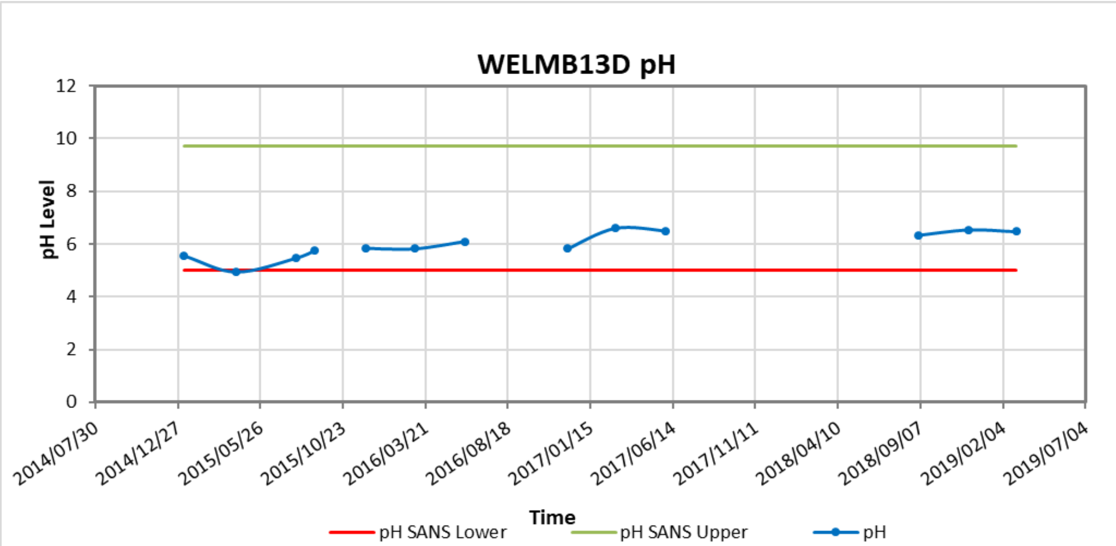

RKL02 pH
12
10
8
6
4
2
0
pH Level
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
pH SANS Lower
pH SANS Upper
pH

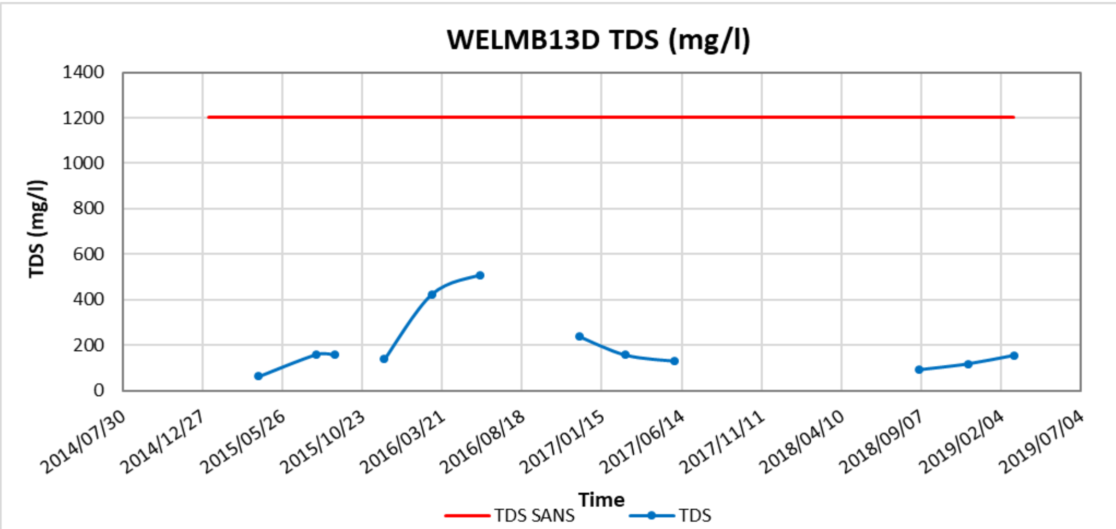

RKL02 TDS (mg/l)
1400
1200
1000
800
600
400
200
0
TDS (mg/l)
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
TDS SANS
TDS

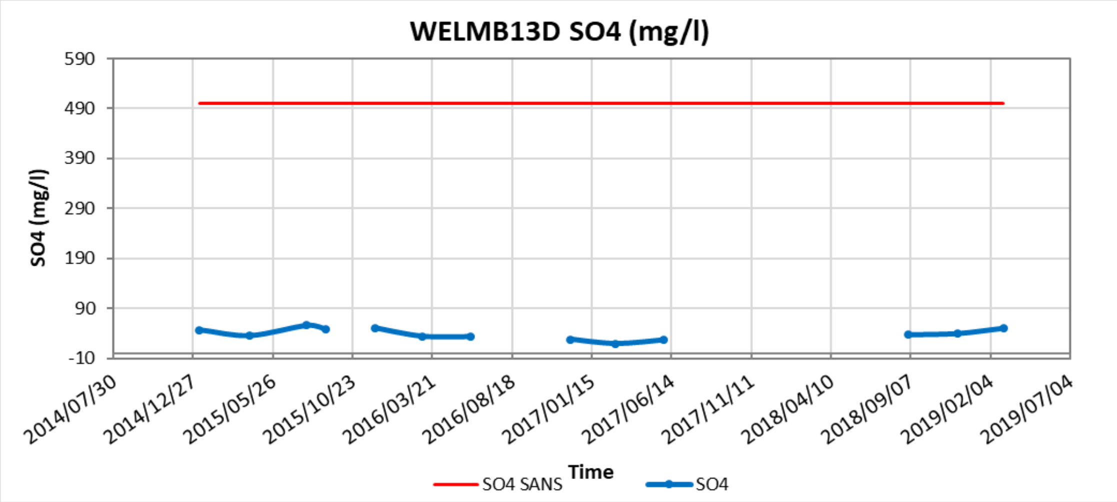

RKL02 SO4 (mg/l)
590
490
390
290
190
90
-10
SO4 (mg/l)
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
SO4 SANS
SO4


RKL02 Fe (mg/l)
Fe (mg/l)
Time
Fe SANS
Fe

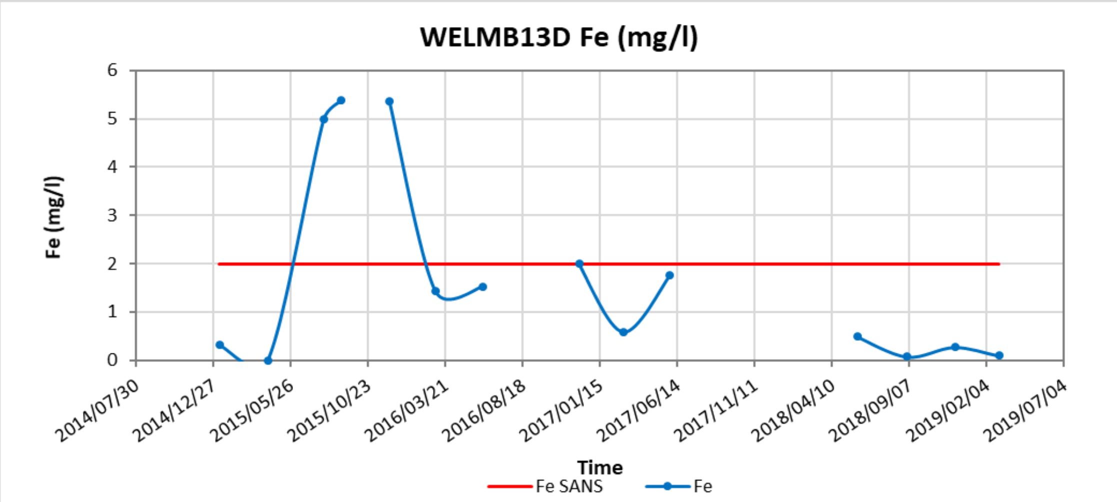
WELMB13D


WELMB13D pH
pH Level
Time
pH SANS Lower
pH SANS Upper
pH


WELMB13D TDS (mg/l)
TDS (mg/l)
Time
TDS SANS
TDS

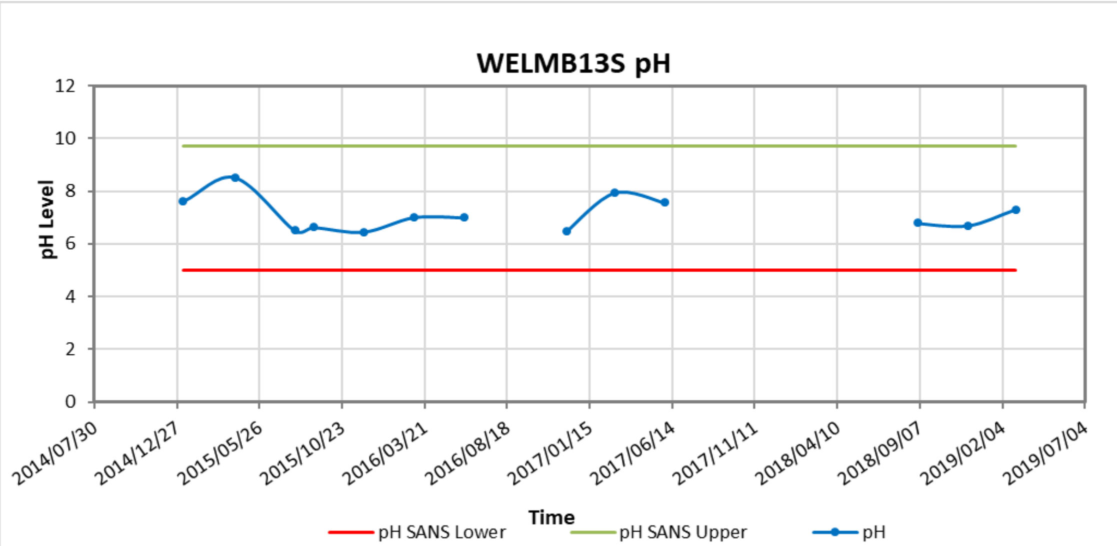


WELMB13D SO4 (mg/l)
SO4 (mg/l)
590
490
390
290
190
90
-10
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
SO4 SANS
SO4

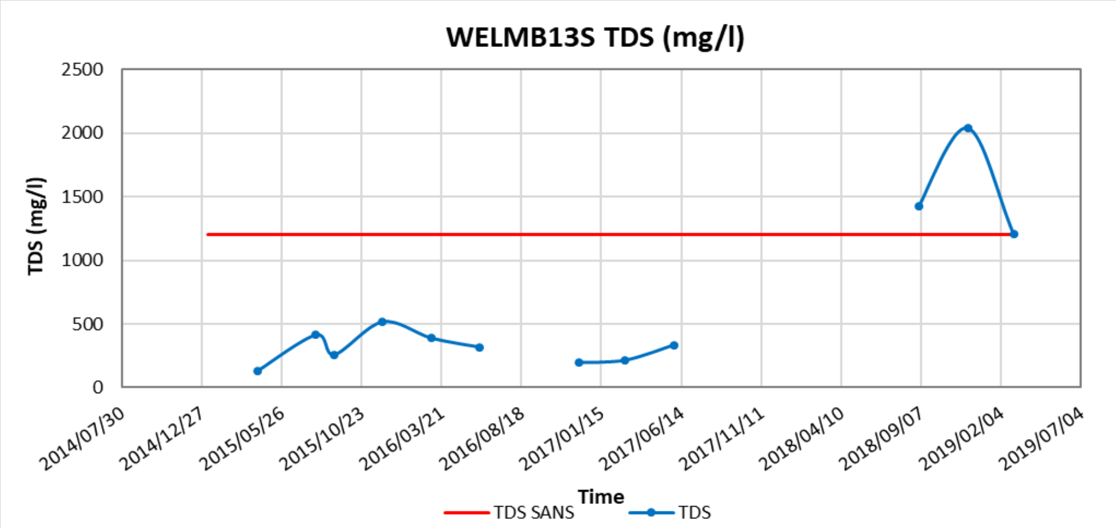


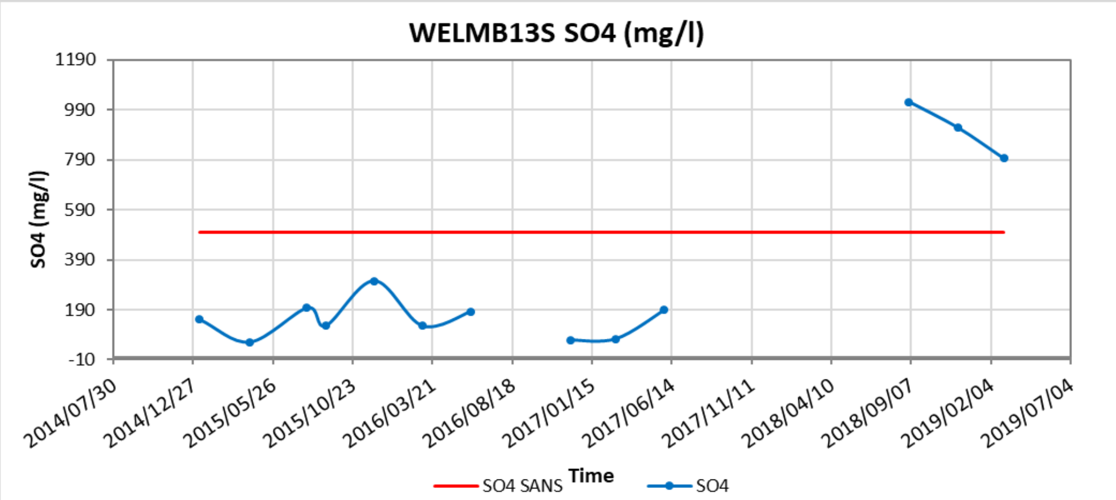
WELMB13D Fe (mg/l)
Fe (mg/l)
6
5
4
3
2
1
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
Fe SANS
Fe

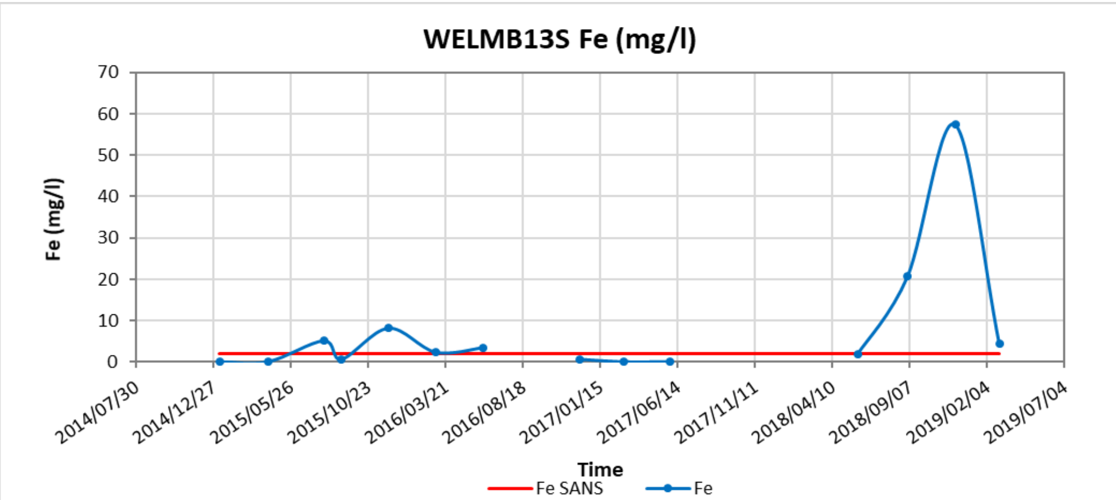
WELMB13S



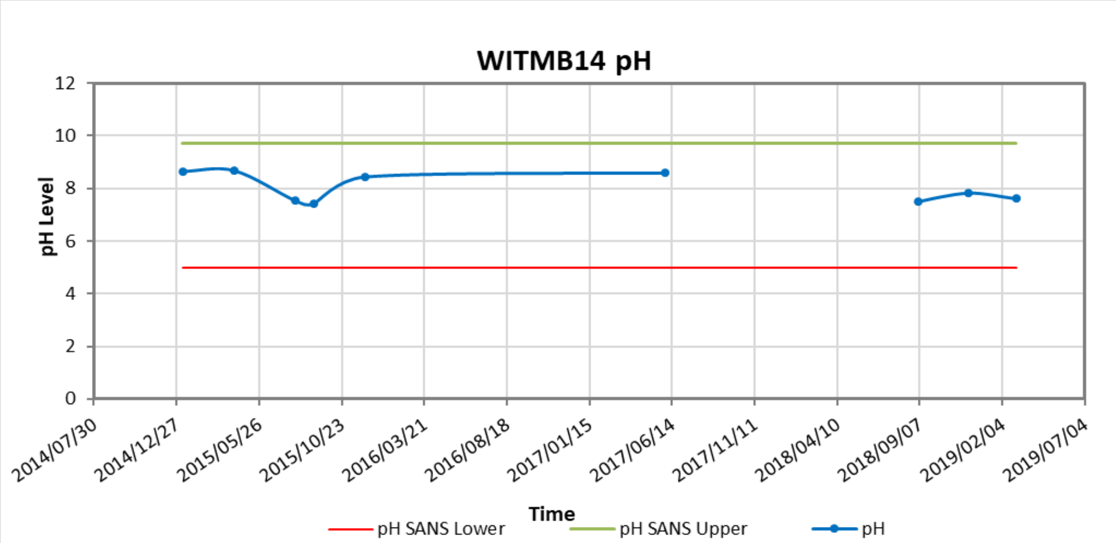
WELMB13S pH
pH Level
12
10
8
6
4
2
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
pH SANS Lower
pH SANS Upper
pH

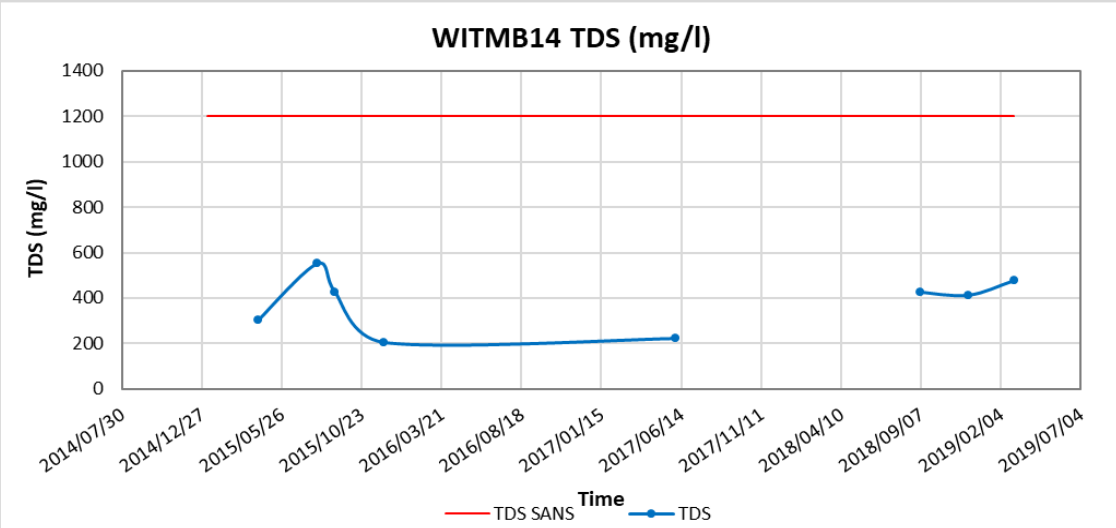

WELMB13S TDS (mg/l)
TDS (mg/l)
2500
2000
1500
1000
500
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
TDS SANS
TDS

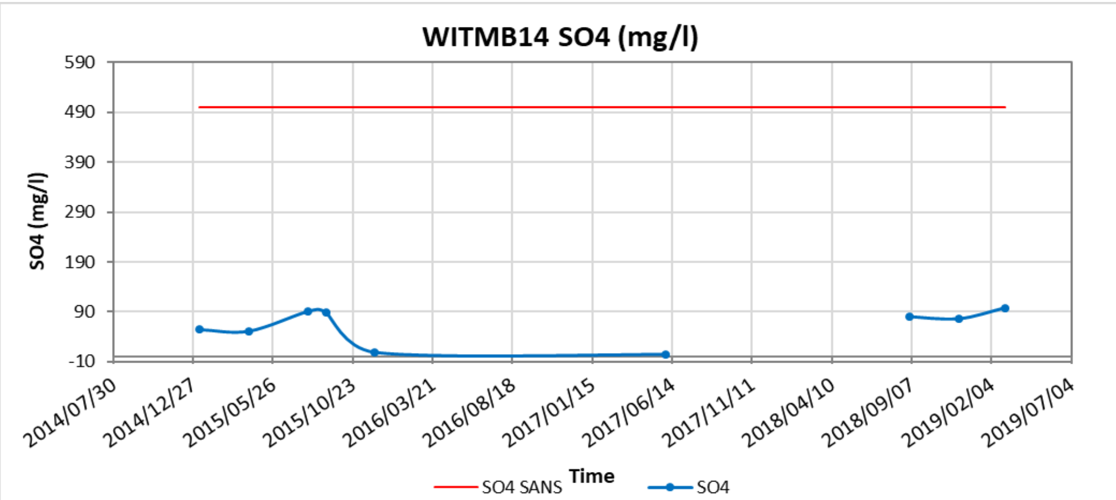

WELMB13S SO4 (mg/l)
SO4 (mg/l)
1190
990
790
590
390
190
-10
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
SO4 SANS
SO4


WELMB13S Fe (mg/l)
Fe (mg/l)
70
60
50
40
30
20
10
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
Fe SANS
Fe

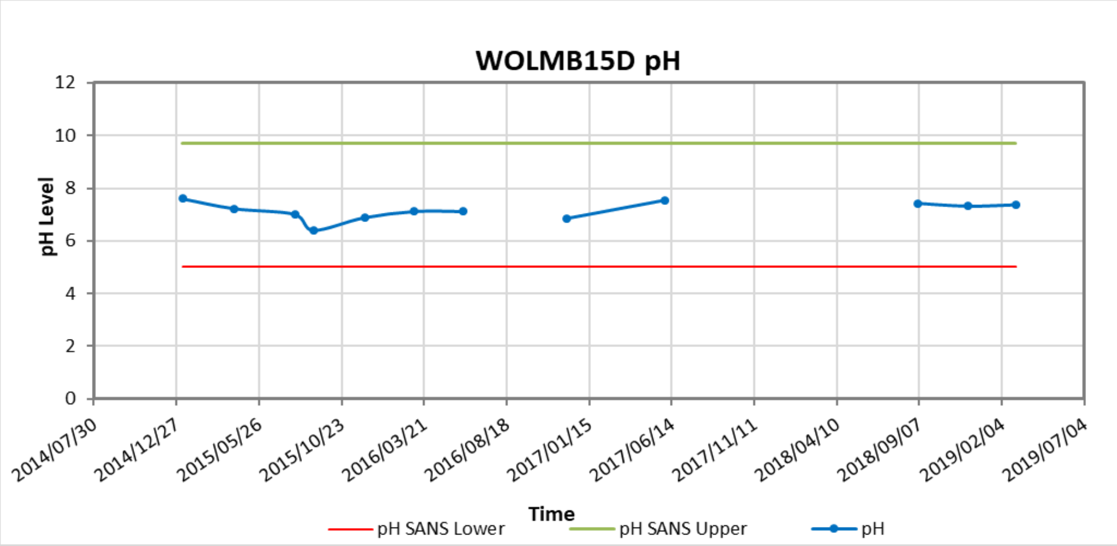
WITMB14

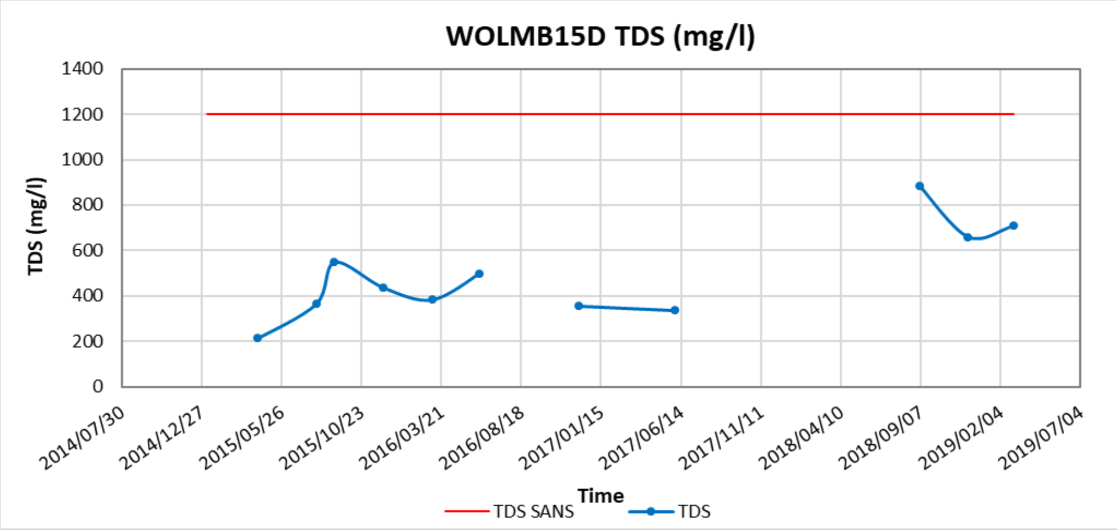

WITMB14 pH
pH Level
12
10
8
6
4
2
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
pH SANS Lower
pH SANS Upper
pH

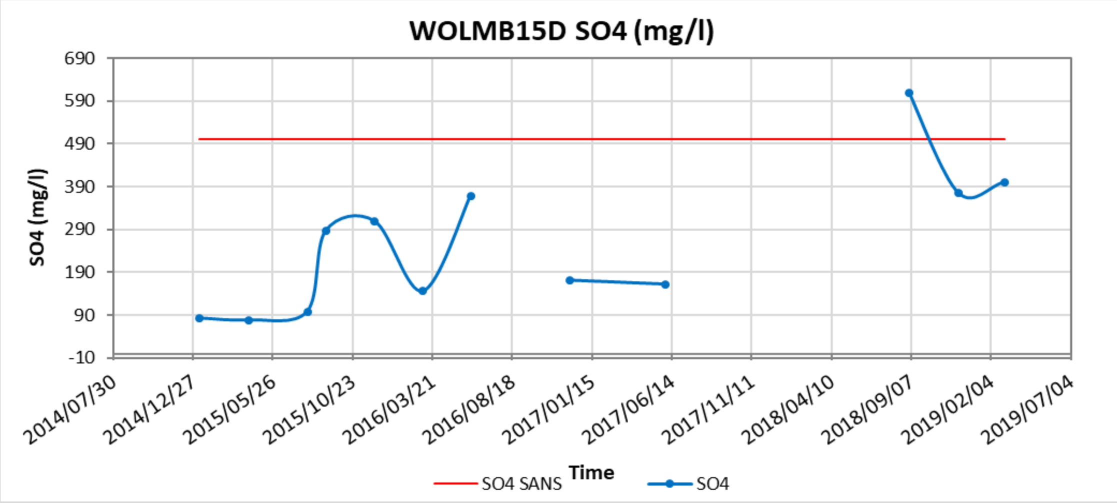

WITMB14 TDS (mg/l)
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
TDS SANS
TDS


WITMB14 SO4 (mg/l)
SO4 (mg/l)
590
490
390
290
190
90
-10
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
SO4 SANS
SO4

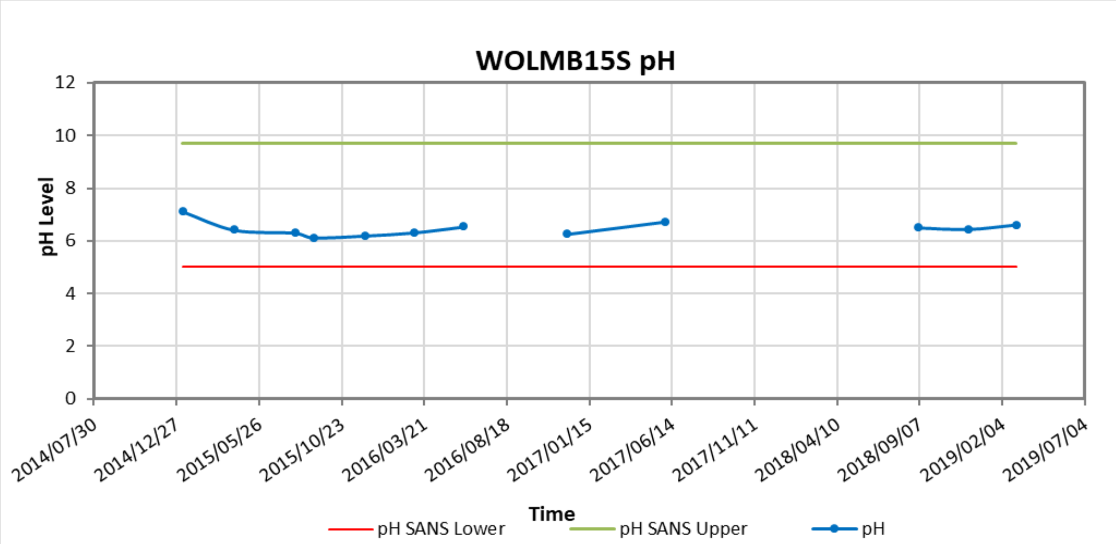
WOLMB15D

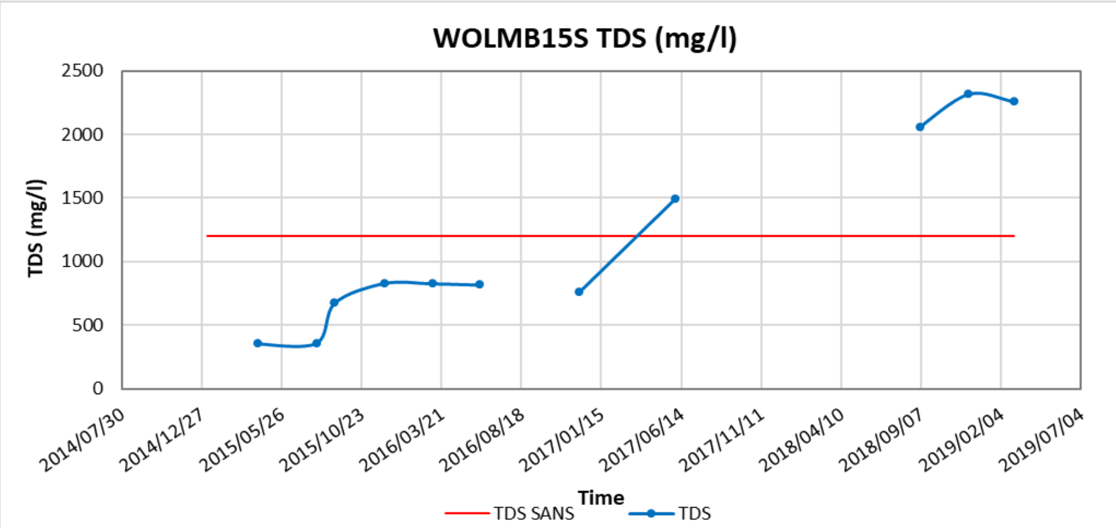

WOLMB15D pH
pH Level
Time
pH SANS Lower
pH SANS Upper
pH

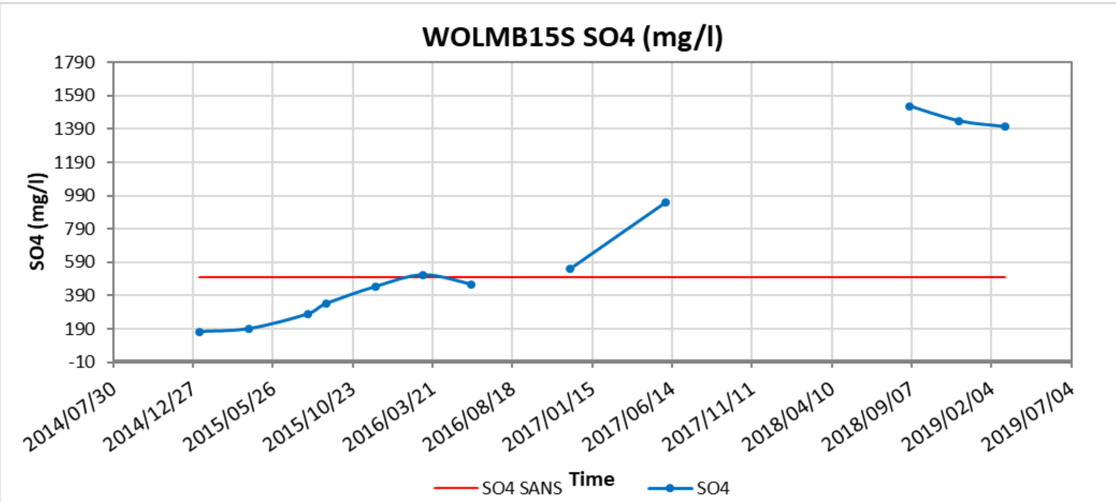

WOLMB15D TDS (mg/l)
TDS (mg/l)
Time
TDS SANS
TDS


WOLMB15D SO4 (mg/l)
SO4 (mg/l)
Time
SO4 SANS
SO4

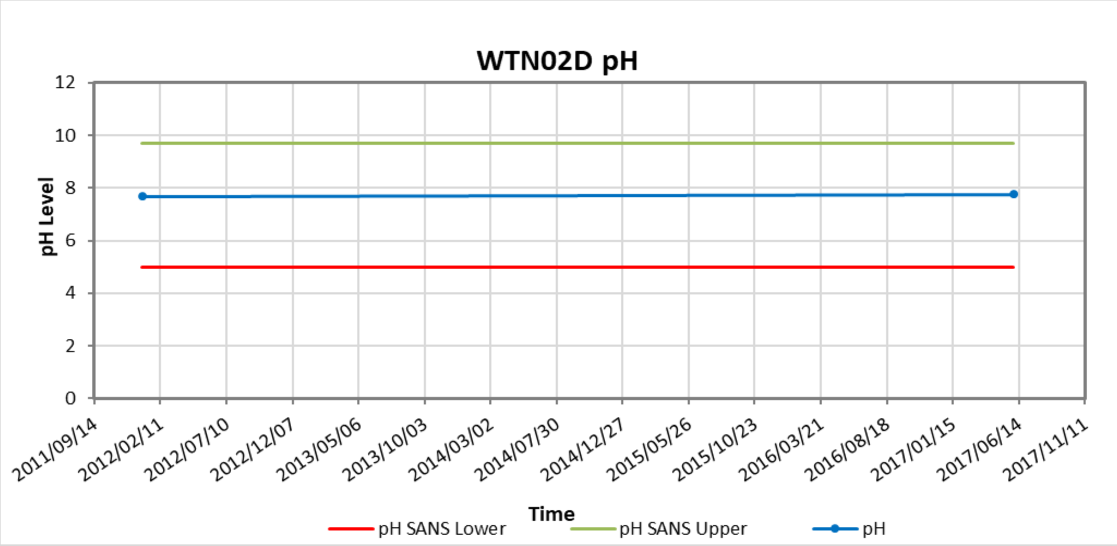
WOLMB15S

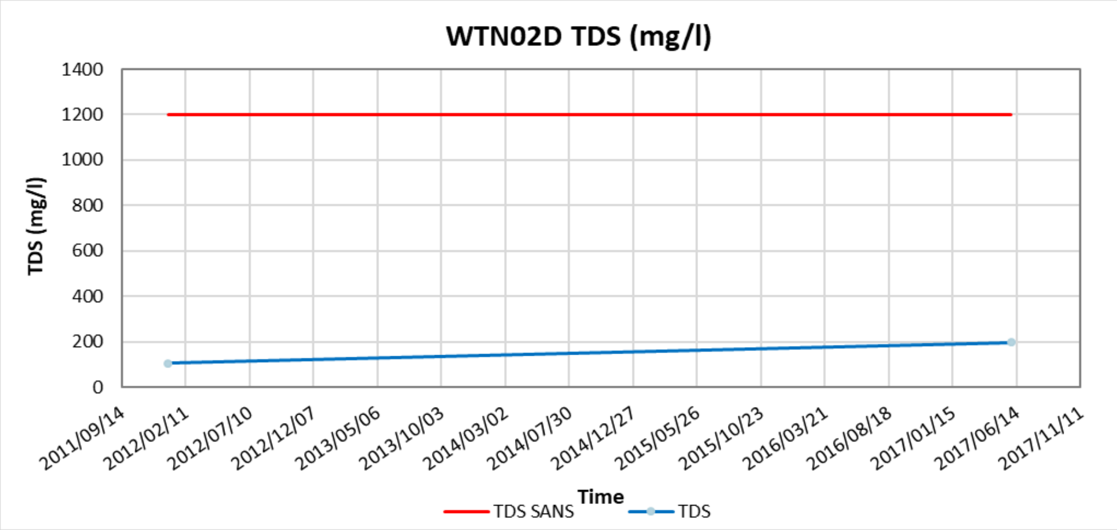

WOLMB15S pH
pH Level
12
10
8
6
4
2
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
pH SANS Lower
pH SANS Upper
pH

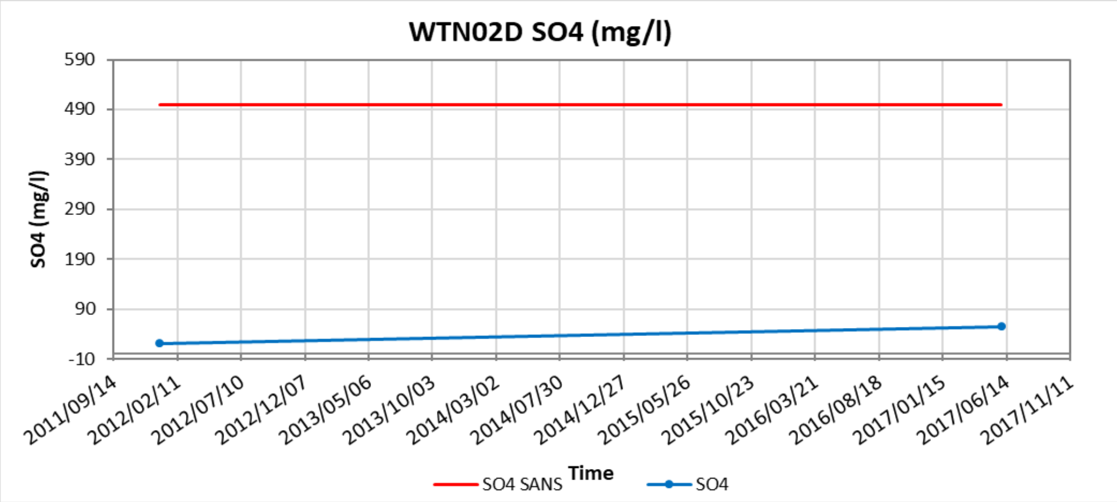

WOLMB15S TDS (mg/l)
TDS (mg/l)
2500
2000
1500
1000
500
0
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
TDS SANS
TDS

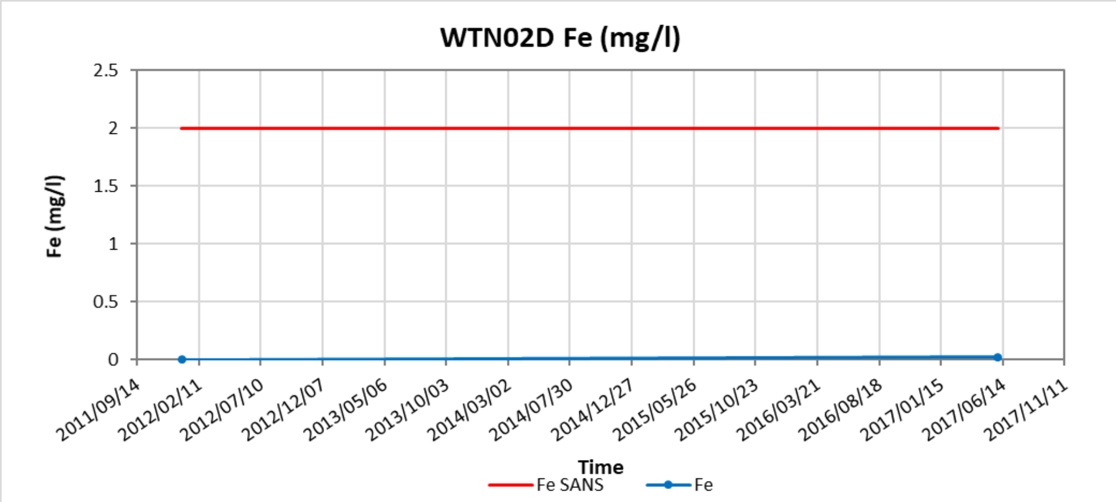

WOLMB15S SO4 (mg/l)
SO4 (mg/l)
1790
1590
1390
1190
990
790
590
390
190
-10
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
SO4 SANS
SO4

WTN02D

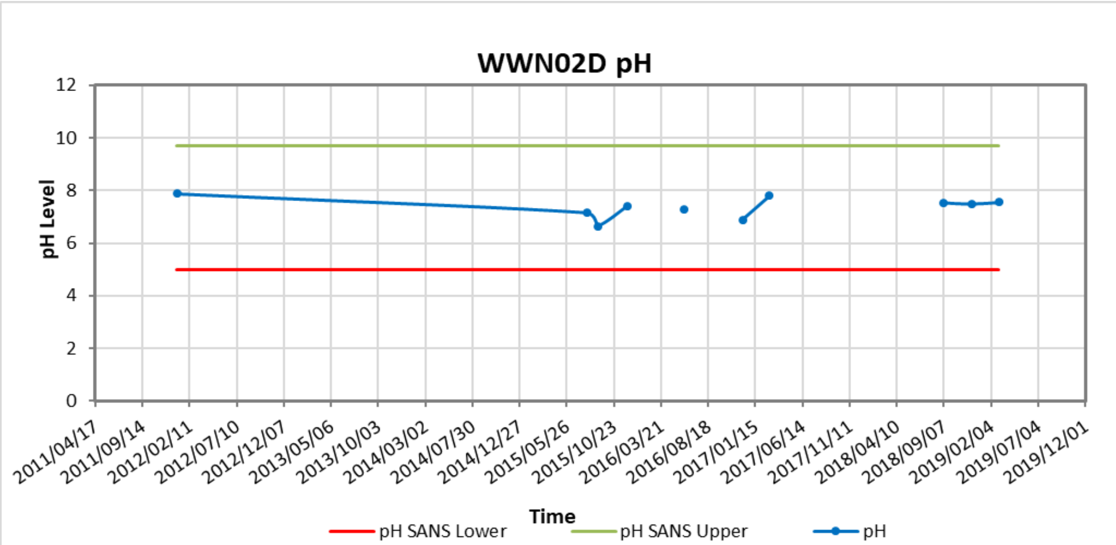

WTN02D pH
pH Level
0
2
4
6
8
10
12
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
Time
pH SANS Lower
pH SANS Upper
pH

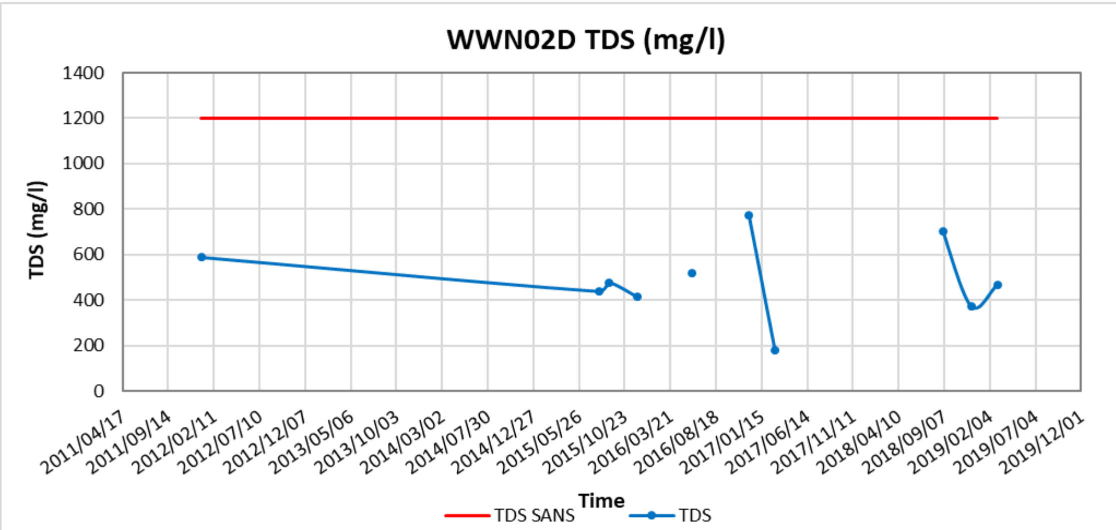

WTN02D TDS (mg/l)
TDS (mg/l)
0
200
400
600
800
1000
1200
1400
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
Time
TDS SANS
TDS

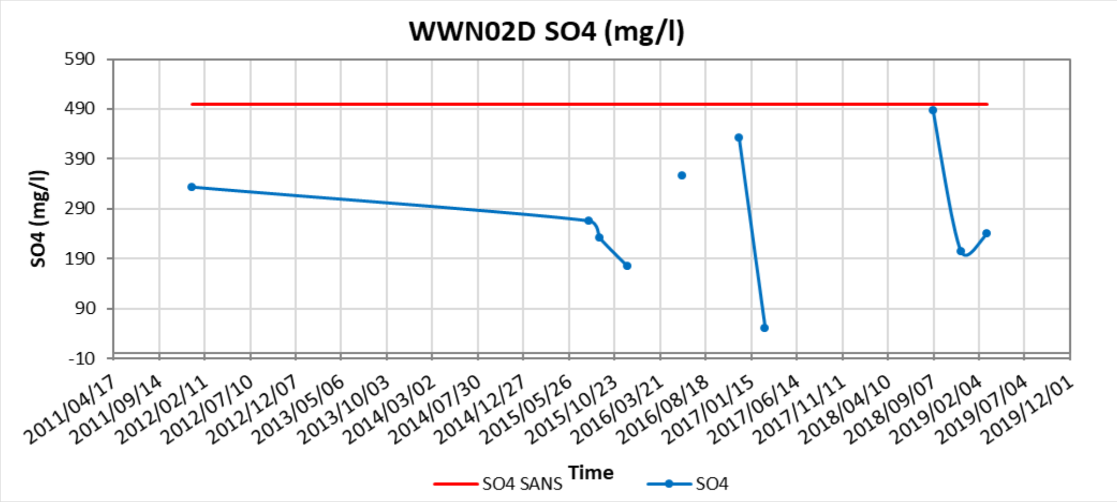

WTN02D SO4 (mg/l)
SO4 (mg/l)
-10
90
190
290
390
490
590
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
Time
SO4 SANS
SO4


WTN02D Fe (mg/l)
Fe (mg/l)
2.5
2
1.5
1
0.5
0
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
Time
Fe SANS
Fe

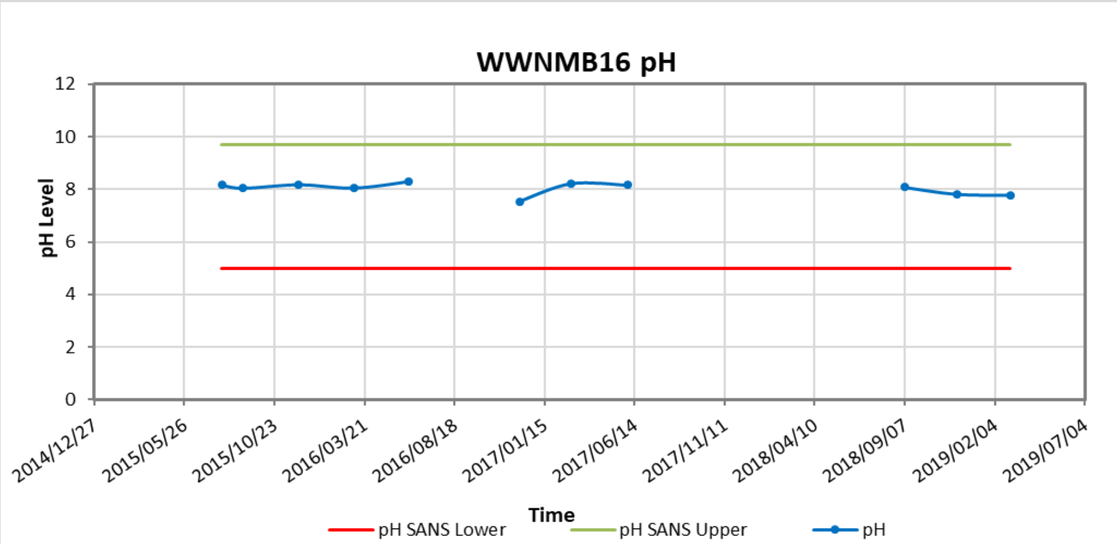
WWN02D

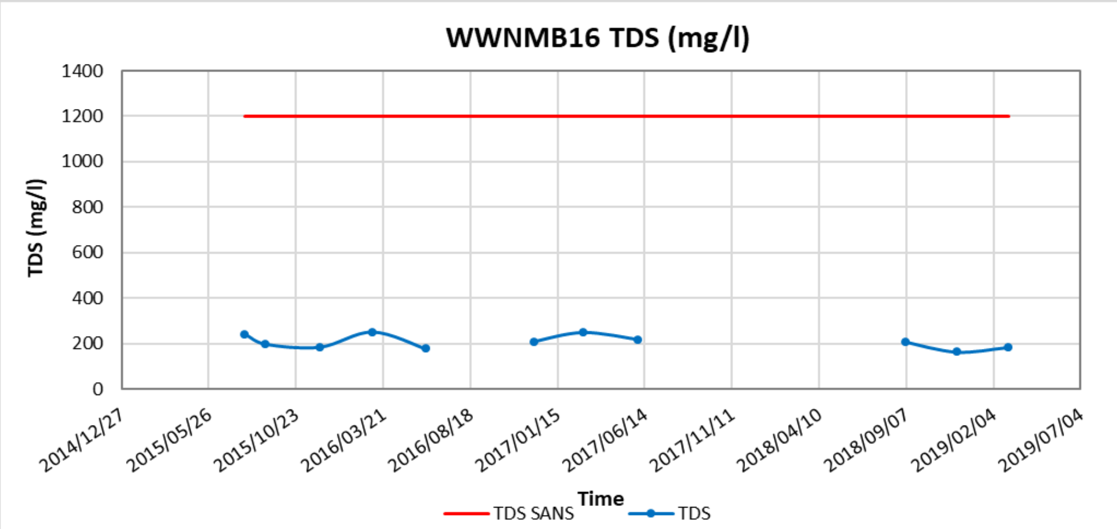

WWN02D pH
pH Level
12
10
8
6
4
2
0
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
pH SANS Lower
pH SANS Upper
pH

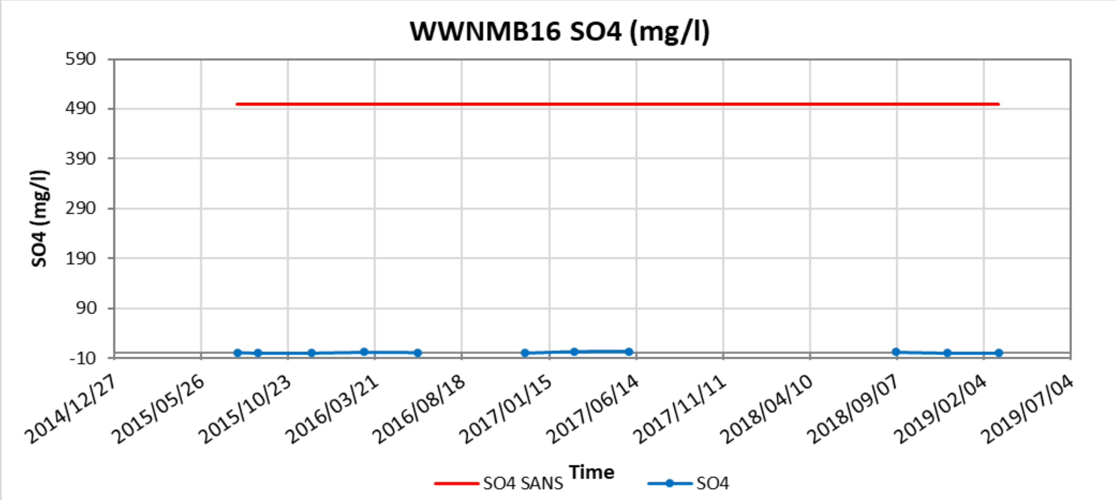

WWN02D TDS (mg/l)
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
TDS SANS
TDS

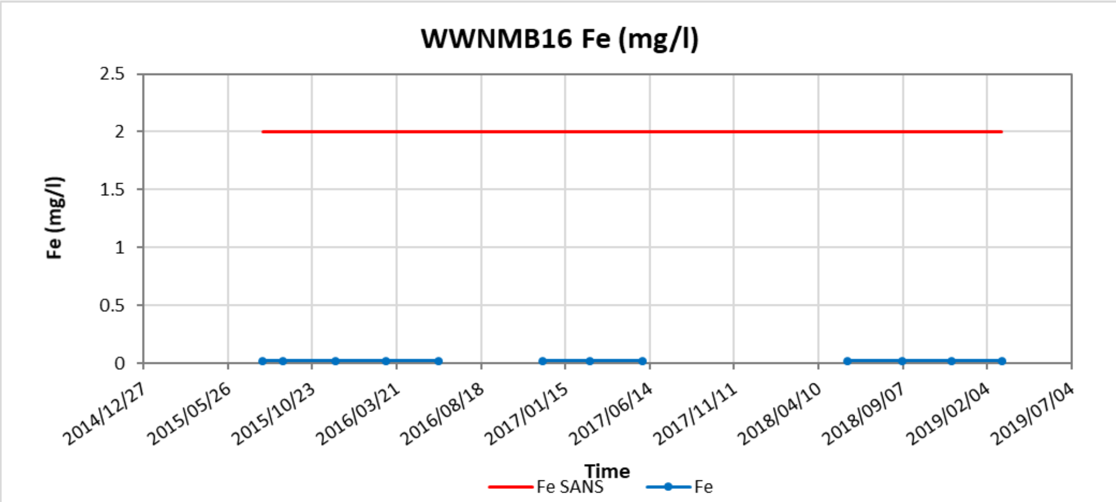

WWN02D SO4 (mg/l)
SO4 (mg/l)
590
490
390
290
190
90
-10
2011/04/17
2011/09/14
2012/02/11
2012/07/10
2012/12/07
2013/05/06
2013/10/03
2014/03/02
2014/07/30
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
2019/12/01
Time
SO4 SANS
SO4

WWNMB16


WWNMB16 pH
pH Level
12
10
8
6
4
2
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
pH SANS Lower
pH SANS Upper
pH


WWNMB16 TDS (mg/l)
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
TDS SANS
TDS


WWNMB16 SO4 (mg/l)
SO4 (mg/l)
590
490
390
290
190
90
-10
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
SO4 SANS
SO4


WWNMB16 Fe (mg/l)
Fe (mg/l)
2.5
2
1.5
1
0.5
0
2014/12/27
2015/05/26
2015/10/23
2016/03/21
2016/08/18
2017/01/15
2017/06/14
2017/11/11
2018/04/10
2018/09/07
2019/02/04
2019/07/04
Time
Fe SANS
Fe