Continuous ash disposal facility at Kendal Power Station

Groundwater numerical model for Source Pathway Receptor study

January 2018

Eskom Holdings SOC Ltd

Report prepared for

Zitholele Consulting

PO Box 6002 Halfway House 1685, SA

Building 1, Maxwell Office Park, Magwa Crescent West c/o Allandale Road & Maxwell Drive, Waterfall City, Midrand

Tel + (27) 11 207 2060 Fax + (27) 86 674 6121.

mail@zitholele.co.za ; www.zitholele.co.za

Report prepared by:

Geo hydraulic and Engineering Services (Pty) Ltd

Inyati Lodge Jim Fouche Road Cnr Road 1, Johannesburg

C:+27 71 022 7981

info@ghes.co.za

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	Zitholele Consulting	Geo Hydraulic and Engineering Services
Contact Persons	Shandre Laven Mathys Vooslo	DP AHOKPOSSI
Project Number		GHES_17_04
Report Number		GHES_17_04_02Final
Review by	Shandre Laven Mathys Vooslo	
Autorized by		DP AHOKPOSSI

Executive Summary

Under appointment by Zitholele Consulting on behalf of "Eskom Holdings SOC Ltd", Geo Hydraulic and Engineering Services (PTY) Ltd (GHES), completed a numerical groundwater investigation as part of the Source Pathway Receptor study for the continuous ash disposal facility of the Kendal power station. The following conclusions are reached:

- Due to the probable leaking of lining (barrier) system, the continuous ash disposal facility with its associated dirty water management infrastructures, constitute the potential sources of contaminants which are specifically associated with the project. The potential contaminants of concern include Mn, SO_4, Fe, and F;
- Based on 03 different lining scenarios (Class C, Intermediate Class C, and Class D), the leakage rates were calculated by Engineering team of Zitholele consulting and provided to GHES;
- Local groundwater is one of the potential pathways for the migration of contaminants to receptors (e.g. borehole water users, and receiving surface water). Potential contamination from ground surface will mostly impact on the shallow weathered and fractured aquifer system;
- The thickness of the local shallow aquifer was estimated to be between 5 and 25 m, and consists mainly of clay, granites and dolerites of the Karoo Supergroup;
- The thickness and the geometry of local sill and lineaments in the area are expected to control the groundwater flow and possible pollution emanating from ground surface;
- One privately owned borehole (Kendal2/ FBB56) is located within less than 1 km to the north of the continuous ash disposal facility's site, risks to be impacted by potential contaminants from the project. The background water quality at the borehole represents unpolluted groundwater.
- The wetland study conducted by Wetland Consulting Services for the continuous ash disposal facility suggests that surface runoff inflow and interflow inflow are likely to be the main hydrological drivers supporting the overall wetness within a wetland, and that minor dependence of the local wetland on shallow saturated groundwater flow may be expected.

- The increases in the concentrations of sulphate in the local aquifer were simulated for each alternative simulated over 40 years after closure using a finite element numerical model:
    - Intermediate Class C is the preferable alternative, since the induced increase of sulphate's concentration after 40 years of simulation at FBB56, is less than 0.01 mg/l, compared to an increase of 0.02 mg/l and 22 mg/l respectively for "Class C" and "Class D".
    - The predicted increase of concentration of contaminant in the aquifer at the continuous ash disposal facility area is lesser for "Intermediate Class C", than for "Class C" and "Class D";

The following recommendations are to be considered:

- Intensify monitoring of water levels and quality along surface drainage to better characterise the local interactions between surface and ground waters;
- Collect monitoring and topographic data from surrounding mine (East of the facility), and also acquire abstractions data from the receptive borehole owner (FBB56), to update the current numerical model;
- Conduct additional sampling and testing to confirm the tests results presented in existing geochemical test data sheet;
- Conduct field Kinetic tests on site to model and predict leachate water quality;
- Develop a geochemical model to predict leachate water quality, using suitable software such PREEQC or equivalent.

Contents

List of figures

List of table

1 Introduction

Geo Hydraulic and Engineering Services (PTY) Ltd (GHES), was appointed by Zitholele Consulting on behalf of "Eskom Holdings SOC Ltd" to conduct numerical groundwater investigation as part of the Source Pathway Receptor (SPR) study for the Kendal Power Station continuous ash disposal facility.

1.1 Background

Kendal Power Station is a coal-fired power station situated south west of the town of Ogies. The power station became operational in 1993, and has an indirect dry-cooling and closed system that uses a cooling tower and water. Cooling water flowing through these elements cools down as the cold air passes over them and returns to the condenser. Kendal has six (6) 686 megawatt (MW) units that generate 4 116 MW and represents with the Kusile Power Station, the largest coal-fired power stations in the world.

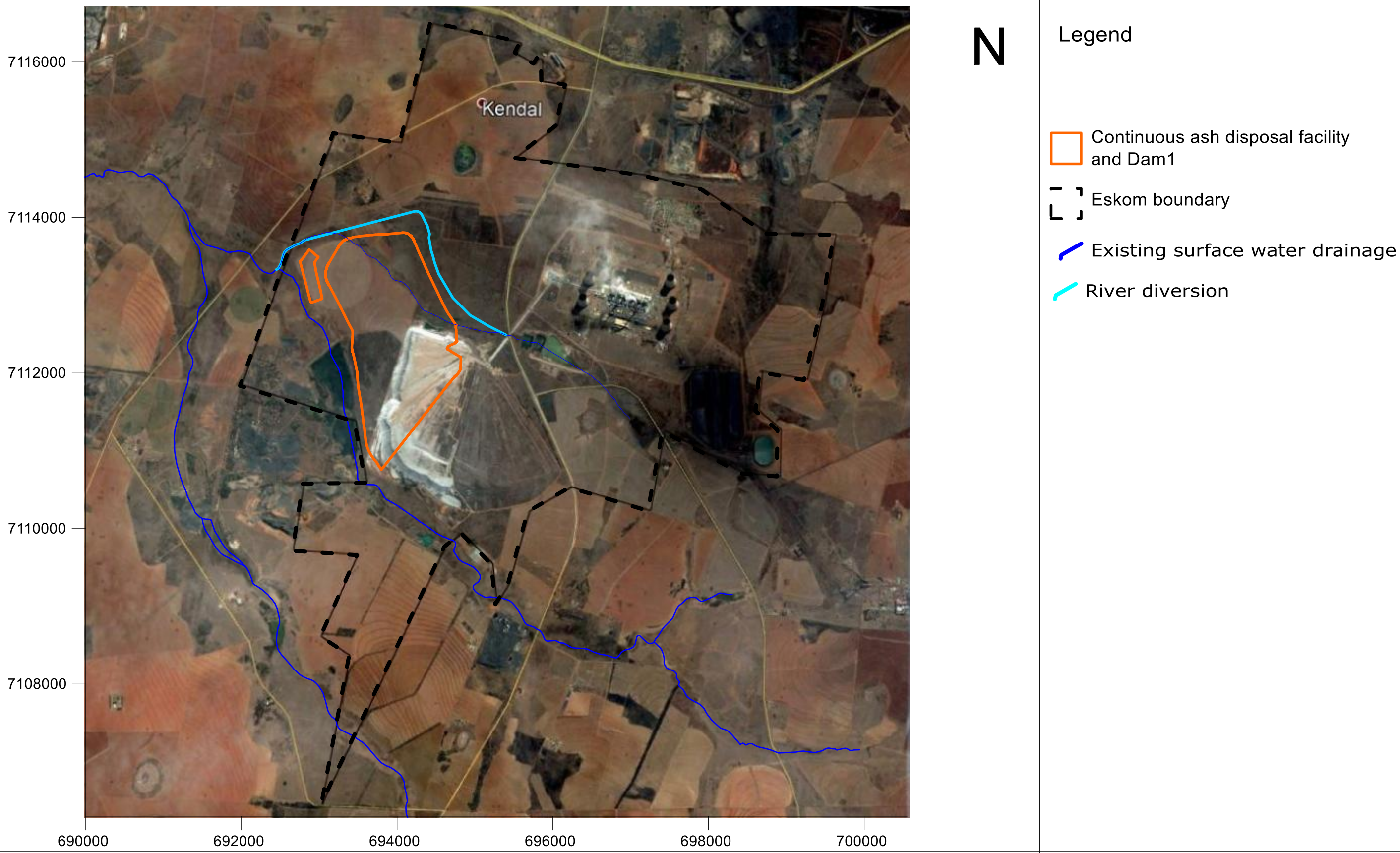
The Kendal Power Station required a new facility with a footprint (Figure 1) that was calculated to be approximately 310 hectares and have a height of 60m, to accommodate an ash volume of 103 Million m^3.

1.2 Objectives

The ultimate objective of the present numerical model is to develop a conceptual and a numerical geohydrological model for the simulations of impact scenarios with focus on:

- Potential sources of contaminants which are specifically associated with the proposed continuous ash disposal facility;
- The route that controls the release and the migration of the contaminant to and through the groundwater resource; and
- The potential human/person or organism (animals and plants) that may be adversely affected by exposure to the contaminants in the groundwater.

Location of the project area



Co-ordinates System: UTM (HART94)
Date(s):09-2017
Drawn by : DP AHOKPOSSI

Project Title: Continuous ash disposal facility at Kendal power station Groundwater numerical model for Source Pathway Receptor study

Project Number: GHES_17_04

Client: Eskom Holdings (Pty.)

Figure 1: Location of the Kendal Power Station and continuous ash disposal area

1.3 Scope of work

Considering the available relevant information/data, the investigation budget and time constraint, field activity was limited to site visit and reconnaissance. The scope of work includes:

- Collect, review, and analysis of all existing relevant information and data;
- Site visit;
- Source-Pathway-Receptor analysis:
  - Identification of groundwater pollution source;
  - Identification of possible pathways of polluted groundwater to potential receptors;
  - Identification of sensitive receptors;
- Development of conceptual geohydrological model;
- Numerical geohydrological model and impact scenarios simulations:
  - Class C liner
  - Intermediate – Unclassified
  - Class D Liner

2 Desktop Study

A desktop study was conducted to establish the base line geohydrological (general occurrence and quality of groundwater) conditions, and assess the level of site characterisation. Relevant available information were collected and reviewed, to describe the site, plan site visiting, analyse source-pathway-receptor, and conceptualize the hydrogeological model.

2.1 Climate

The climate of the study area is typical of the South African Highveld climatic zone with summer rainfall and cold winters. Recent rainfall data (1/06/2001 to 10/05/2013) collected at the Middelburg EDE farms (0516/232LO) suggest a mean annual precipitation of 735 mm per annum (**Figure 3**). This confirms the long term precipitation recorded at the station of Ogies (number 0478093_W), 8km west of KPS, which suggests mean annual rainfall of 736 mm (50 years). The area receives the lowest average monthly rainfall in July (2.69mm) and highest average monthly rainfall in January (160mm) **(Figure 3**). The average minimum and maximum monthly temperatures are shown in **Figure 2**. Temperature extremes range from 28.37°C in summer to -1.89°C in winter.

2.2 Topography and drainage

The Kendal Power Station is located on the water divided of 03 quaternary catchments (B20F, B20E and B11F). Those quaternary catchments form part of the Limpopo–Olifants primary drainage region. The main characteristics of these catchments are given in

Table 1.

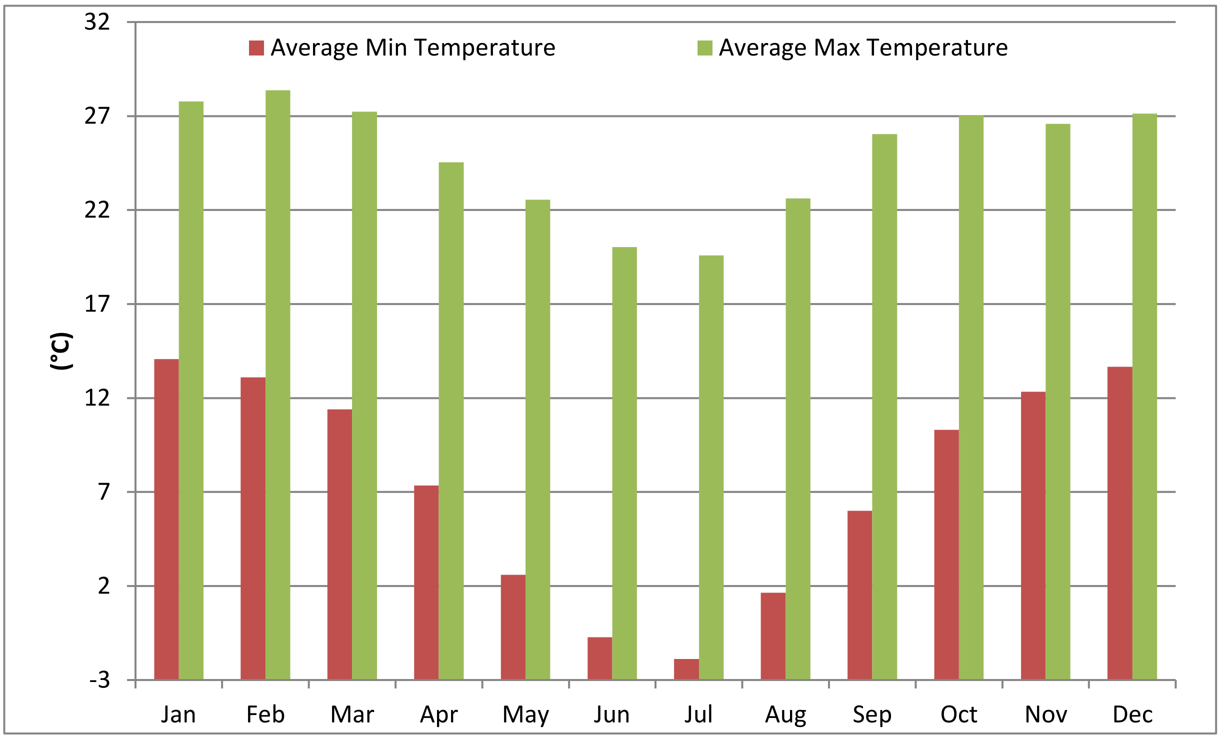


Figure 2: Daily Average temperatures

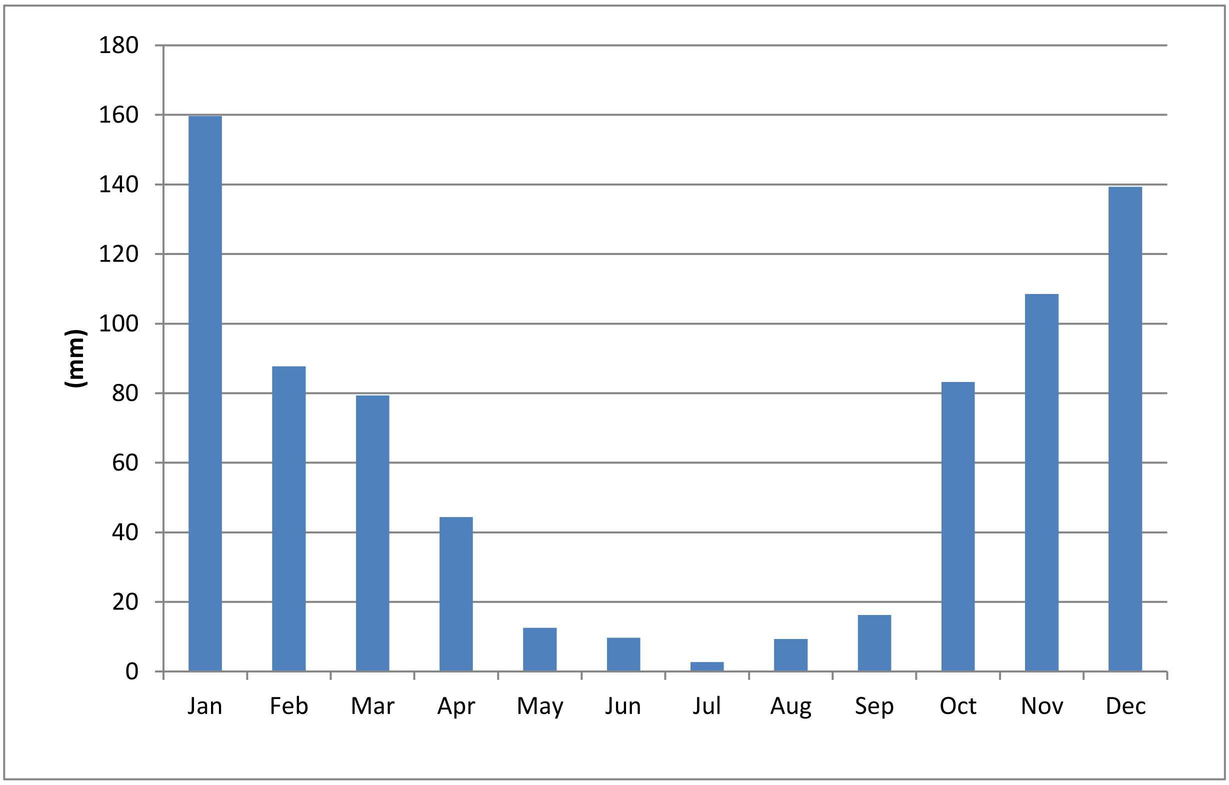


Figure 3: Average monthly rainfall

Table 1: Characteristics of catchments

Catchment	Area	Mean Annual runoff	Mean annual rainfall
	(Km^2)	(mm/a)	(mm/a)
B20F	506.07	33.3	666.79
B20E	622.18	33.9	657.25
B11F	430.13	34.3	691.60

The continuous ash disposal facility is located on quaternary catchment B20E which is mainly drained by the perennial river "Wilge". In the catchment, the Wilge river flows from North (1696 mamsl) to South (1501 mamsl) on approximately 41 km (**Figure 4 and Figure 5**). The topography drops gently SE-NW and SW-NE toward the Wilge River. The site of the continuous ash disposal facility is drained by 02 tributaries westward into the Wilge River. The Leeufontein Spruit, and an unnamed tributary drain from the south of the facility. Schoongezight Spruit, a non-perennial stream drains the north eastern site of the ash disposal facility into the Leeuwfontein Spruit. Schoongezight Spruit will be diverted upstream during the construction of the continuous" ash disposal facility.

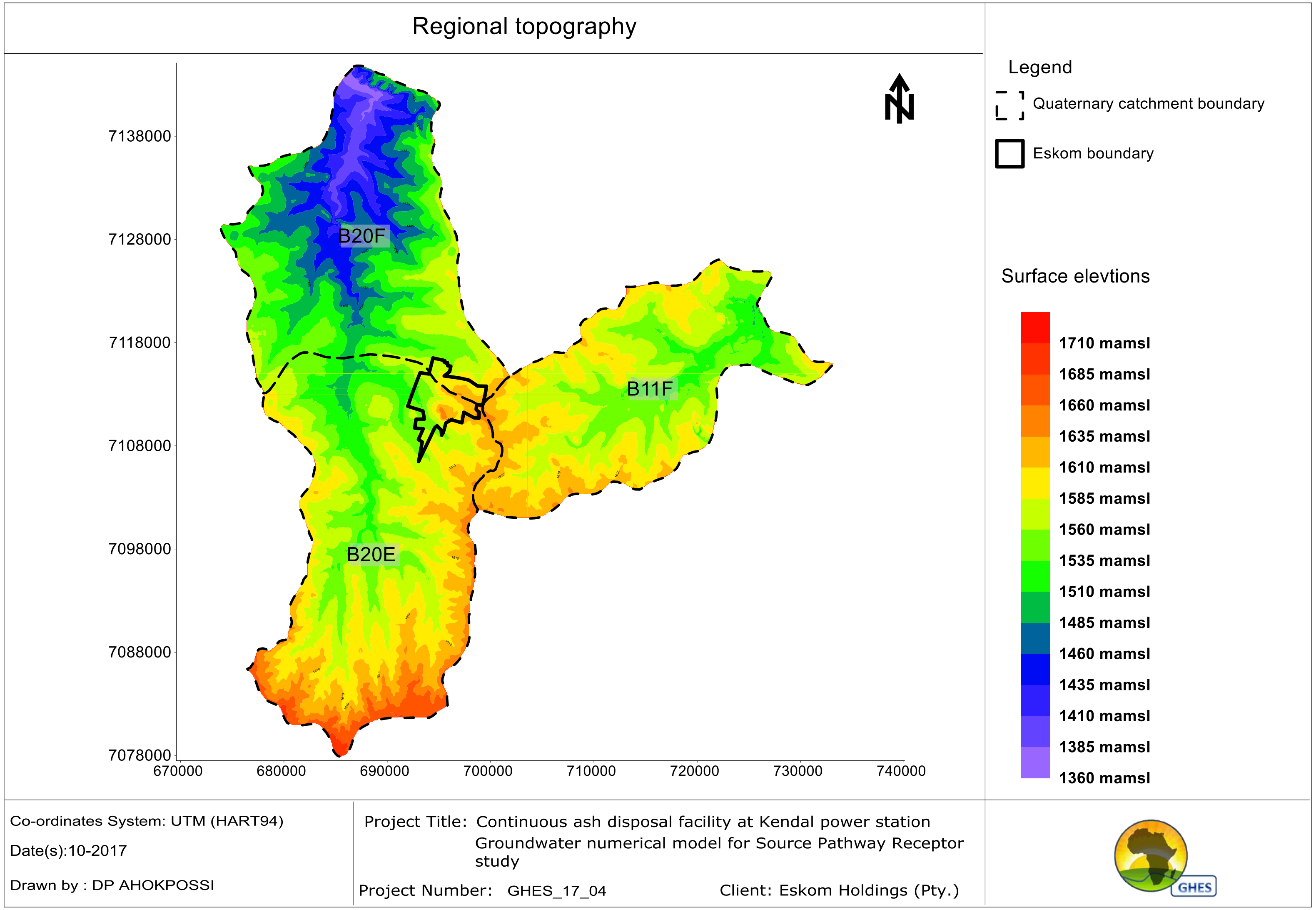


Figure 4: Catchment B20E topography

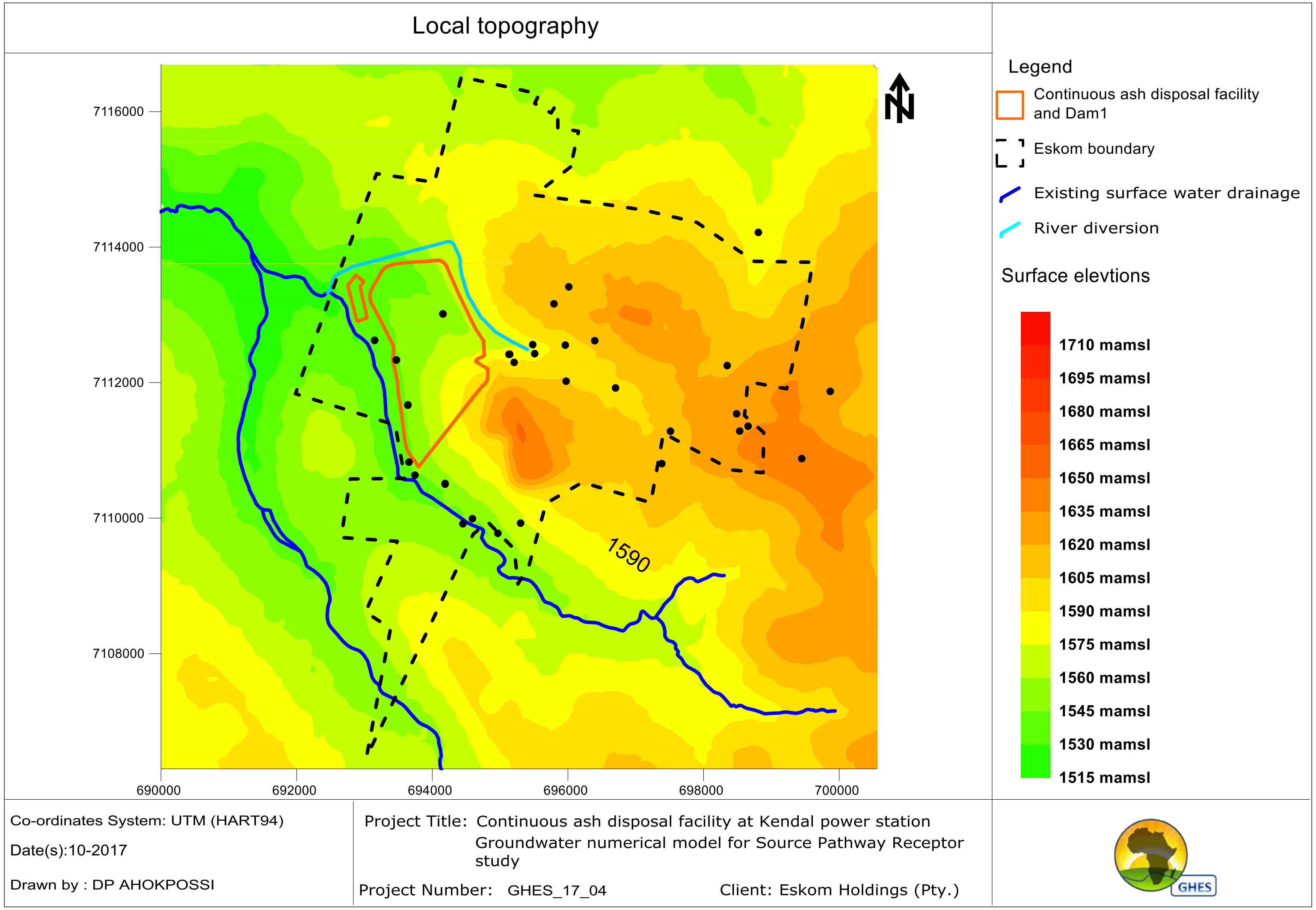


Figure 5: Local topography

2.3 General geology and geohydrology

The description of general geology (**Figure 6 and Figure 7**) and geohydrology are based on the analysis of the:

- "1/250 000 Geological Series: 2628 East Rand" published in 1986 by the Government Printer; and
- "Exploration of the 1:500 000 general hydrogeology map done by Barnard (2000).

2.3.1 General geology

The prevailing formations in the region are:

- Ecca, Dwyka (found at the base in the pre-Karoo topography), and Vryheid of the Karoo Sequence;
- Rayton, Magaliesberg, Sylverton, Daspoort, and Strubenkop of the Pretoria Group; and
- Loskop of the Rooiberg Group.

The soil consists of a silty to clayey sand. A typical stratigraphic section at Kendal Power Station is illustrated in Figure 6. The local lithology of the continuous ash disposal facility consists of:

- Sandstone, Shale, Mudstone, Coal Bed of the Vryheid Formation (Ecca Group in the Karoo Sequence);
- Diabase of Loskop Formation (Rooiberg Group of Transvaal Sequence);
- Porphyritic rhyolite with interbedded mudstone and sandstone of the Selons Rivier Formation (Rooiberg Group of Transvaal Sequence);
- Diabase; and
- Granite suite.

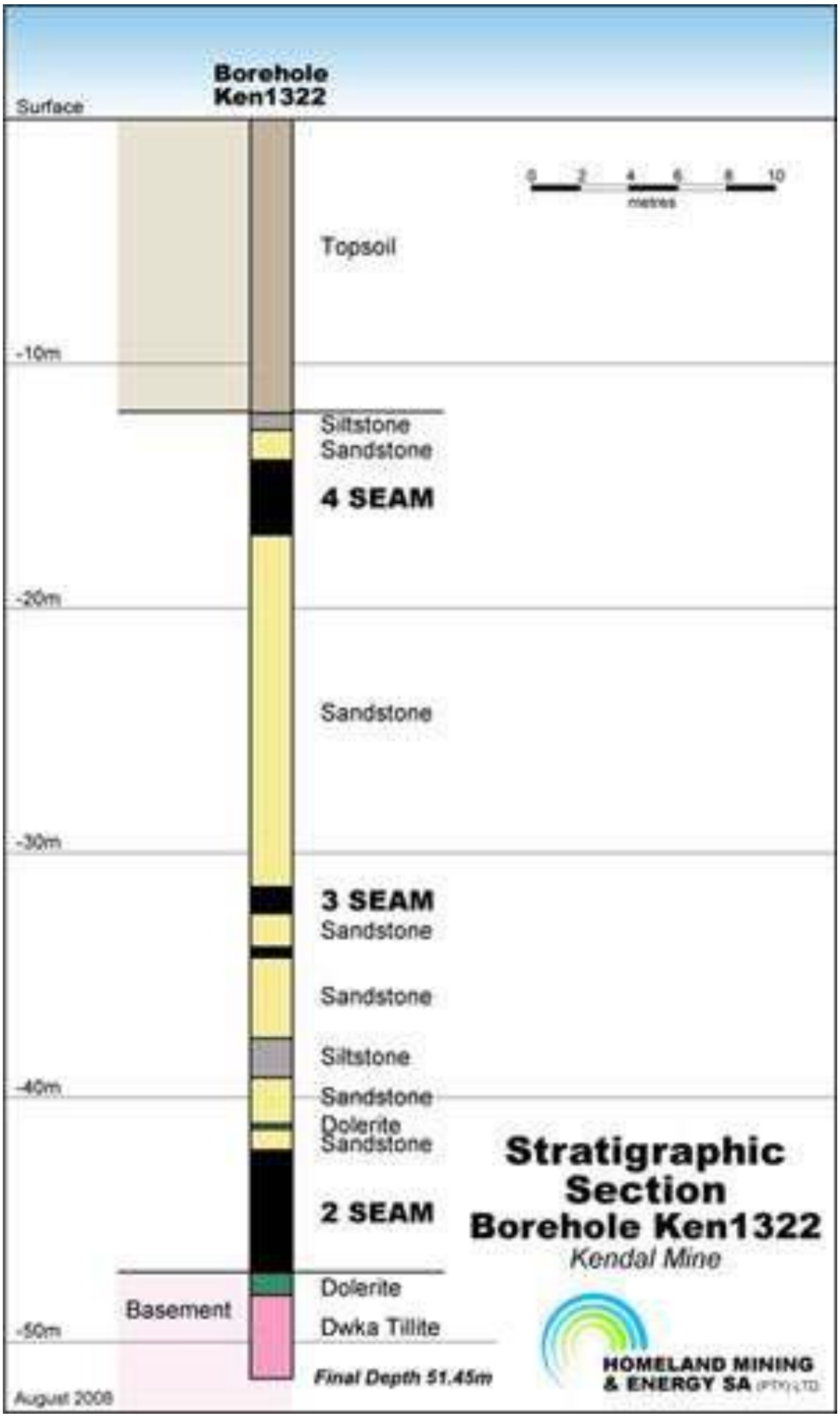
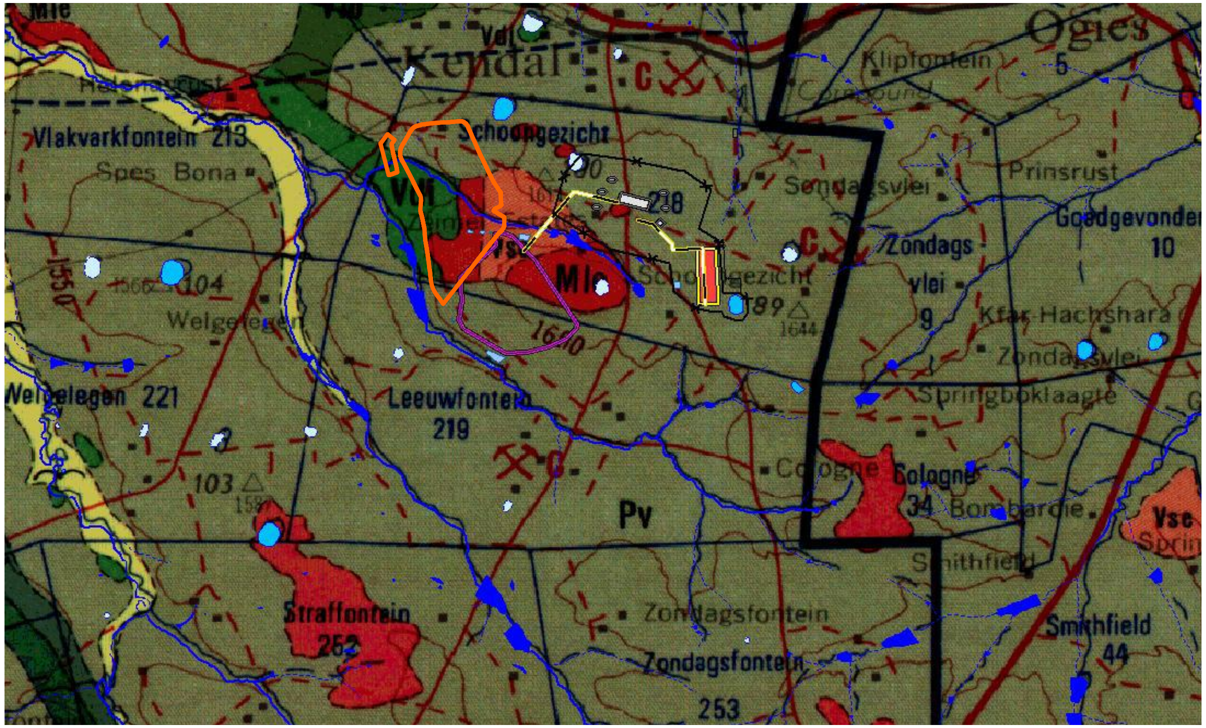


Figure 6: Typical stratigraphic section at KPS (Homeland Mining & Energy SA)

General geology



Legend

- Continuous ash disposal facility and Dam1

Mle :	Granite suite
Jd :	Dolorite
Pv :	Vryheid Formation Sandstone, Mudstone, Shale, and Coal
Vse :	Selons River Formation Porphyritic Rhyolite, Mudstone, and Sandstone
Vle :	Loskop Formation Agglomerate, Lava
Vdi :	Loskop Formation Diabase

Co-ordinates System: UTM (HART94)

Date(s):10-2017

Drawn by : DP AHOKPOSSI

Project Title: Continuous ash disposal facility at Kendal power station Groundwater numerical model for Source Pathway Receptor study

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Figure 7: General geology of the study area

2.3.2 General Geohydrology

Two main water-bearing rock type formations control the storage, flow (movement), recharge, and withdrawal of groundwater: Fractured aquifer system (Class B), and inter-granular and fractured aquifer (Class D). The predominant formations of the site of the project are Vryheid; Loskop; and Selons Rivier. The site is generally associated with one or combined forms of the following:

- Fractures associated with the intrusion of acidic lava, contact zones between different sediments;
- Weathered and/or fractured sedimentary rocks not associated with dolerite intrusion,
- Indurated and jointed sedimentary rocks alongside dykes,
- Narrow weathered and fractured dolerite dykes,
- Weathered dolerite sills and jointed sedimentary rocks,
- Weathered and fractured upper contact-zones of dolerite sills,
- Weathered and fractured lower contacts-zones and coal seams.

Key aquifer characteristics that are associated with such aquifers are summarized in **Table 2**. In Vryheid formation, the recharge is estimated by Vegter et al (1995) at 4 to 5% of the mean annual rainfall.

Table 2: Geological sequence with selected aquifer characteristics

Formation/Group	**Maximum borehole yield**	**Range of water level**
	l/s	(m) bgl
Loskop	6.40	10 and 30
Vryheid	12.60	5 – 25
Ecca	9.20	--

2.4 Collect and review of existing documents and information

Information that was collected and reviewed included existing surface water, geological, hydrogeological, and geochemical, geotechnical, and wetland study reports compiled from the previous investigations, and data collected as part of the monitoring programme at the power station. The list of the documents which were received from Zitholele Consulting and reviewed is given in **Table 3**. In addition to these documents valid water use licences, memos, and shape files were also received and reviewed.

Table 3: List of received documents

Report	Document title / Date	Reference or Report number
7.4 Hydrocensus	Hydrocensus report/ February 2016	RVN716.13/1641 by GHT consulting scientists
7.4 Aquifer Vulnerability Report and Risk	Aquifer classification for vulnerability and risk/ April 2012	RVN601.12/13111641 by GHT consulting scientists
12810-IA Report-003-GroundWater-rev3 Nov 2013	Groundwater baseline study at Kendal power station -Continuous ash disposal facility report/November 2013	12614149-12075-1 by Golder Associates
12614149-120751_GW_Baseline_Kendal_May_2014_rev_gvdl	Groundwater baseline study at Kendal Power Station - Continuous ash disposal Facility/May 2014	12614149-12075-1 by Golder Associates
13614982-119711_Kendal_Terrestrial_Final_June2013	Terrestrial ecosystems assessment of proposed Continuous and emergency ash dumps at Kendal Power Station	13614982-11971-1 by Golder Associates

7.2 Geophysical Report	Drilling of eight monitoring boreholes at the ash stack/ May 2015	RVN716.6/15811641 by GHT consulting scientists
12614145-12017 2_Kendal Ash Dump_Report_Rev1	Geotechnical Investigation for Proposed Extensions to the Present Ash Dump Facilities / April 2013	12614145-12017-2 (Rev1) by Golder Associates
Ash bentonite test_2014	Kendal power station Ash disposal facility extension Ash-bentonite test/ January 2014	Report No.: JW002/14/E353 – Rev 1 By Jones & Wagener
15067-45-rep-004-ddr-rev0 draft 2 - ak	Detailed Design Report for Eskom Kendal Power Station: Continuous Ash Disposal Facility/ July 2017	379-KEN-BDDD-D00185-3 by Zitholele Consulting
Ash dump manual KENDOP4 - Figs r1x	Dry ash disposal facility/ April 1999	KENDOP4.DOC of Generation Eng. Dept.
Water Monitoring reports	Phases: 54, 55, 56, 57, 59, 60, 61, 64, 66, 72, 74, 78, and 79	By GHT consulting
Kendal-A-2016 v2	Aquatic biomonitoring Kendal power station Mpumalanga Wet season survey /March 2016	Kendal/A/2016 by Biotox & Clean Stream Biological Services
Kendal-B-2016_V2	Aquatic biomonitoring kendal power station mpumalanga dry season survey / September 2016	Kendal/B/2016 by Biotox & Clean Stream Biological Services
7.5 Numerical Model Report 2015	Groundwater numerical model update / July 2015	RVN 716.8/1588 by GHT consulting scientists
7.5 Numerical Model Report	Groundwater numerical model update / December 2016	RVN 716.21/1714 by GHT consulting

		scientists
13615231_12149_2_Eskom_KendalContinuous_Final June 2014	Kendal Continuous Ash Disposal - Surface Water Assessment / June 2014	13615231-12149-2 by Golder Associates
13615231-12423-5_Appendix B	Impact Assessment of Kendal Power Station Ash Dam on surface water resources / June 2014	13615231-12423 -5 by Golder Associates
Kendal continuous ADF wetland assessment report Final	Wetland Delineation & Impact Assessment for the Kendal Power Station Continuous Ash Disposal Facility, Mpumalanga Province / June 2014	Reference: 978/2013 by Wetland Consulting Services
1658499_Processed _B1_05092016	Static ABA test results (Excel sheet)	--

2.4.1 Previous hydrocensus

Golder Associated (Report Number: 12614149-12075-1) conducted a hydrocensus during February 2013 and identified privately owned boreholes (Kendal1/FBB39, and Kendal2/ FBB56) in the north and within less than 1 km to the continuous ash disposal facility's site. The 2 boreholes were equipped with submersible pumps and were used for domestics. With the exception of elevated concentrations of Nitrate (NO_3) and Manganese (Mn), and the lower pH (<6) at sampled site Kendal1, the groundwater quality at these two sampling points are generally of good quality when compared to South African national standard (SANS_241_2011) and South African Water Quality Guidelines (SAWQG), Volume1_Domestic Use. Fertilizer which is used for cropping was suggested as probable source for elevated concentrations of NO_3 and Mn on the groundwater quality at sampled site Kendal1 (FBB39). Kendal2 was found to represent unpolluted groundwater.

Another hydrocensus was conducted by GHT consulting scientists (Report Number: RVN 716.13/1641) in February 2016, and confirmed that these 2 boreholes are the closest privately owned boreholes to the continuous ash disposal facility's site. The quality and the uses of these boreholes were confirmed to be the same as in 2013. The Mn concentration in the water from FBB39 improved from 0.099 mg/l in 2013 to 0.001 mg/l in 2016, but the NO_3 remained at 17.40, which is above South African National Standard (SANS_241_2015 for drinking water).

In addition of these 2 boreholes, 36 groundwater sites (**Figure 10**) were identified in the area 19 of which are in catchment B20E. The uses of groundwater and surface water, as recorded during hydrocensus in the area, are illustrated in **Figure 8** below.

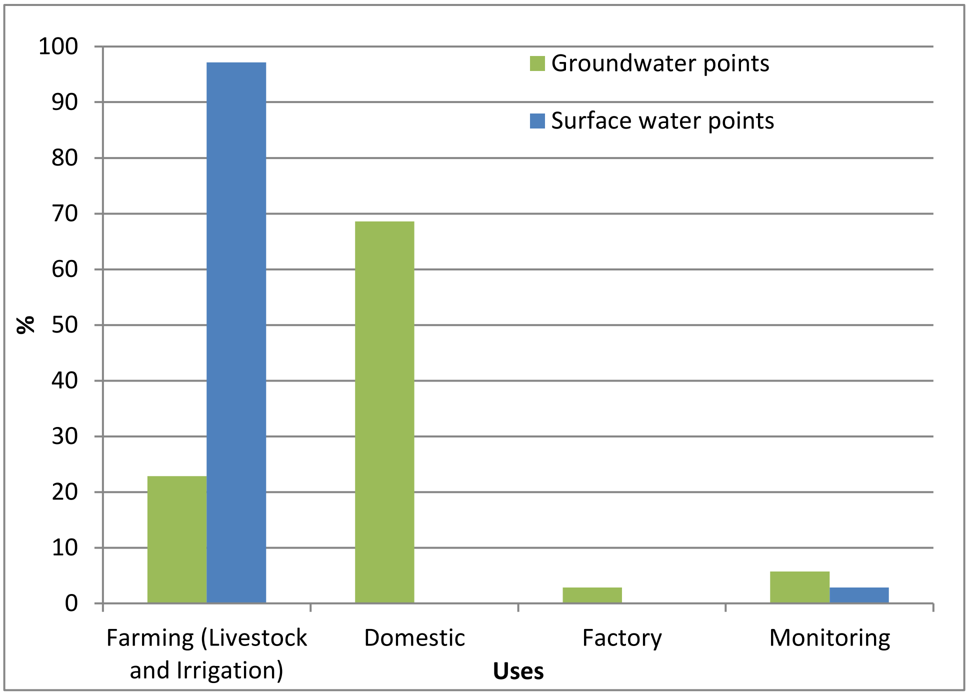


Figure 8: Groundwater uses in the study area

06 groundwater levels were measured during hydrocensus, and will be discussed with the water levels measured during monitoring in the study area.

The boreholes that were sampled during the hydrocensus in the catchment B20E were classified in Class 1 water quality and suitable for human consumption according to SANS_241_2011 except for high concentrations of NO_3 (FBB35, and FBB54), Na and SO_4 (FBB40), and F (FBB38) in 4 boreholes. They are all located more than 2.5 km south east of the ash disposal facility's site and the potential sources of these high concentrations of solutes in groundwater were not associated with any activity of the Kendal power station.

Out of the 13 surface water sites visited in the catchment B20E during the hydrocensus, only 2 (FBR13, R05) were found dry. All the surface water sites surrounding the ash disposal facility's site were found to have the required minimum level of water, and were sampled. Sampled sites FBP16 and FBR18, located upstream of Leeuwfontein Spruit from the ash stack (**Figure 9**), were classified as Class 1 water quality and were considered representative of the natural surface water quality. Leeuwfontein Spruit water quality did not comply with recommended standard (SANS_241_2011) (FBR15) due to high concentrations of F, Mn, and SO_4. The site is located upstream of Leeuwfontein Spruit from the ash stack but might have been affected by run-off water from the coal conveyor belt upstream. Sampled site R01 located upstream of Leeuwfontein Spruit ,but much closer to the ash disposal facility's site, showed very high concentrations of Ca (570 mg/l), Mg, SO_4 (2911 mg/l), and Mn (37.1 mg/l). The close proximity of coal mining to the sampling site was suspected to be the source of such negative change of the surface water at that point.

The Schoongezicht Spruit (FBR14), upstream of the ash facility's site is classified Class 1 water quality. Schoongezicht Spruit was being affected by Kendal power station, as it was shown by the poor water quality (increase in EC, Na, Ca, Mg, Cl and SO_4 concentrations) observed at sampled site R04 (see Figure 9).

At the sampled sites R02 and R06 on the Leeuwfontein Spruit the observed water quality was under recommended standard limits. The factors that influence the improvements of the water quality at these points despite them receiving water from respectively from R01 and R04, and FBR20 respectively have not been investigated. Site FBP18 on Leeuwfontein Spruit showed high fluoride concentration, which might be representative of the natural surface water quality or impact from only agricultural activities (see Figure 9).

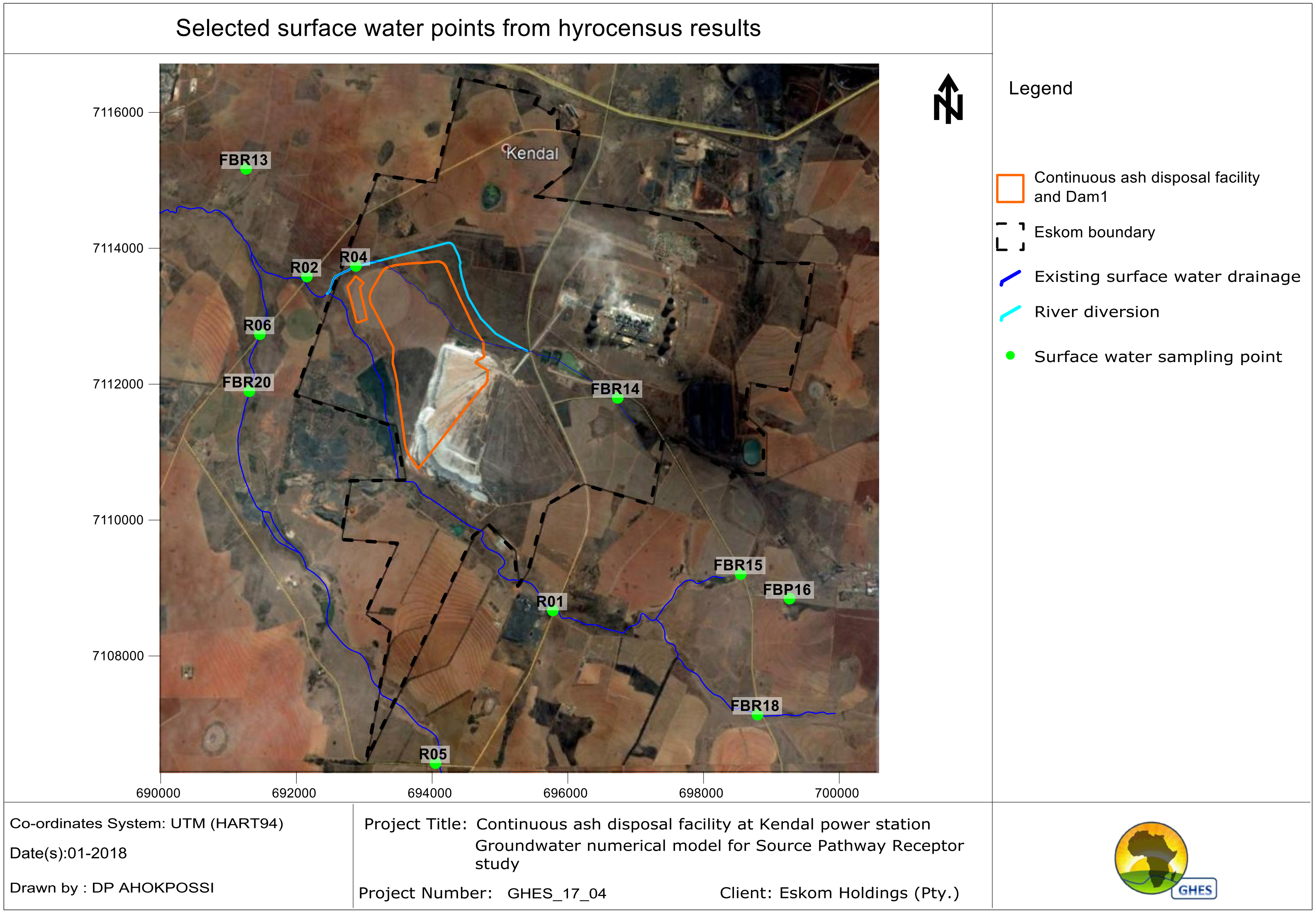


Figure 9: Selected surface water points from hydrocensus results

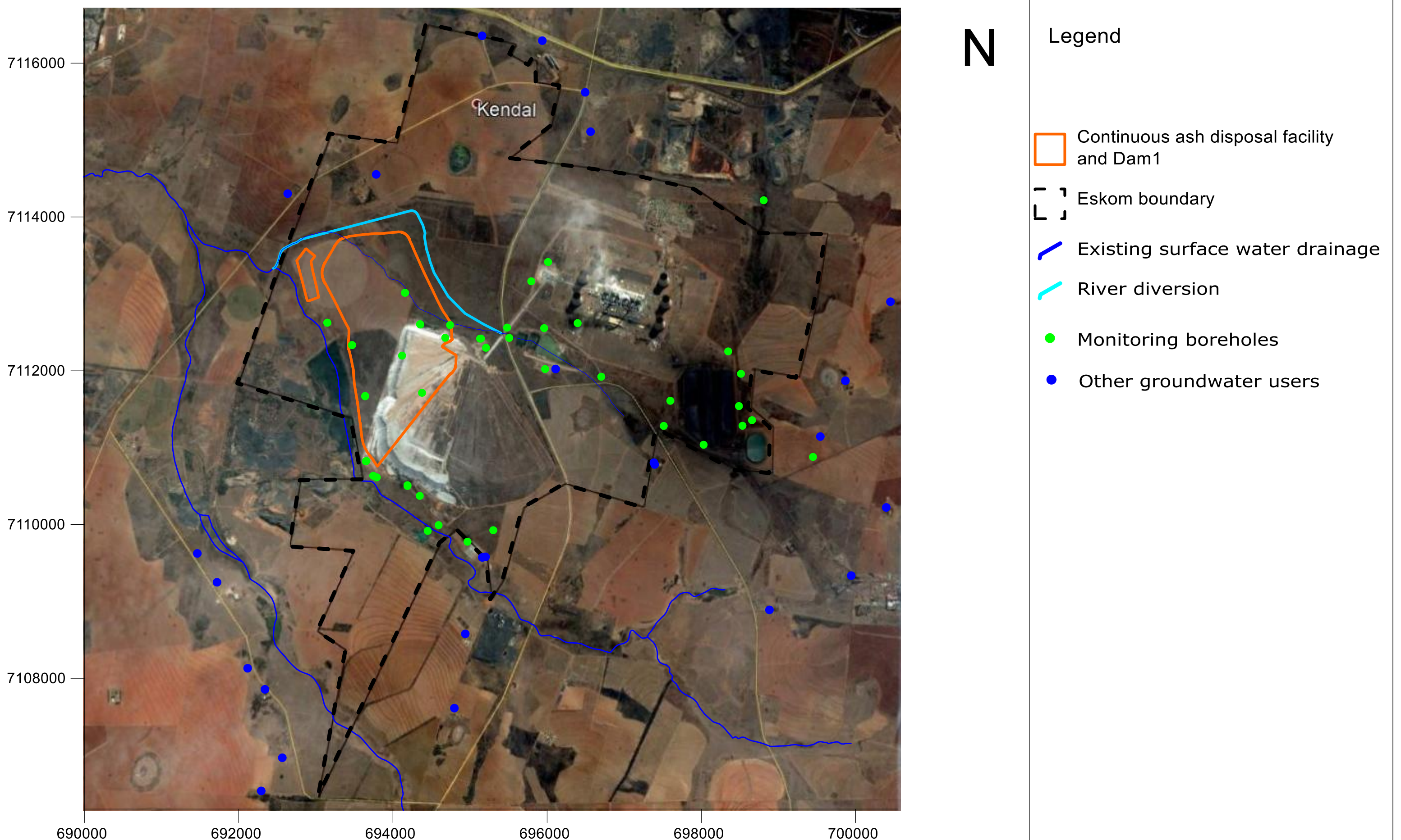
2.4.2 Groundwater monitoring data

Surface water and groundwater monitoring is conducted at KPS according the WUL requirements. Monitoring (quality, and quantity) data from 86 sites has been collected quarterly and captured by GHT Consulting Services since 2011. The latest monitoring report, which was reviewed, is on monitoring Phase 79 (May 2017). Among these monitoring sites, 69 are located in the catchment B20E, specifically in the Shchoongezicht Spruit (44 sites) and Leewfontein Spruit (25) drainage systems respectively (**Figure 5** and **Figure 10**). Currently, a total of 41 surface water sampling points and 45 groundwater sampling points (Report Number: RVN 716.23/1746) are sampled around the potential sources of pollution at the power station.

The main groundwater chemical constituents exceeding the SANS241-1_2011's limits in the catchment B20E include Manganese (AB07, AB08, AB16, AB22, AB51, AB52, CB55, AB57, and WB18S), Sulphate (AB08), Fluoride (PB04, PB06, PB23, and CB54), and Iron (AB08 and AB48). When compared to the SAWQG, Manganese (PB04 and PB05), Fluoride (PB04, PB06, PB23, and CB54), and Iron (AB08 and AB48) are of concern. The locations of the contaminated monitoring boreholes in the project area are shown in **Figure 11**.

AB51, AB52 are located on the footprint of the continuous ash disposal facility's site, north of the existing ash disposal facility (**Figure 11**). AB07, AB08, AB16, AB57, are located north of the existing ashing area drainage, and south east of the continuous ash disposal facility's site (Schoongezicht Spruit). PB04, PB05, PB06, PB23 are located at the south of the power station area drainage, at more than 500m east of the continuous ash disposal facility's site (Schoongezicht Spruit). AB22 and AB48 are located to the south of the existing ashing area drainage, and south east of the continuous ash disposal facility's site (Leeuwfontein Spruit). CB54, CB55, and WB18S are located west of the coal stockyard area drainage (Schoongezicht Spruit), more than 2.5 km south-south east of the continuous ash disposal facility's site.

Groundwater infrastructures in the area



Co-ordinates System: UTM (HART94) Date(s):09-2017 Drawn by : DP AHOKPOSSI	Project Title: Continuous ash disposal facility at Kendal power station Groundwater numerical model for Source Pathway Receptor study Project Number: GHES_17_04 Client: Eskom Holdings (Pty.)	GHES

Figure 10: Overview of borehole resources in the area

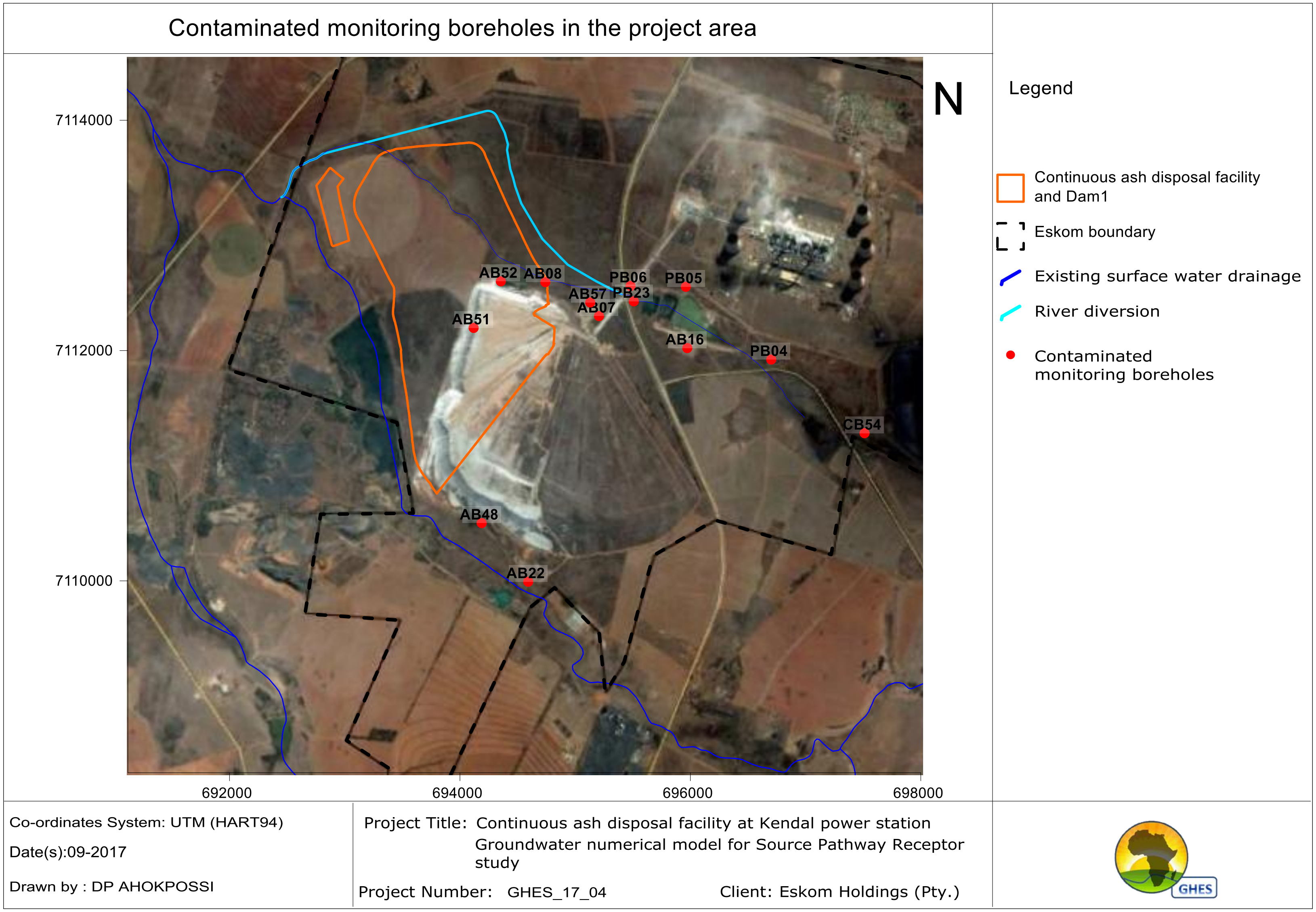


Figure 11: Contaminated monitoring boreholes in the project area

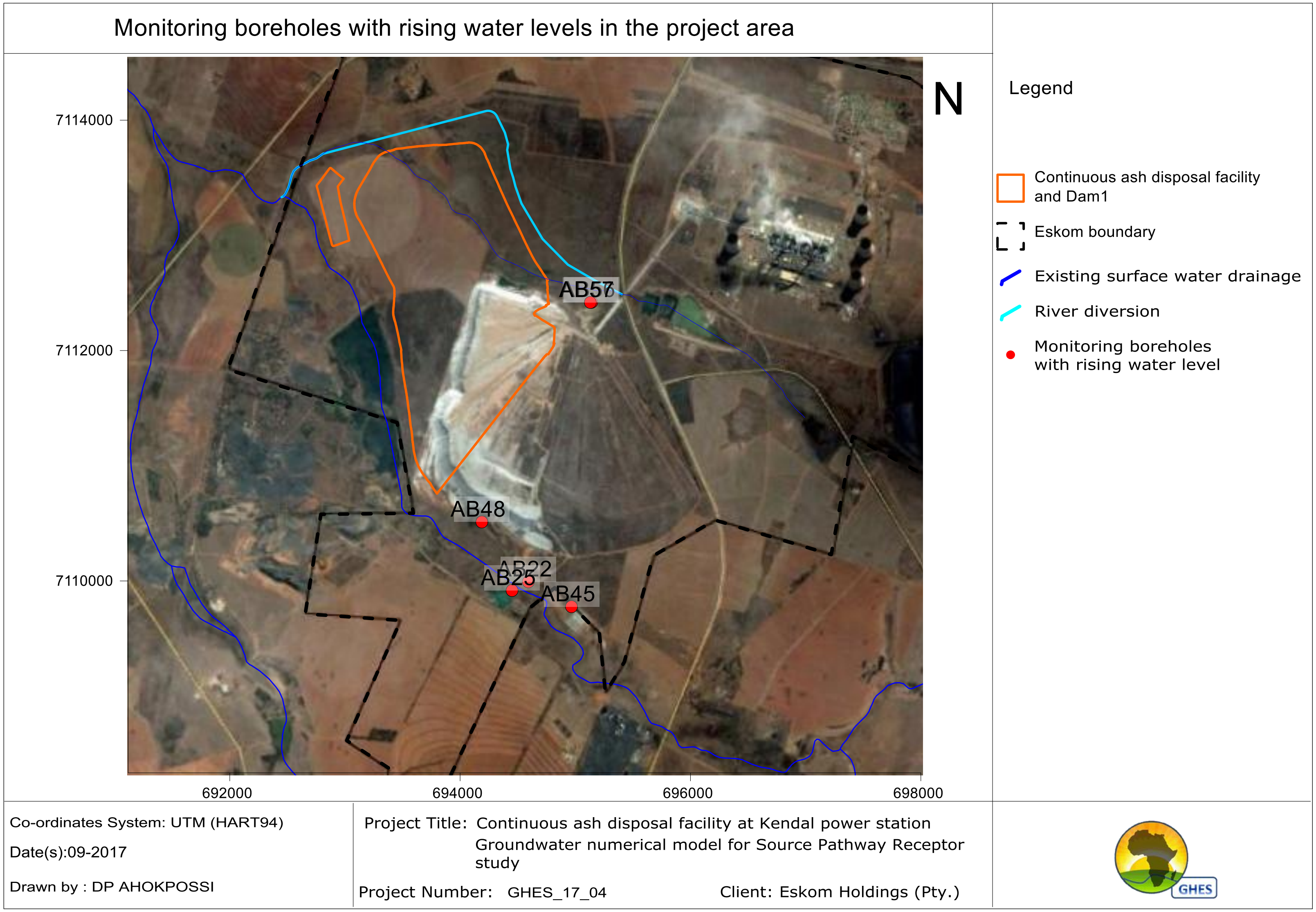


Figure 12: Monitoring boreholes with rising water level

Seasonal fluctuating water levels are observed in the majority of the boreholes, and the highest annual decreases of depths to groundwater (rise of water elevations) in the monitoring boreholes, are generally observed between January and March. This decrease in the depths to groundwater levels during the wettest months of the year, alternate with an increase (drop of water elevations) during the dry period of the year. This suggests that the groundwater in the study area is being recharged by the infiltration of summer rainfall (starting from November). The groundwater elevations in monitoring boreholes AB22, AB25, AB45, AB48, AB56, AB57, and WB12, show a continuous increasing trend, especially from July 2012 (**Figure 12 and Figure 13**). The increased groundwater elevations in these boreholes result in relative steep groundwater gradients towards these boreholes, and may be associated with seepage from the existing ash disposal facility.

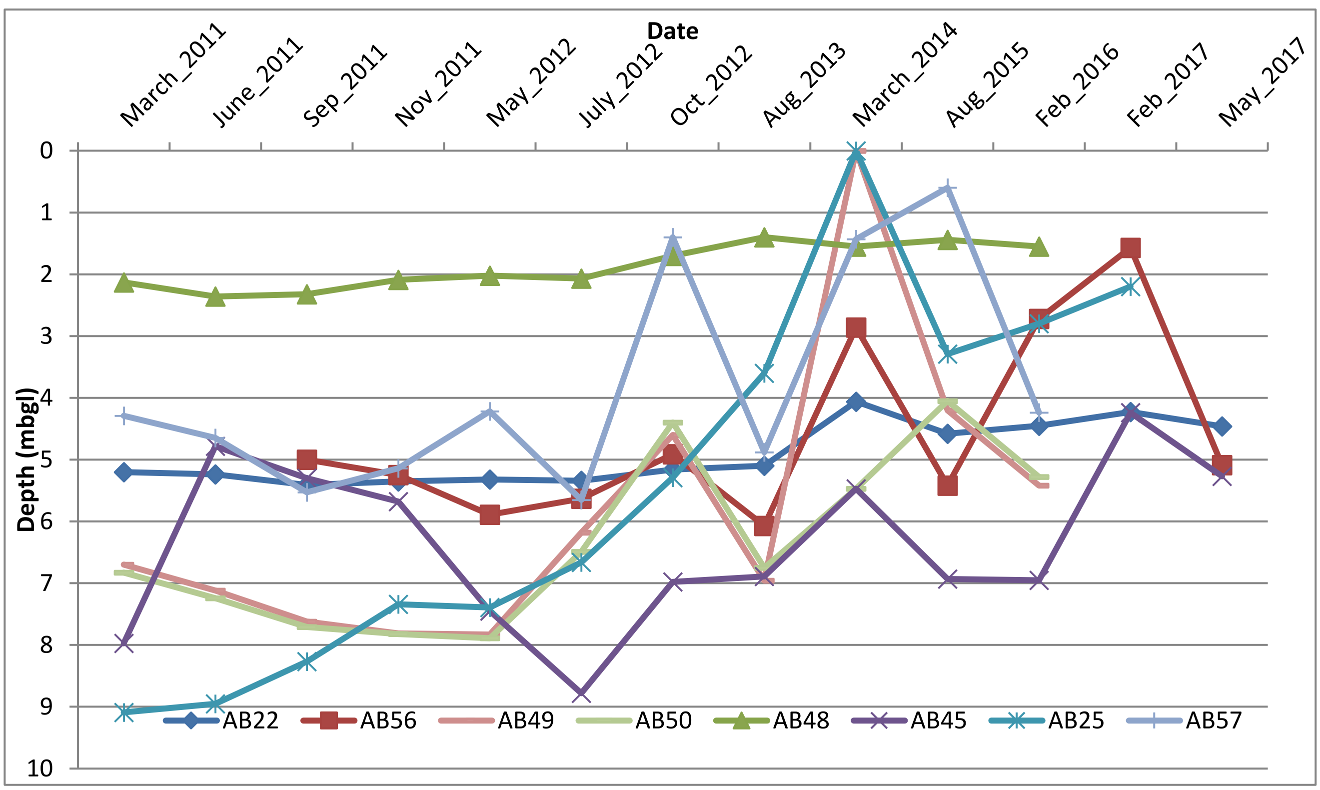


Figure 13: Monitoring boreholes with rising water level

Because of seasonal groundwater elevations fluctuations and associated flow dynamics, it is deemed necessary to discuss the groundwater heads, as measured in February

2016. This allows integration of the depths to groundwater levels which were recorded during the hydrocensus (Report Number: RVN 716.13/1641) and the ones of the monitoring Phase 74.

In February 2016 the depths of groundwater at the boreholes in the study area ranged from 0.9 to 35mbgl (**Figure 14**). The highest frequency (mode) of the recorded depths to groundwater levels is from 0.9 to 2.9 mbgl, and a decrease in frequency is observed as the depth of groundwater level increase. 85% of the overall recorded groundwater levels are shallower than 10 mbgl, and 60% are less than 5 mbgl. The majority (6 of 7) of the shallow (not profound than 16 mbgl) monitoring boreholes (AB48, AB50, AB57, AB67, AB61, AB65) show shallow water level ranging between 1.5 and 5.5 mbgl. These observations confirm the general shallow water level (limited unsaturated zone) across the ash disposal area.

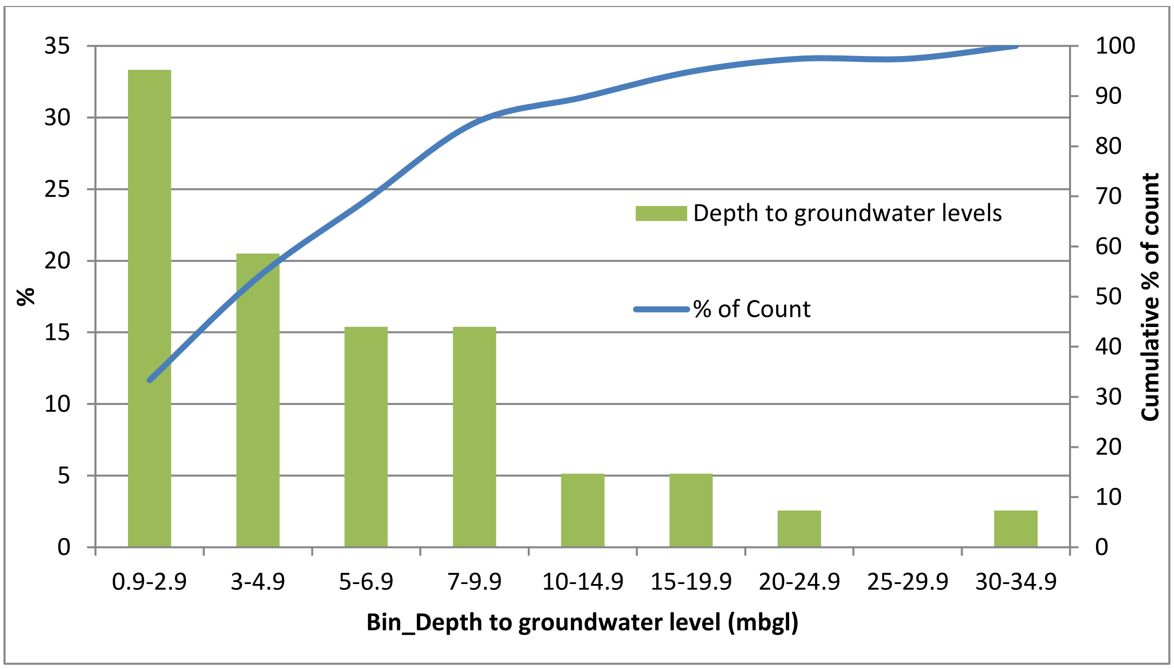


Figure 14: Frequency distribution of recorded depths to water levels

Using the ground surface elevations retrieved from digital elevations models (SRTM), groundwater elevations were calculated and plotted against surface elevations. A correlation of 99% (**Figure 15**) is observed between the two elevations, suggesting that the groundwater level will mimic the topography. The Bayesian interpolation was then used to compile the groundwater heads contour map and assess the groundwater drainage in the study area (**Figure 16**).

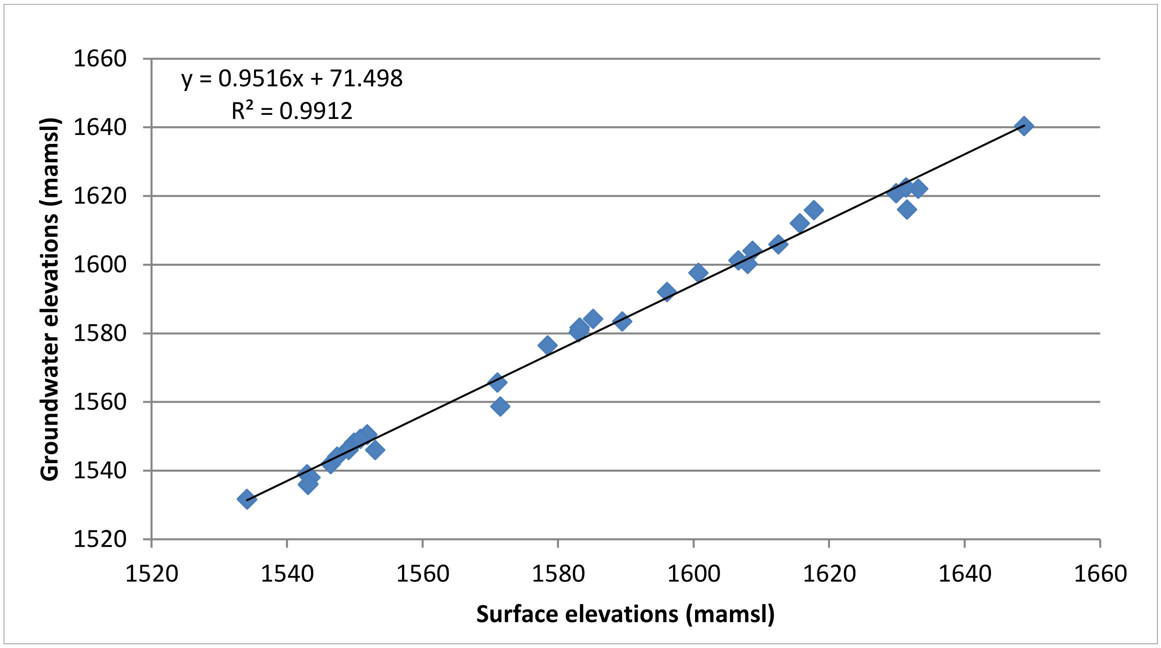
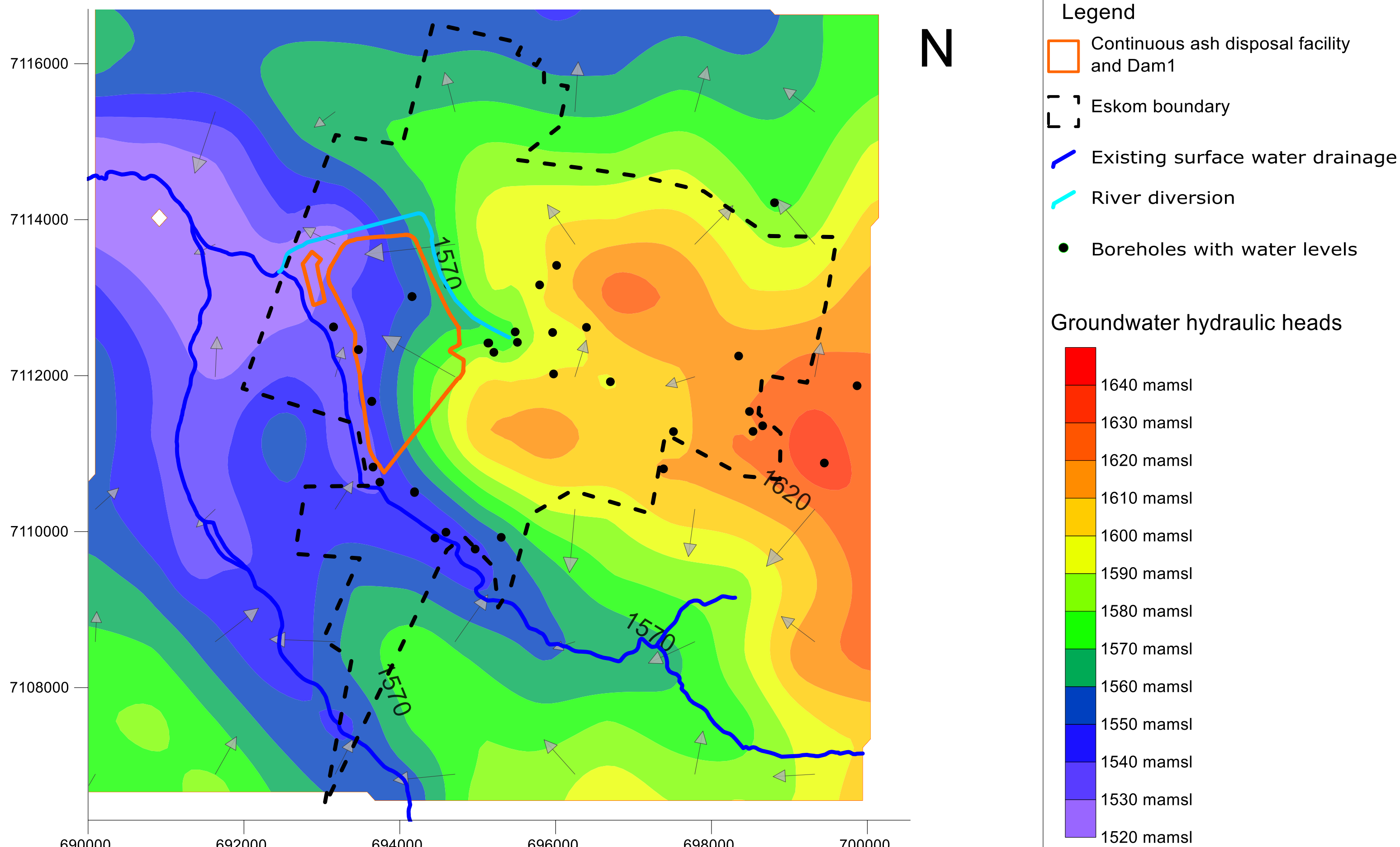


Figure 15: Correlation between groundwater elevations and surface elevations

Groundwater elevations and drainage_river diversion



Co-ordinates System: UTM (HART94)

Date(s):09-2017

Drawn by : DP AHOKPOSSI

Project Title: Continuous ash disposal facility at Kendal power station Groundwater numerical model for Source Pathway Receptor study

Project Number: GHES_17_04

Client: Eskom Holdings (Pty.)

Figure 16: Groundwater elevations and drainage

2.4.3 Existing geophysical survey and drilling data

In April 2012, preliminary geophysical surveys were conducted south of the continuous ash disposal facility's site, by GHT Consulting Services as part of "aquifer classification for vulnerability and Risk assessment at KPS" (Report Number: RVN 601.12/1311). The magnetic method was used on 24 traverses (T1 to T24) to detect geological features (dolerite dykes, sills, hidden faults) that may be associated with preferential pathways for groundwater migration and contaminant transport from the existing ash disposal facility and other potential pollution sources (e.g. Coal stack yard, emergency stack, dirty water dams) at the power station. These geophysical investigations suggested presence of relatively highly magnetised rocks (dolerites) around the existing ash disposal facility. A dolerite dyke is probably crossing the south of the existing ash disposal facility as shown by magnetic anomalies on traverses T1, T2 and T12 (**Figure 17**). The size, depth, strike, and the shape of the dyke were not determined.

GHT Consulting Services conducted other magnetic geophysical surveys (Trav1 to Trav4) on the continuous ash disposal facility's site, in 2015 (Report Number: RVN 716.6/1581). The magnetic data were collected to site boreholes for the extension of groundwater monitoring network at KPS. The results of the magnetometer survey suggested the presence of dolerite sill underlying the continuous ash disposal facility's site. Five pairs of deep and shallow monitoring boreholes were subsequently drilled for monitoring purpose on the continuous ash disposal facility's site. More detail can be found on the construction of the boreholes in report RVN 716.6/1581.

In addition to the geophysical and drilling reports (Reports Number: RVN 601.12/1311, and RVN 716.6/1581), 47 geological borehole logs information were reviewed from the numerical pollution plume model update, compiled by GHT Consulting Services in 2016 (Report Number: RVN 716.21/1714).

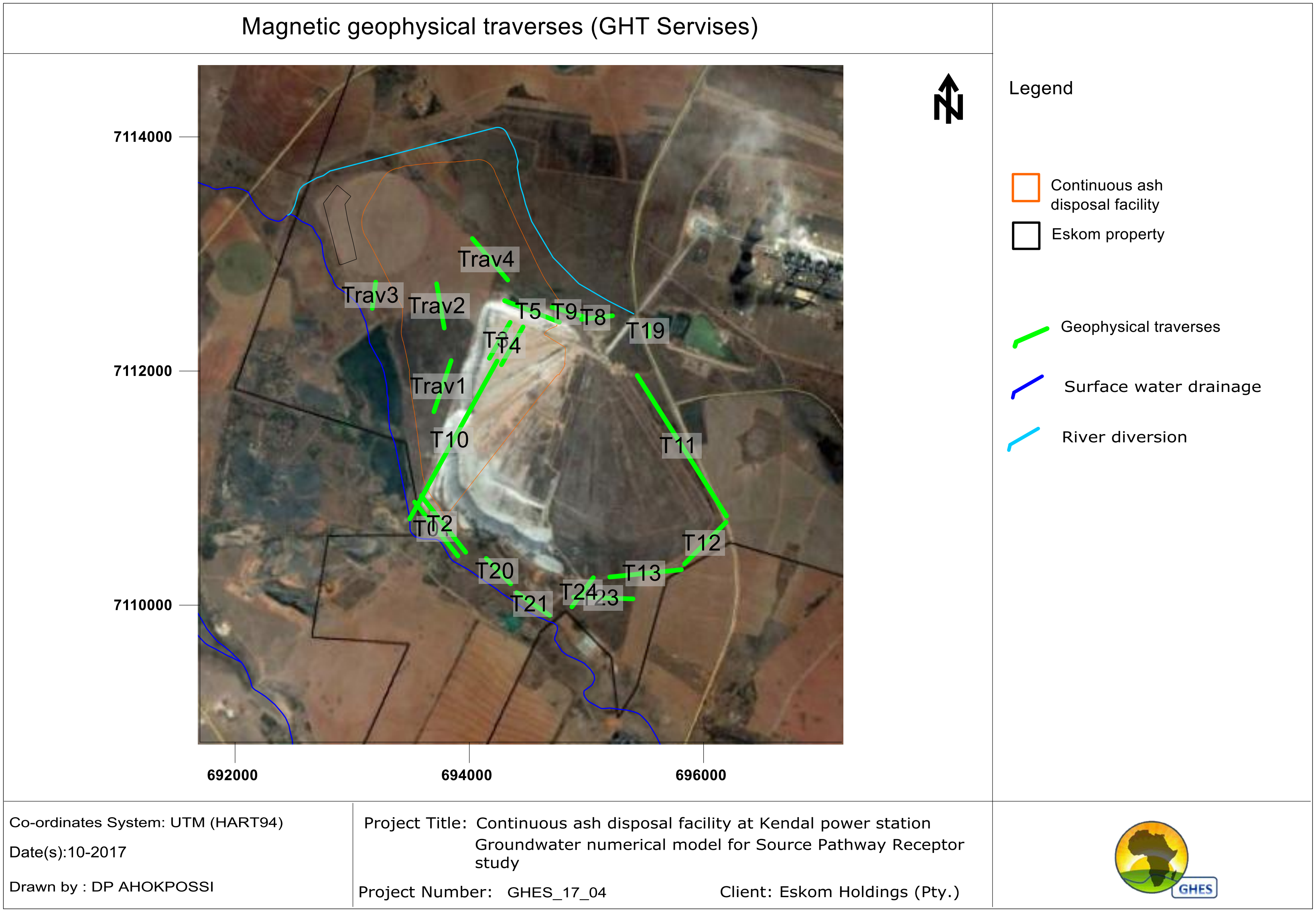


Figure 17: Previous geophysical survey's traverses

The main geological features (lithology) encountered during drilling on the site consisted of clay, granites and dolerites of the Karoo Supergroup:

- Clay: The clay is very fine texture with a soft and silty feature, and extends approximately 6 – 19 m thick nearby the ash stack;
- Granite: Reddish brown to brownish white fine to coarse grained and weathered to hard, massive granites, which extends approximately 3 – 36 m (or more) thick;
- Dolerite: The dolerites are mainly massive hard and fresh, no prominent weathered zones were intersected during the drilling.

The frequencies of borehole according to depths follow a normal distribution at KPS. 66% of boreholes depths vary from 15 to 40 mbgl, and 90% of boreholes depths are less than 40 mbgl (**Figure 18**). Shallow depths to first water strikes prevail at KPS. Water was encountered before 10 mbgl in 47% of boreholes, and before 20 mbgl in 80% of boreholes (**Figure 19**). This might explain the generally shallower (approximately 40 mbgl) drilling depths in the catchment.

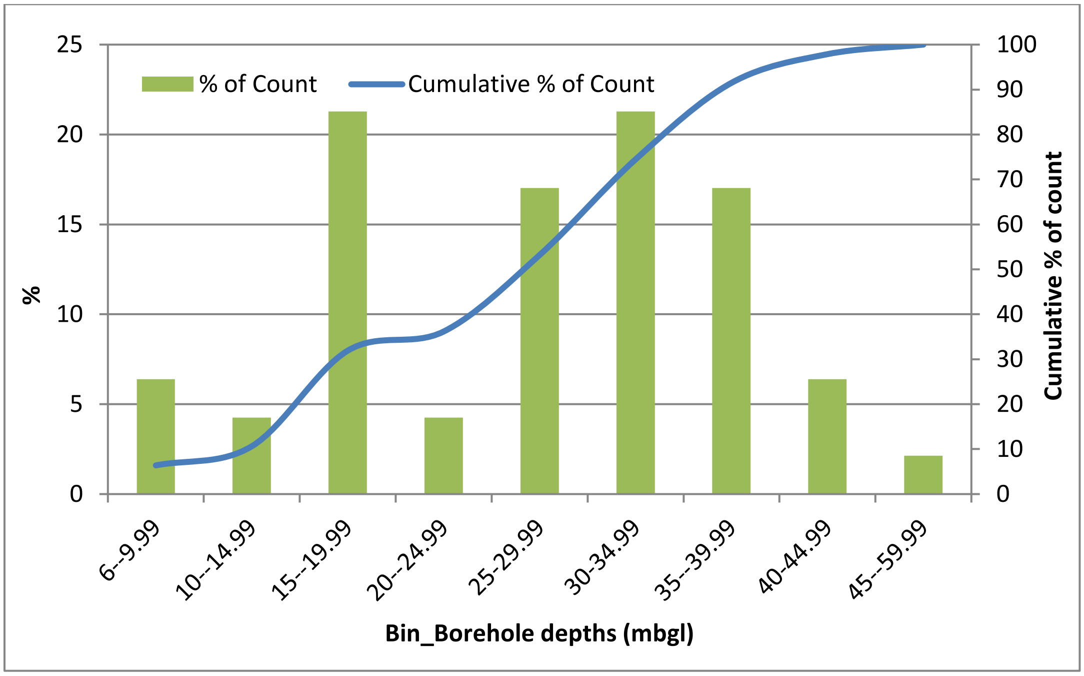


Figure 18: Frequency distribution of recorded boreholes depths

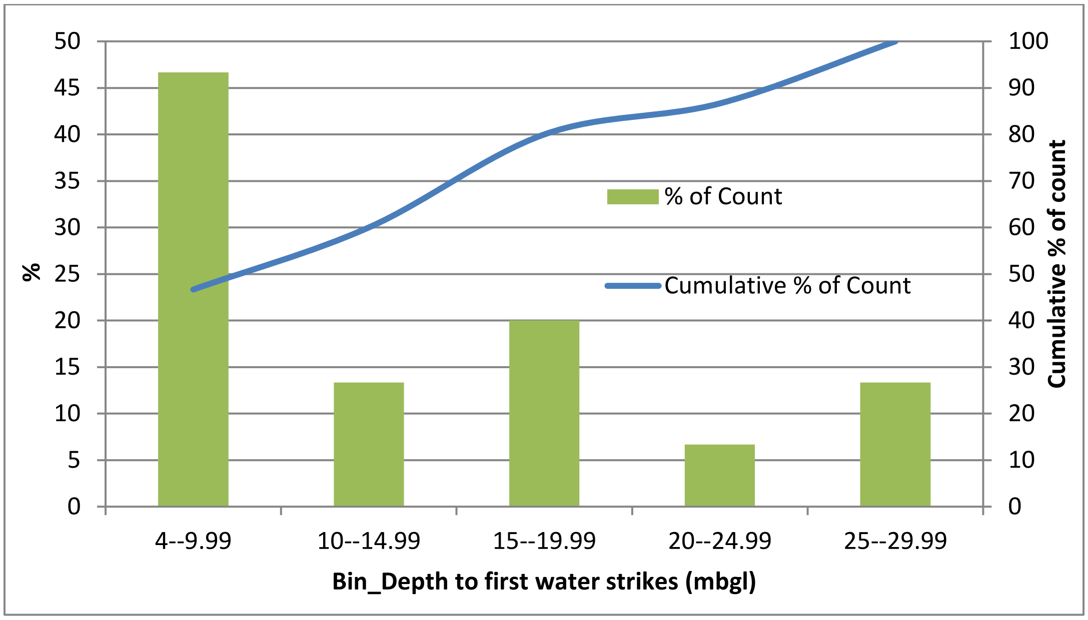


Figure 19: Frequency distribution of recorded depths to water strikes

The intrusive magnetic dolerite were encountered in 18 monitoring boreholes (AB14, AB15, AB19, AB21, AB49, AB50, AB51, AB52, AB56, AB60, AB62, AB63, AB66, CB01, CB13, PB58, PB59, and WB18) among which 12 are on the continuous ash disposal facility's site. This confirms that a sill is undelaying the facility's site, at a depth generally between 6 and 19 mbgl. The sill nearly outcrops at the south east of the facility's site (AB19). The thickness and the geometry of such sill in the area is expected to control the groundwater flow and associated solute transport, especially possible pollution emanating from ground surface.

Hydraulic conductivities and boreholes' yields were recorded for both shallow and deep boreholes, and no clear dependence of such hydraulic parameters values on borehole depths could be detected. The yields of 28 boreholes (Report Number: RVN 716.21/1714) were recorded at the KPS. The yields of boreholes range from 0.001 to 9 l/s blow yields (**Figure 20**). Only 7% of the boreholes have yielded (blow yield) more than 1 l/s whereas 46% of the boreholes have yielded between 0.1 and 0.9 l/s.

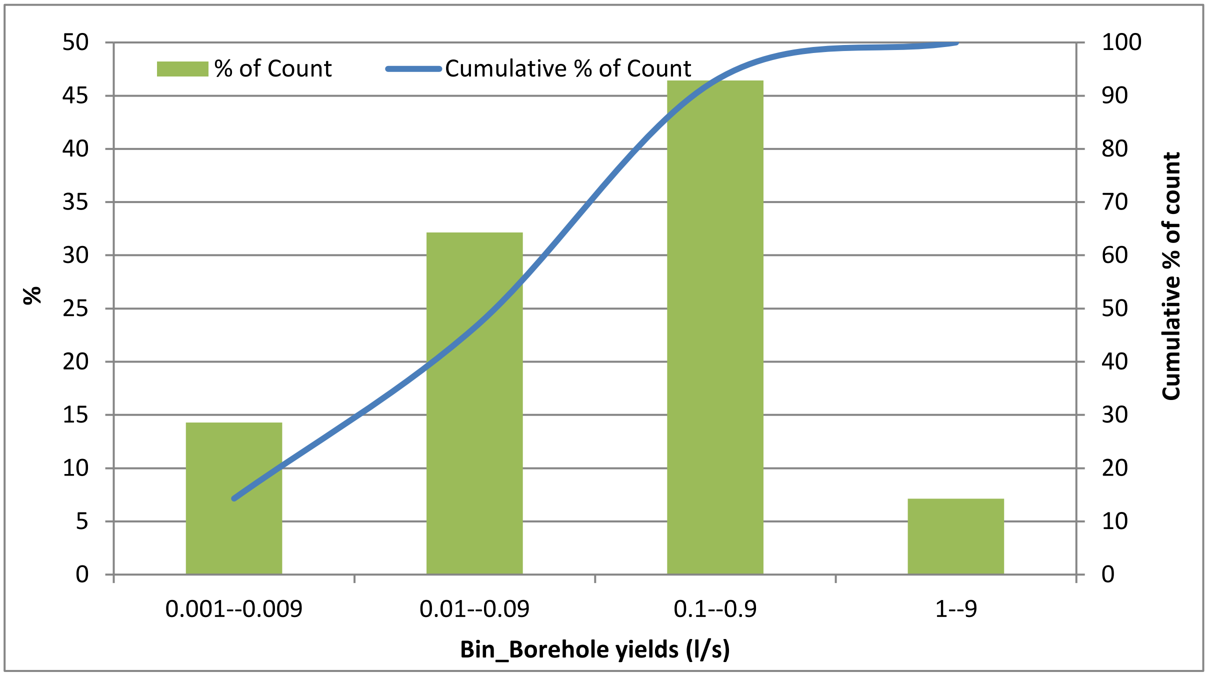


Figure 20: Frequency distribution of recorded boreholes yields

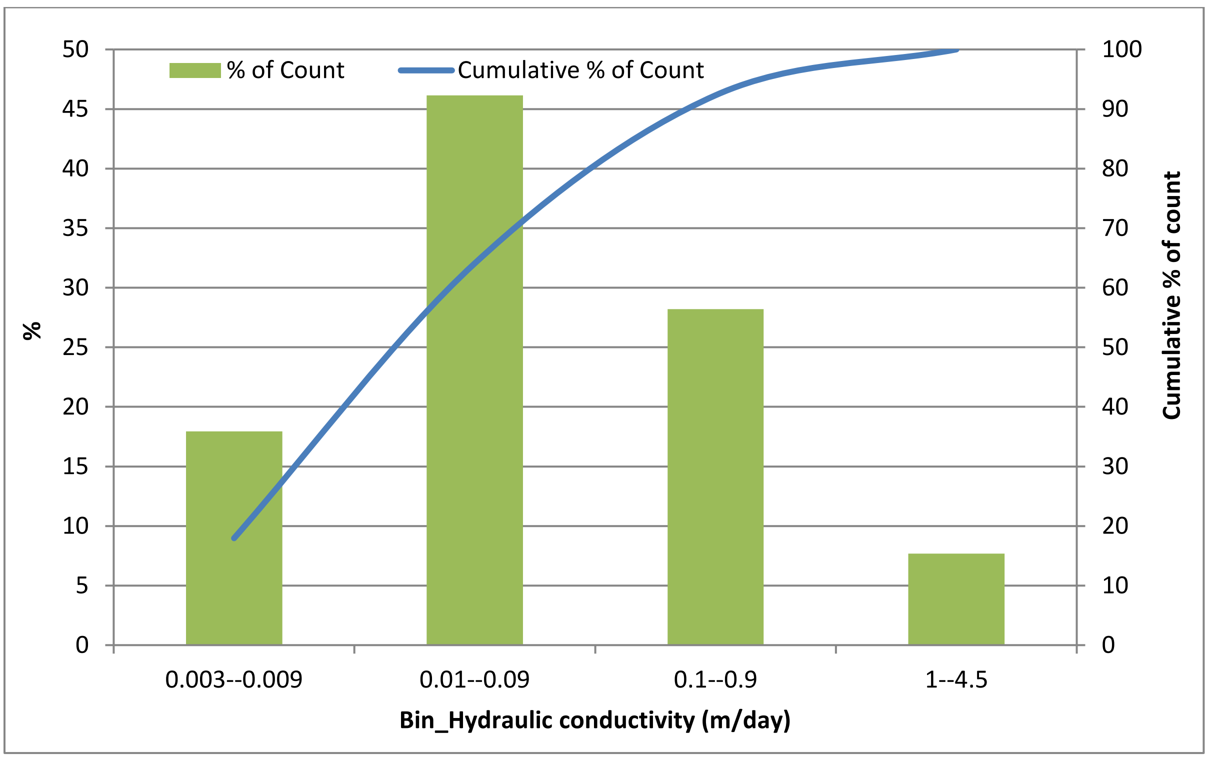


Figure 21: Frequency distribution of recorded conductivity

In total, 39 hydraulic conductivity values (Report Number: RVN 716.21/1714) were estimated at the KPS, using bail down test approach. 46% of the hydraulic conductivities vary between 0.01 and 0.09 m/day, and 75% of the hydraulic conductivities vary between 0.01 and 0.9 m/day (**Figure 21**). However, only 11% of the boreholes have hydraulic conductivity values above 1 m/day, and the maximum recorded value is 4.5 m/day. This spatial variability in hydraulic conductivity values was expected, considering the complexity of geological setting and different intrusions which probably enhanced the development of relatively higher hydraulic conductivity zones and preferential flow paths. A correlation of 99.66% exists between the estimated boreholes' yields and hydraulic conductivities, for values above 0.036 l/s and 0.005 m/day respectively (**Figure 22**). This confirms the consistency in the different technics used to estimate these hydraulic parameters.

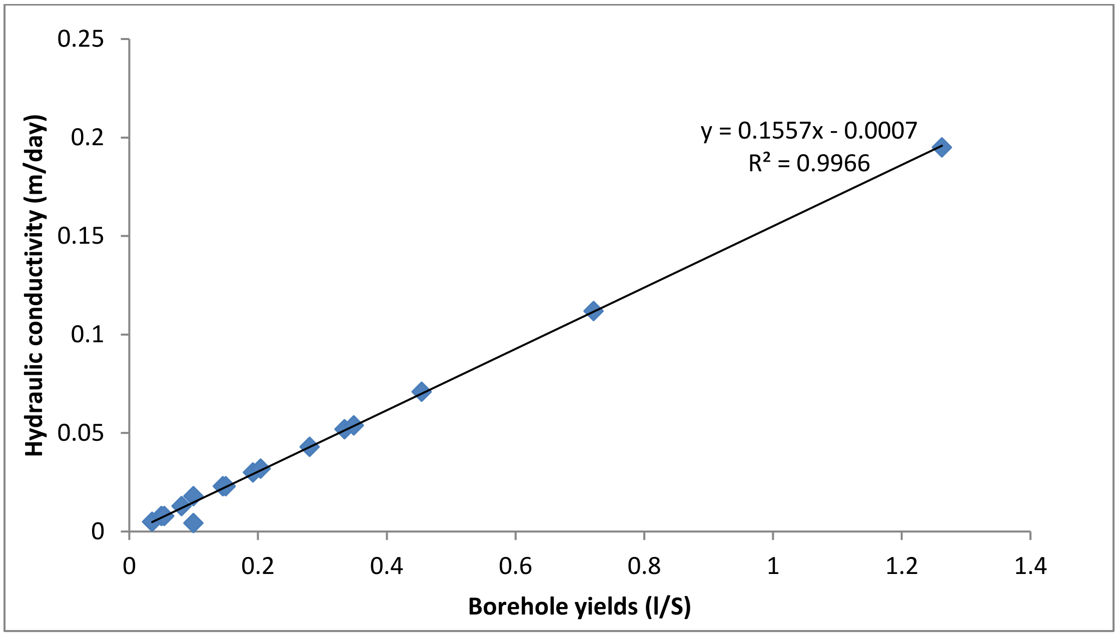


Figure 22: Correlation between recorded hydraulic conductivity and borehole yields (for values above 0.036 l/s and 0.005 m/day)

2.4.4 Previous geotechnical and soil study

19 auger holes were drilled by GHT Consulting Services across the entire KPS area close to potential pollution sources in 2012 (Report Number: RVN 601.12/1311) to determine the hydraulic parameters of the unsaturated zone. The vertical distribution of such hydraulic parameters is illustrated in **Figure 23**.

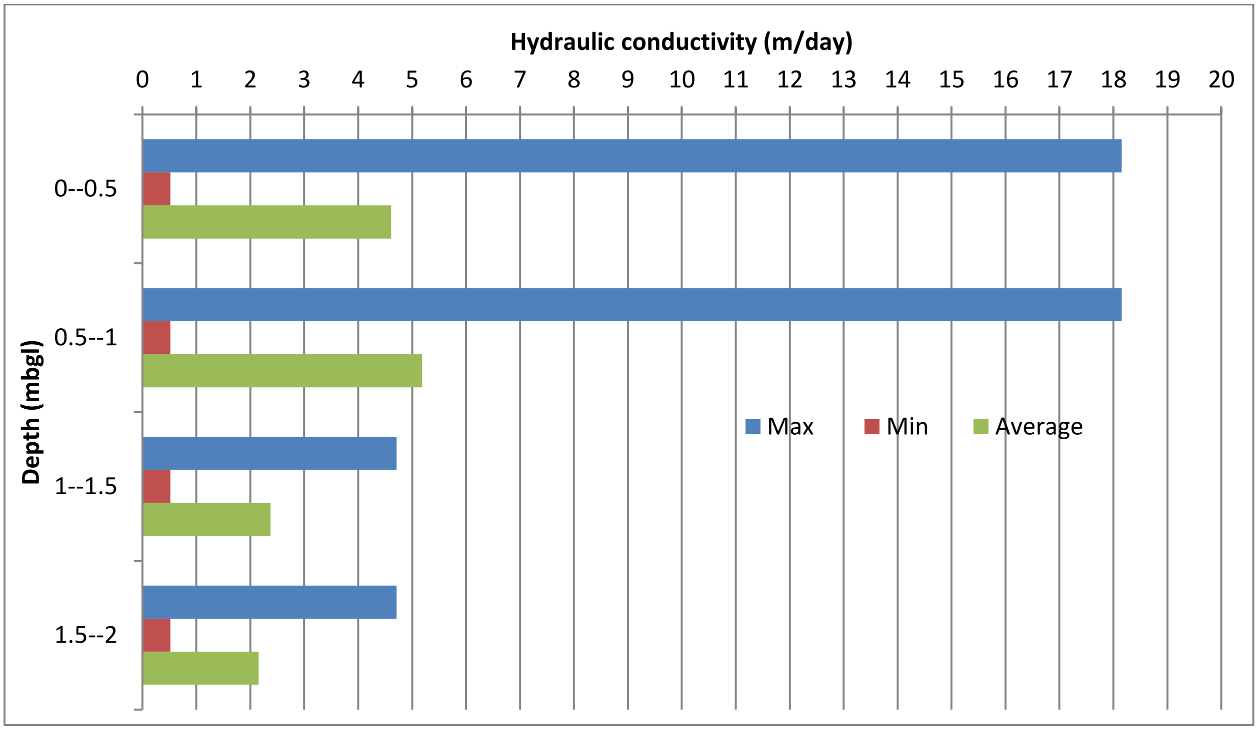


Figure 23: Vertical distribution of recorded conductivity in the soil

2.4.5 Existing hydro-geochemical data

Static ABA test results were provided by Eskom in form of an excel spreadsheet (Reference 1658499_Processed _B1_05092016) on 04 samples (KEN-ADF, KEN-ADW, KEN-B/CA, KEN-FA). However, with only the static ABA testing:

- Many natural neutralizing minerals are not capable of neutralizing pH above a value of 6;
- The total sulphur to calcium carbonate conversion factor is theoretical and based on geochemical assumptions that depend on the acid-generating conditions;
- The hydroxide titration (to measure acidity) contains a level of uncertainty as minerals will re-precipitate at varying rates, which in turn affects the mass of hydroxide needed to reach pH 7;
- The material tested is ground to 0.8 mm and therefore the exposed surface area is much greater than would occur once the material had been deposited;

2.4.6 Existing groundwater conceptual and numerical model

As part of the overall water resources management at the Kendal power station, a conceptual groundwater model exists for the station, and various models were run in the past. The two most recent two groundwater numerical model update reports (Reports Number: RVN 716.8/1588, and RVN 716.21/1714) compiled by GHT Consulting Services were provided for review.

The existing groundwater models were developed to simulate pollution plume migration from the existing potential pollution areas (ash stack, emergency ash, dirty water dams, etc.…). The area included in the aforementioned groundwater models overlaps with the 90% of the area earmarked for the continuous ash disposal facility site.

The finite difference numerical discretisation approach of the computer software program Visual Modflow was used. Hydraulic variables (Hydraulic conductivities, storage parameters) as estimated from recalibrating the previous numerical model and pumping test data interpretations, were considered for each facies. For more information on such existing models, the reader is referred to the reports (Reports Number: RVN 716.8/1588 and RVN 716.21/1714).

Conceptual hydrogeological models were also developed in the area for different projects including:

- JMA Consulting: Groundwater specialist study report: Groundwater specialist study report. New Largo/GROUNDWATER/VER-02/2012;
- Aqua Earth Consulting: Proposed Kusile Ash Disposal Facility. Biophysical study: Groundwater Assessment, February 2014. AEC0180/05/03-2014.

3 Update of the conceptual hydrogeological model

Conclusions are drawn about the potential risks caused by the source of contamination. A set of assumptions based on the available information, are considered to reduce the real problem (pollution) and the real aquifer domain to a simplified version that is acceptable in view of the source-pathway-receptor geohydrological modelling and of the associated management problem. The conceptual model excludes any underground mining works and/or and surrounding surface activities (Open pit at the East of the project site). Using the reviewed information, the conceptual model is described with focus on the sources, pathways and receptors.

3.1 Source-Pathway-Receptor analysis

It is fundamental to construct a simple conceptual process that defines the potential contaminants linkage to the potential environmental receptor. The process that leads to the establishment of such linkage is referred to as the source-pathway-receptor model. Three essential elements need to be understood so that the contamination of concerns can be defined, and the associated risk to receptors can be quantified. The chevron list in **Figure 24** illustrates how source-term characterisation is linked to groundwater and receptor study.

The sources and the unsaturated pathway are discussed together as source-term analysis. The prevailing groundwater's characteristics are then discussed as aquifer pathway. The users and sensitive environmental components that depend on the groundwater that is flowing from the continuous ash disposal facility's site are also analysed. Note that we did not consider in the present study the Aquifer as receptor but rather as pathway to groundwater users (boreholes) and sensitive environmental components (river, wetland); If groundwater has to be considered as receptor, then the SPR model would not consider these last ones.

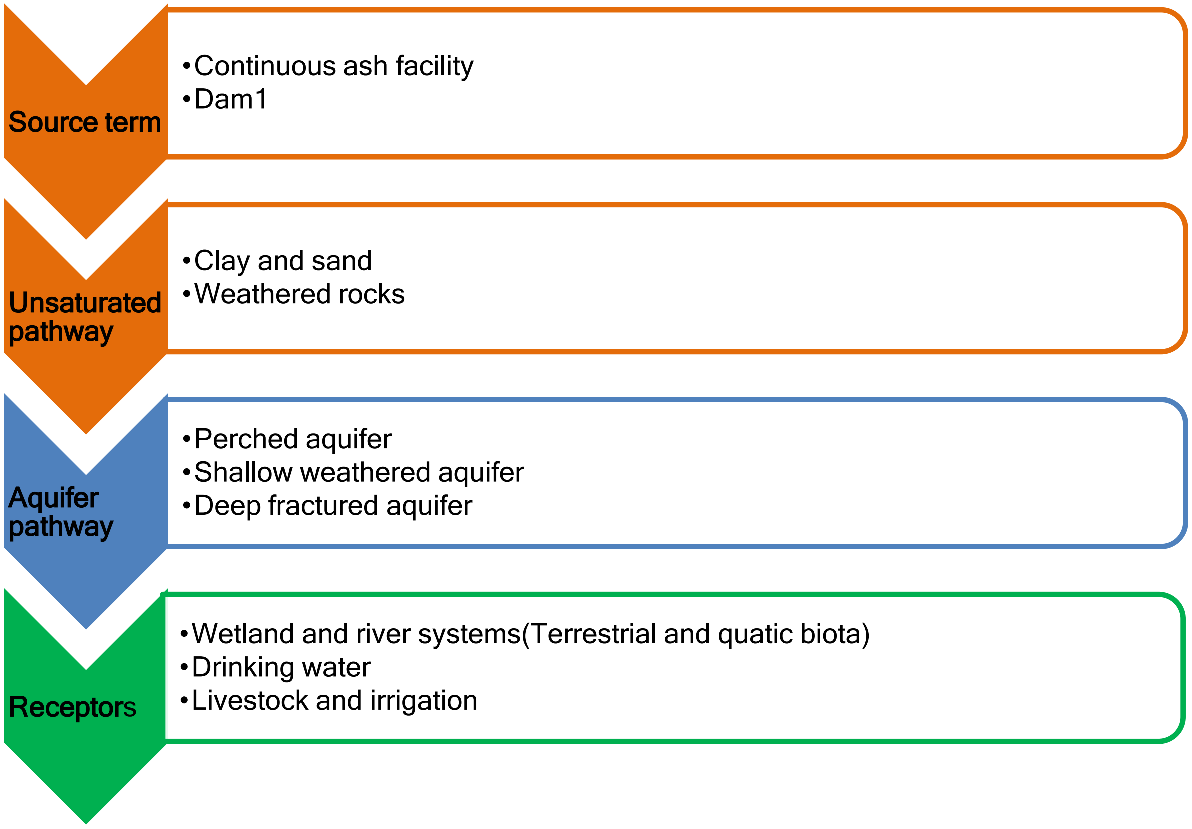


Figure 24: Link between source-term, groundwater and receptor studies

3.1.1 Groundwater pollution source-term analyses

3.1.1.1 Site history

Up to recent site visit (September 2017), the northern part of the site of continuous ash disposal facility was used for crop farming (maize and sugar beans) purpose, using two centre pivot irrigation facilities, each with a diameter of approximately 800 m. The remainder of the site is covered by other crops and virgin veld grass.

The causes or sources of the current and potential contaminations were identified and located mainly around existing ash facility (**Figure 11** and **Figure 12**). They form part of the overall delineated pollution sources of contamination to groundwater as delineated at KPS by GHT Consulting Services in 2012 (Report Number: RVN 601.12/1311). Five main pollution sources (ash stack, coal stockpile, dirty water dams, station drain dams, and emergency Ash Stack) were identified in the overall power station. These pollutions sources are not lined, and may leach into the surrounding water resources either by infiltration and percolating through the unsaturated soil zone to reach the water table, or surface water runoff and reach surface water features (streams, wetlands). The rises of groundwater elevations in boreholes located downstream at north (AB56, and AB57) and at south (AB22, AB25, AB48) of the existing ash disposal facility are probably the indications of water seepage into the ground (**Figure 11 and Figure 12**). The high concentration of Manganese (AB07, AB08, AB16, AB22, AB51, AB52, and AB57), Sulphate (AB08), and Iron (AB08 and AB48) confirms such a probability. Note that AB51, AB52 are located on the continuous ash disposal facility's site, north of the existing ash disposal facility. Contaminations were detected in both deep and shallow boreholes (AB48, and AB57). The construction of the boreholes and the sampling technique (purge and sample with low flow pumping rate) during monitoring, make it difficult to determine the exact vertical extent of the contaminations.

3.1.1.2 Continuous ash disposal facility (source)

The continuous ash disposal facilities with its associated dirty water management infrastructures (dam1 and dam2) are to be lined according to regulatory and design requirements. These are however susceptible to leak at certain specific rates and at points or areas (drains and leachate drains, finger drains) as calculated from literature (Giroud & Touze-Foltz, 2005), hence they constitutes potential pollutions sources. For further discussion on sources analyses in the present project, focus is given to continuous ash disposal and the associated dams.

The proposed lining (barrier) system is supposed to mitigate any impact to groundwater that may be caused by infiltration of dirty water into the ground. Under perfect conditions, no seepage, or infiltration of dirty water should occur. But for contingency purposes, certain leakage rates have to be considered according to different lining design alternatives. Based on 03 different lining scenarios: Class C, Intermediate (intermediate liner between Class C and D), and Class D, the leakage rates were calculated by Engineering team of Zitholele consulting and provided to GHES. As the sources would be continuous over time the calculated leakage rate (s) would be assumed to be the water available for percolation into the subsurface within the continuous ash disposal area. Assuming a groundwater recharge rate of 3 % to such available water, the annual recharge to saturated groundwater is determined for each scenario (**Table 4**).

The static leachate test conducted on four ash samples at Kendal Power Station indicated a maximum concentration of 133 mg/l for sulphate. However, considering the observed concentrations of sulphate in the groundwater at AB08 and AB57 (586 and 480 mg/l respectively), and at dirty water monitoring points AP10, AC05, AP32, and AP33 (621, 611, 720 and 598 mg/l, respectively), a sulphate concentration on 600 mg/l is assumed to be a reasonable concentration in any leachate that may leak from the continuous ash disposal facility into the ground. The corresponding mass flux (source term) of the contamination (Sulphate) was then calculated for each alternative scenario (**Table 4**). The percolation of contaminated water through the unsaturated soil will mainly be controlled by soil characteristics (**Table 5**).

Water strikes were recorded before 20 mbgl in 80% of boreholes, and a dolerite sill is present below the continuous ash disposal facility's site, at a depth generally between 6 and 19 mbgl. Hence, we assume that contaminations from the pollution sources associated with the continuation of disposing of ash are likely to be limited to the shallow weathered aquifer.

Table 4: Sources characteristics

Pollution sources	Volumes/weigh	Contaminant of concerns	Leakage rate m3/ha/day	Recharge to saturated groundwater mm/m²/year	Concentrations of Sulphate for mg/l	Max flux g/m²/day
Pollution Control Dam 1	120 Ml	Mn SO4 Fe F	**Class C:**0.038 **Inter C:**0.007 **Class D:** 0.87	**Class C:** 1.387 **Inter C**: 0.2555 **Class D:** 31.755	600	**Class C:**$2.28*10^{-3}$ **Inter C**: $0.42*10^{-3}$ **Class D:** $52.2*10^{-3}$
Continuous ash disposal facility	6200000 m/a or 5300000 m^2 *7 0m					

Table 5: Unsaturated zone characteristics

	Hydraulic Conductivity m/day	Thickness mbgl	Material
Unsaturated pathway	0.5—18	1.5 – 5	Clay, sand, weathered rocks (granite, dolerite), gravel

3.1.2 Aquifer pathway and receptors

The pathway is the route from the source to given receptors (Who and what will be impacted). If contamination is to cause harm, it must reach a receptor. Each receptor is identified and their sensitivity to the specific contaminant assessed.

As confirmed by different borehole surveys (hydrocensus) the closest (less than 1 km radius) privately owned water supply boreholes (FBB56, FBB39 see Figure 24) to the continuous ash disposal facility's site are equipped with submersible pumps and are in use. They both may constitute receptors of any migration through the aquifer, of contamination from the continuous ash disposal facility. FBB39 falls under Eskom's property but FBB56 does not. The continuous abstraction of water from those boreholes will locally draw down the groundwater levels and create local and dynamic cone of depression. The details of the background groundwater quality at these boreholes for contaminants of concerns are summarised in Table 6.

Table 6: Sensitive Receptors - Boreholes

		FBB56	FBB39
Coordinates	X	28.92523	28.93734
	Y	-26.07738	-26.07506
Owner/Farm		JG Prinsloo Cel: 0826600942 Vlakvarkfontein 213/4	Kendal Power Station, but used by JG Prinsloo / Schoongezicht 218/24
Use(s)		Domestics and farming/ Submersible pump	Domestics and farming/ Submersible pump
Signs of Pollution		No	Yes

pH	8.11	5.98
EC	21.70	26.10
Mn (mg/l)	<0.001	0.001
SO_4 (mg/l)	0.41	9.36
Fe (mg/l)	<0.004	<0.004
F (mg/l)	0.22	<0.142
NO_3 (mg/l)	4.35	17.40*
***Above SANS_241_2011 Limit**		

The wetland study conducted by Wetland Consulting Services (Reference: 978/2013) in October 2017, for the continuous ash disposal facility do not suggest any clear dependence of the local wetland on shallow saturated groundwater flow. Surface runoff inflow and interflow inflow are likely to be the main hydrological drivers supporting the overall wetness within a wetland. The most significant likely impacts on local wetlands are: the direct loss of wetland habitat falling within the footprint of the continuous ash dam facility; the risk of water quality deterioration posed mainly by spills, leaks (construction) seepage, and runoff from the ash disposal facility. The ecological integrity of wetland areas on site ranges from moderately to largely modified with PES of C and D respectively (although HGM Unit 2 may be considered critically, although not irreversibly, modified due to the influence of the large dam). All the wetlands on site have moderate or low/marginal ecological sensitivity status. The wetlands have the ability to provide various ecosystem services such as biodiversity support, maintenance of water quality, flood attenuation and sediment trapping.

Water quality at a monitoring point R04, is the only background quality information on surface water receptor. The details of such quality in light of contaminants of concerns are summarised in **Table 7**.

Table 7: Sensitive Receptors-Rivers

		R04
Coordinates	X	28.92840
	Y	-26.08260
Owner/Farm		Public Stream/ Schoongezicht218/20
Use(s)		Monitoring, Livestock
Signs of Pollution		
pH		7.70
EC		113.00
Mn (mg/l)		<0.001
SO_4 (mg/l)		507.00*
Fe (mg/l)		<0.004
F (mg/l)		0.29
NO_3 (mg/l)		0.23

3.1.2.1 Aquifer pathway

The aquifer conceptualizations provided in the existing groundwater models, were considered with site specific conditions (Lithology, groundwater level, aquifer parameters, topography and drainage, etc.…) to update the conceptual hydrogeological model for the proposed continuous ash disposal facility.

As groundwater flow and aquifer occurrence (development) are linked to the geology and structural features of an area, it is therefore assumed that the surface geology forms the generalized basis on which the conceptual hydrogeological model is based spatially (**Figure 6 and Figure 7**).

Hydro-stratigraphic units and groundwater occurrence

Two dominant hydro-stratigraphic units (aquifer system) were identified within the Kendal power station area.

- *Shallow weathered and fractured aquifer system:* this aquifer is unconfined to semi-confined and is recharged by rainfall. The shallow weathered aquifer is formed of lower permeable rock material. According to previous investigations (percussion drilling logs), the local thickness of the shallow aquifer was estimated to be between 5 m – 25 m. The water-bearing fractures occur from 15 to 25 m below ground surface. The weathered and fractured horizon consists mainly of clay, granites and dolerites of the Karoo Supergroup. It is important to note that this is not an absolute thickness value for the entire study area. Different thicknesses can occur from the competent hard rock outcropping in places.
  Although most of groundwater strikes are recorded in this shallow aquifer because of weathering conditions, the recorded borehole yields in this aquifer are generally low. The static groundwater water level is often naturally perched (0.9 and 3.0 mbgl). The occurrence of natural wetlands in the area is probably associated with lower permeable underlying rock material in the unsaturated zone, which allows static groundwater level to even be artesian in places. Prevailing boreholes yields range between 0.1 and 0.9 l/s. Hydraulic conductivities vary considerably in the area, and are generally estimated between 0.01 and 0.9 m/day.
- *Deeper Localized fractured to fresh aquifer system:* the deeper fractured to fresh aquifer rock aquifer formed by competent rock of the Vryheid Formation that has been subjected to fracturing associated with tectonic movements, is developed below the shallow and fractured weathered aquifer. This aquifer is semi-confined and is

controlled by geological structures (dolerite intrusions and fault zones) and horizontal conductive layers (coal seam) contact zones. Groundwater flows in the deeper aquifer along discrete pathways associated with the fractures. Although occasional high yielding boreholes may be intersected, the deeper aquifer does not constitute an extensive aquifer able to sustain excessive pumping.

Three layers were conceptually used to describe the groundwater conditions and also the man-made structures within the upper part of the topsoil:

- The top layer represents all manmade structures and the unsaturated soil zone. This layer is represented by one facies;
- The second layer comprises the saturated zone, and was represented by three facies as represented by the geological map;
- The third layer represents the deep geological formations and was represented by three facies.

Recharge and Discharge

The recharge to the shallow aquifer in the area is directly from rainfall, and is estimated to be between 2 % (7.35mm) and 6 % (22.05mm) of the Mean Annual Precipitation (735 mm). In typical unconfined system, groundwater divides developed approximately beneath the major surface water divides, as a result of local recharge and discharge.

The deeper fractures aquifer is assumed to be interconnected to the shallower one, and is also recharged mainly by rainfall recharge, and groundwater seeps from the perched aquifer into the fractured rock aquifer. Direct recharge from rainfall or surface stream can also occur where the fractured, competent rock outcrops, or from the base of perennial rivers.

Most of the groundwater recharge that is occurring within the study area may discharge internally to the: the base of perennial river drainage systems Wilge; and the surrounding mining pit.

Figure 25 shows the identified sources, pathway (groundwater) and receptors.

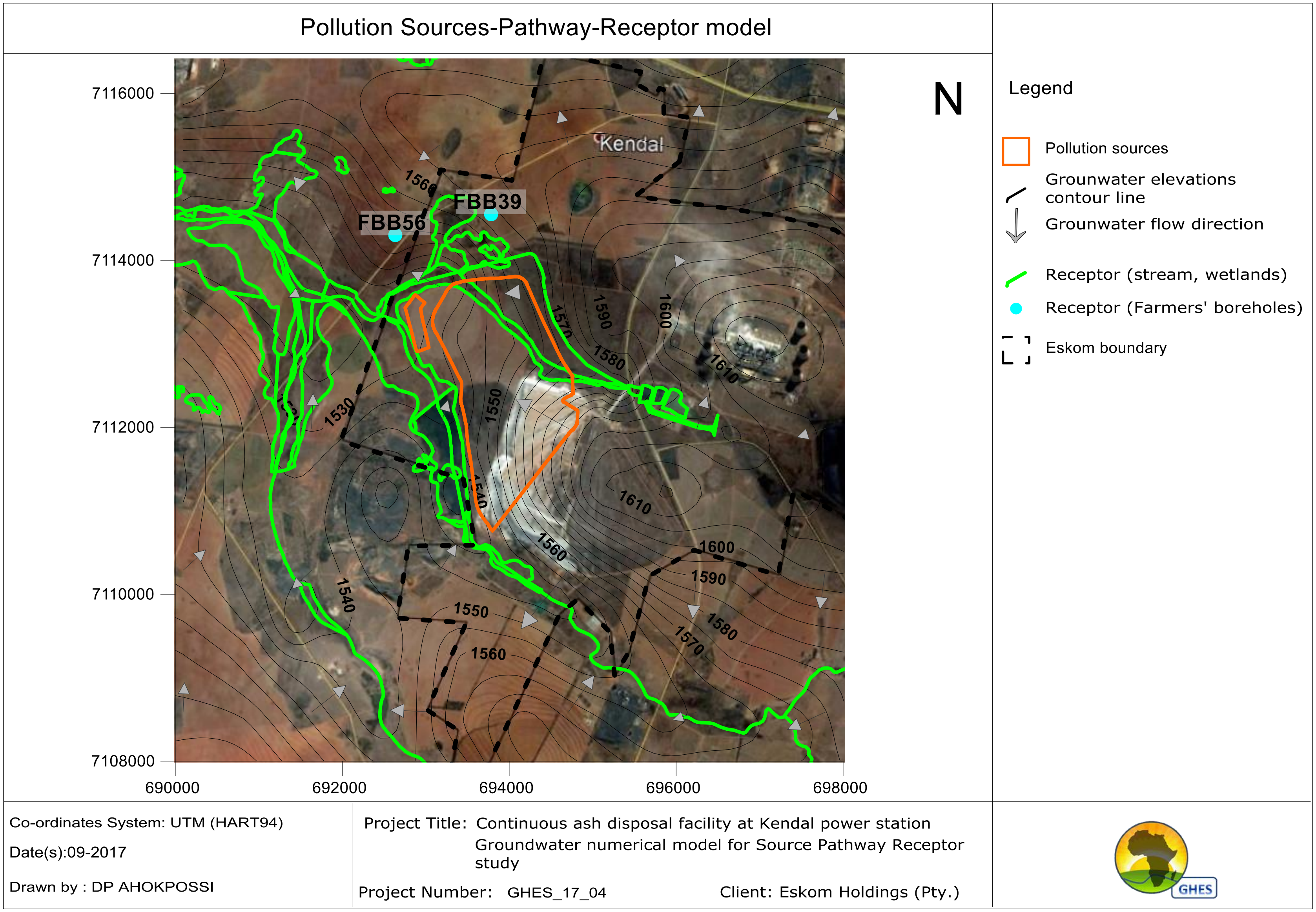


Figure 25: Pollution Source-Pathway-Receptor map

4 Update of the numerical geohydrological model and impact scenarios

The ultimate goal of the numerical groundwater model is to simulate the contamination migration scenarios (Pollution plume) for each contamination barrier (lining) alternative.

4.1 Numerical software code

The modelling software package Feflow (Diersch, 1979), is used to rebuild the current finite-element 2D/3D numerical groundwater model.

4.2 General assumptions and model limitations

A numerical model solves both complex and simple problems, and serves as basis for the simulation of various scenarios. However, it should be reiterated that, as a simplified representation (approximation) of the real system, its level of accuracy is sensitive to the quality of the data that is available.

Errors due to uncertainty in the data and the capability of numerical methods to describe natural physical processes are always associated with groundwater numerical models. The building of a numerical model requires some assumptions to make an easier representation of the real aquifer systems. Such assumptions involve mainly:

- Geological and hydrogeological features;
- Boundary conditions of the study area;
- Initial water levels of the study area;
- The processes governing groundwater flow; and
- The selection of the most appropriate numerical code.

Based on the available field data, the following assumptions have been made for the above developed conceptual model:

- The top of the aquifer is represented by the generated groundwater heads;
- Averages of the distribution of the estimated parameters have been used as input of the model, and a homogenous and continuous aquifer system has been assumed. The

complexities of fractured rock aquifers imply that the model can only be used as a guide to determine the order of magnitude of contaminant transport;

- Where specific aquifer parameters have not been determined for some reason, text book values have been used, where applicable, considering typical hydrogeological environment, with reasonable estimates of similar hydrogeological environments;
- The system is initially in equilibrium and therefore in steady state, even though natural conditions have been disturbed.
- The boundary conditions assigned to the model are considered correct.
- The impacts of other activities (mine, agriculture, etc...) have not been taken into account.
- Potential preferential flow paths along the boreholes that exist at the footprint of the facility have not been taken into account;
- The complexities associated with flow and transport in aquifer systems (fractured, fractal, act…) have not been taken into account.

Any interpretation and decision from the model results should be based on these assumptions.

4.3 Flow model boundaries and initial conditions

One of the first and most demanding tasks in groundwater modelling is the identification of the appropriate model boundaries. A model boundary is the interface between the model area and the surrounding environment. Conditions on the boundaries, however, have to be specified. Boundaries occur at the edges of the model area and at locations in the model area where external influences are represented, such as rivers, wells, and leaky impoundments. Criteria for selecting hydraulic boundary conditions are primarily catchments topography, hydrology and geology. The topography, hydrology, and groundwater drainage were used mainly in the definition of the lateral boundary, whereas available geology and hydrogeology information were used for the aquifer layer thickness. Unlike the existing models which used finite difference software packages, the present model makes use of finite elements mesh to mimic the physical boundary shapes (Water divided, Rivers (including diversion), boreholes, etc.…). The mesh of the model was also more finely discretised to include special features (Continuous ash disposal and dams areas, lineaments, etc.…). The following boundary conditions were set (**Figure 26**):

- Fluid flux (Neumann) at the northern East boundary and the western side of the South boundary;
- Hydraulic head (Dirichlet) at the West, at the perennial tributaries of the Wilge River which receives water from the confluence of Leeuwfontein Spruit and Schoongezight Spruit;
- Fluid transfer (Cauchy) along the Non perennial streams Leeuwfontein Spruit and Schoongezight which drain the project site;

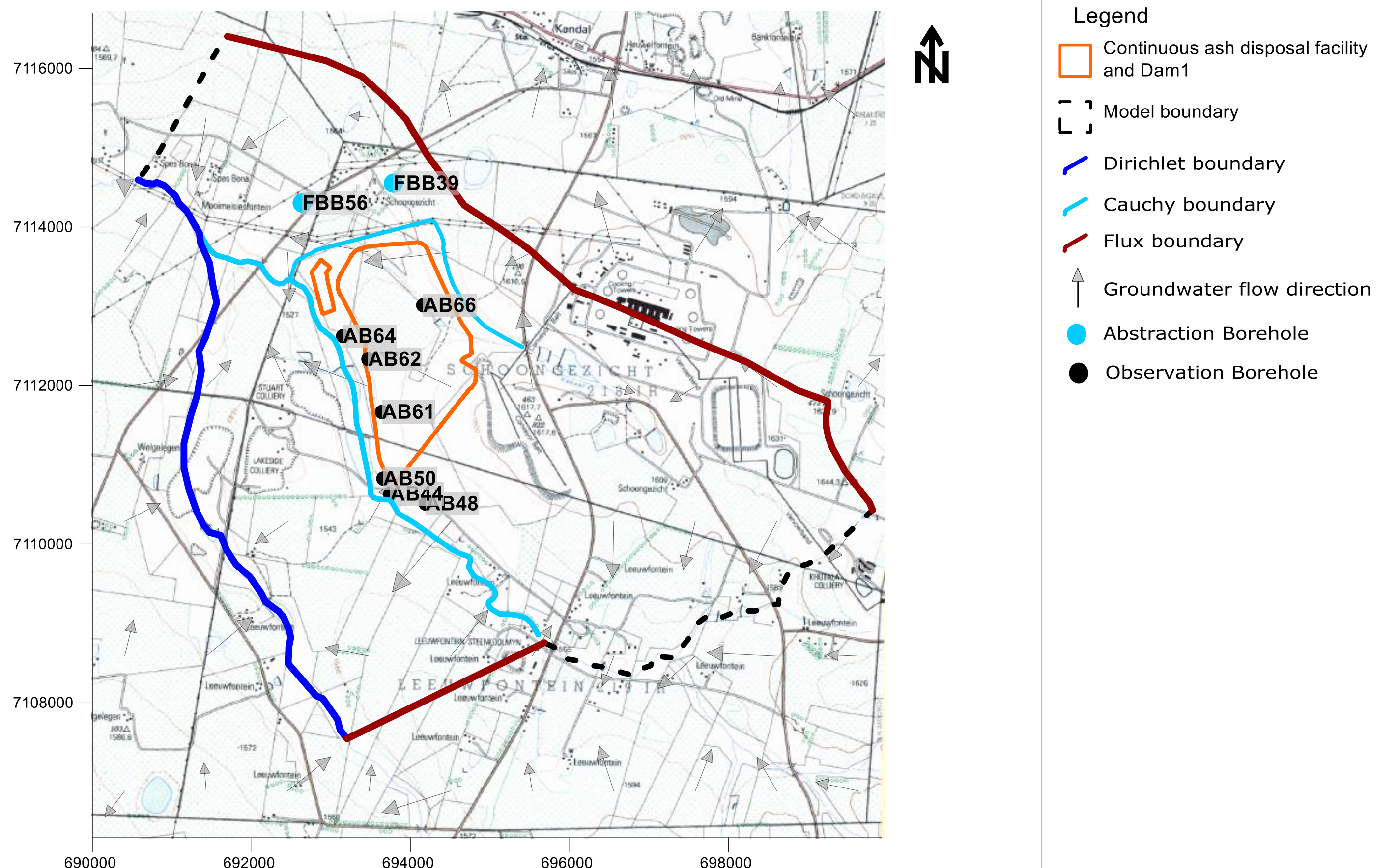
The numerical model is built of 3 layers (**Figure 27**).

Table 8: Details of model layers

Layer number	Hydro-stratigraphic unit	Top of the layer m (below Static water elevations)	Type of Aquifer
Layer 1	Weathered fractured sandy clay	0	Unconfined
Layer 2	Weathered fractured sandy clay, granite, dolerite	10	Confined/ Unconfined
Layer 3	fractured rock	30	Confined/ Unconfined

Initial conditions are vital for modelling flow problems. Initial conditions were specified for the entire area. The water elevations distributions shown in **Figure 16** were used as initial conditions for the models' steady state calibration. After steady state calibration, the resultant groundwater elevations (drainage) distribution was used as the new set of initial heads for the of scenarios simulation.

Groundwater model boundary



Co-ordinates System: UTM (HART94)

Date(s):11-2017

Drawn by : DP AHOKPOSSI

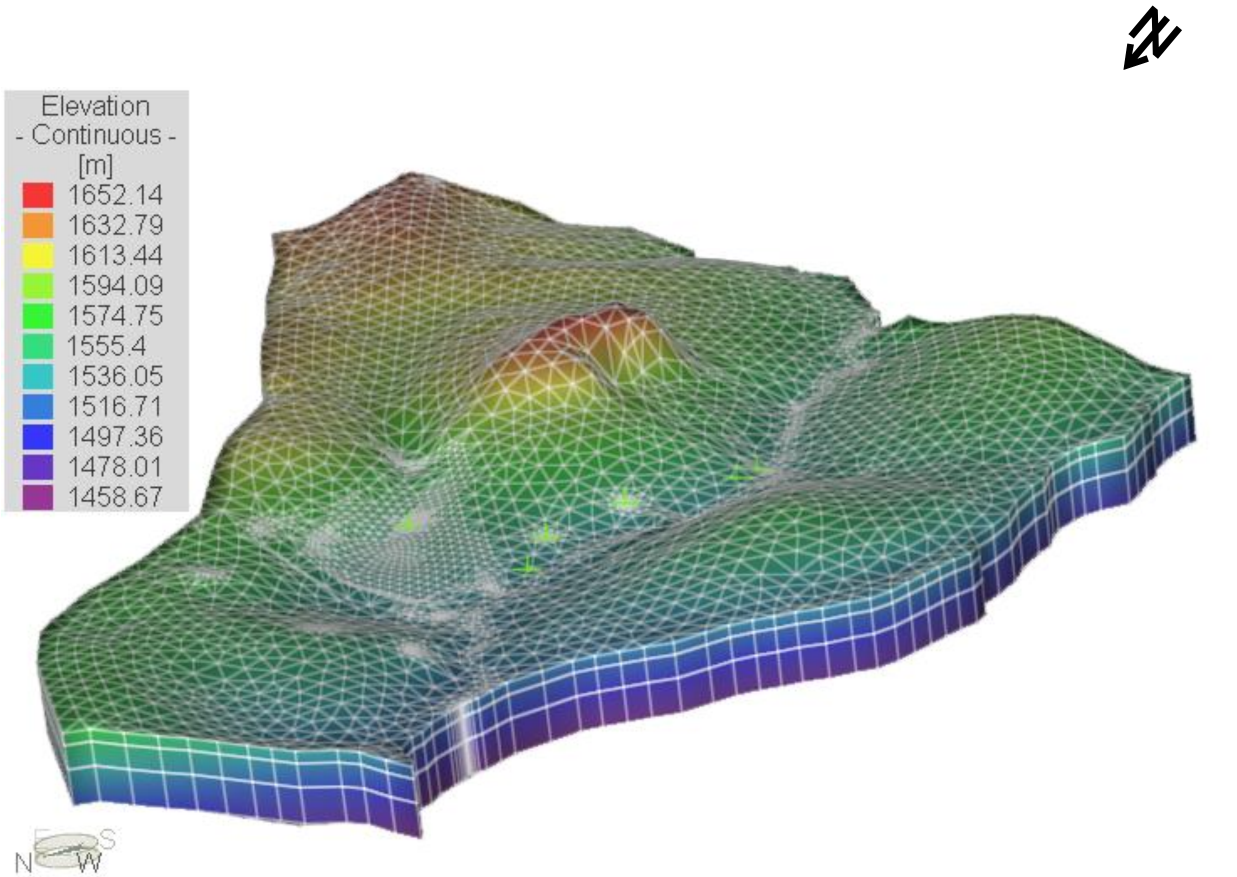
Project Title: Continuous ash disposal facility at Kendal power station Groundwater numerical model for Source Pathway Receptor study

Project Number: GHES_17_04

Client: Eskom Holdings (Pty.)

Figure 26: Groundwater model domain

Groundwater model mesh and goemetry



Co-ordinates System: UTM (HART94) Date(s):11-2017 Drawn by : DP AHOKPOSSI	Project Title: Continuous ash disposal facility at Kendal power station Groundwater numerical model for Source Pathway Receptor study Project Number: GHES_17_04 Client: Eskom Holdings (Pty.)

Figure 27: Mesh and geometry of the numerical model

4.4 Flow model calibration

Boundary conditions, and hydrological parameters (recharge and conductivity/transmissivity), were selected by a combination of trial and error, to generate the result that most strongly matches field measurements of hydraulics heads. Observations boreholes (**Figure 26**) have been chosen to verify the conditions in the boundary of ash disposal facility and surrounding. A correlation of 98% is observed between measured and calculated groundwater elevations (**Figure 28 and Figure 29**).

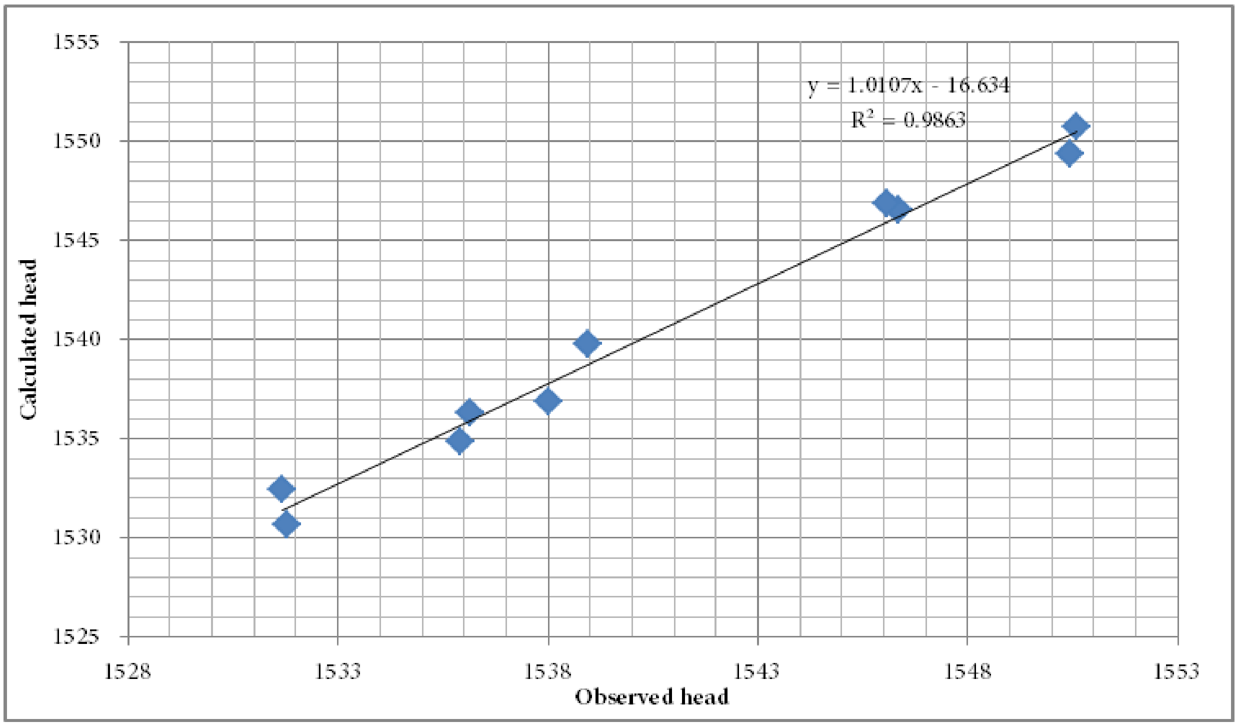


Figure 28: Observed versus calculated groundwater elevations

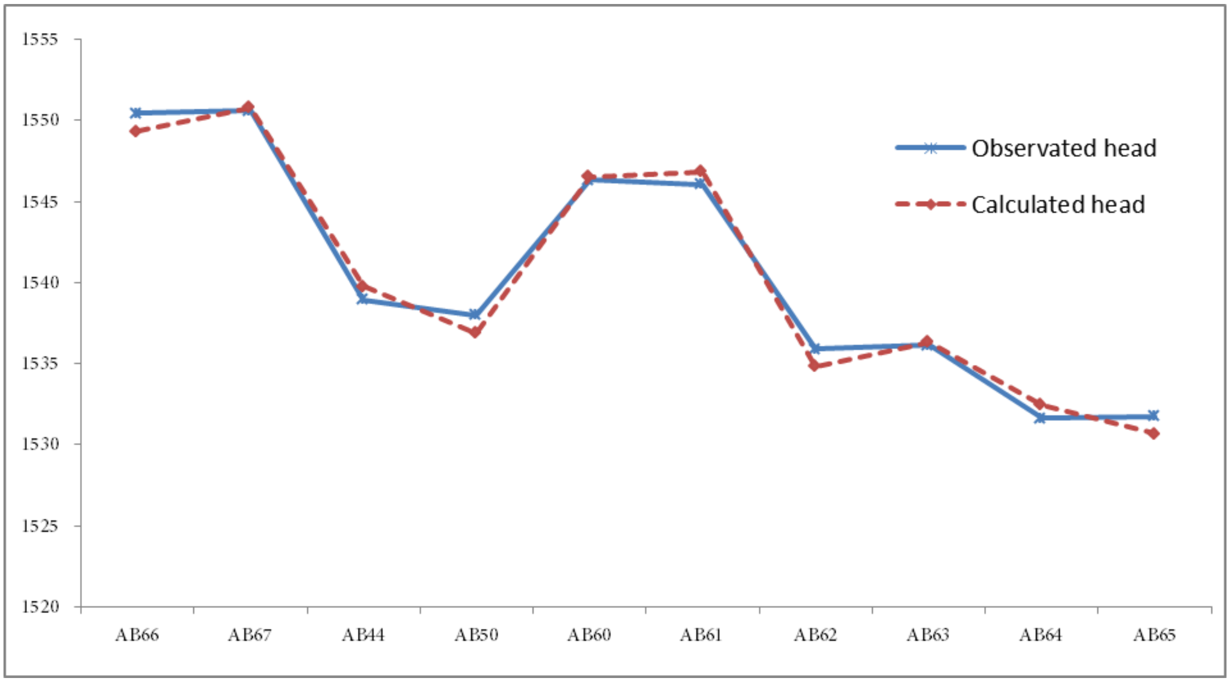


Figure 29: Model calibration

4.5 Numerical mass transport model

The most important processes in the transport through a medium are Advection, and the Hydrodynamic dispersion (Mechanical dispersion and Molecular diffusion). Other phenomena (sorption, adsorption, deposition, ion exchange, etc...) may affect the concentrations distribution of a contaminant as it moves through a medium. The effective porosity is required to calculate the average linear velocity of groundwater flow, which in turn is needed to track water particles and to calculate contaminant concentrations in the groundwater.

Among the biggest uncertain parameters used during transport modelling of pollutants are the kinematic porosity of the aquifer and the longitudinal dispersivity. Bear and Verruijt (1992) estimated the average transversal dispersivity to be 10 to 20 times smaller than the average longitudinal dispersivity. The transport model input parameters are summarized in

Table 9.

Table 9 Summary on the input for transport simulation

	Effective Porosity	Longitudinal Dispersivity	Transversal Dispersivity
	--	(m)	(m)
Layer 1	0.25	25	2.5
Layer 2	0.05-0.1	25	2.5
Layer 3	0.0001	25	2.5

4.5.1 Mass transport model boundaries and initial conditions

By default initial concentration of 0 mg/l, represents the fresh water. The contamination sources are represented by a higher initial concentration in the areas of the continuous ash disposal facility and associated dams in the top aquifer. For each alternative, the mass flux (source term) of the contamination (Sulphate) was assigned accordingly (**Table 4**).

Any water entering the domain through the northern East boundary and the western side of the South boundary is fresh water with a concentration of 0 mg/l. Therefore a max flux of 0 g/m^2/day is assigned as a boundary condition at these locations.

4.6 Simulation of predictive scenarios and discussion

The simulation of scenarios of the contamination migration scenarios (Pollution plume) for each contamination barrier (lining) alternative was conducted using the calibrated model. The simulated increases in the concentrations of sulphate in the aquifer, for each alternative for 5, 10, and 40 years after closure, are given from **Figure 30 to Figure 38**.

"Class C" and "Intermediate" are the alternatives which pose less contamination risk than "Class D". One of the particularities Class C" and "Intermediate is the presence of the finger drains which have the function to drain (collect) any water that may leak through barrier system, toward water management infrastructure. Leakage is likely to be concentrated to the finger drains area.

"Intermediate" is the preferable alternative, since the induced sulphate's concentration after 40 years of simulation at FBB56, is less than 0.01 mg/l, compared to an increase of 0.02 mg/l and 22 mg/l, respectively, for "Class C" and "Class D". **Table 10** gives a comparative predicted induced contamination impacts per alternatives.

The predicted increase of concentration of contaminant in the aquifer at the source (continuous ash dam facility area) is lesser for "Intermediate Class C" (1.8 mg/l), than for "Class C" and "Class D". "Class D" would induce the worse contamination scenario with a predicted increase in the concentration of contaminant of 125 mg/l after 40 years of simulation.

Table 10: Simulated increase in concentrations of sulphate at FBB56 after 40 years

	Current Background concentration @FBB56	Increase in concentration @FBB56	Increase in concentration @Source	SANS_241_2015 Limit
	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Class C		0.02	10.6	
Intermediate Class C	0.41	<0.01	1.80	≤ 500
Class D		22	125	

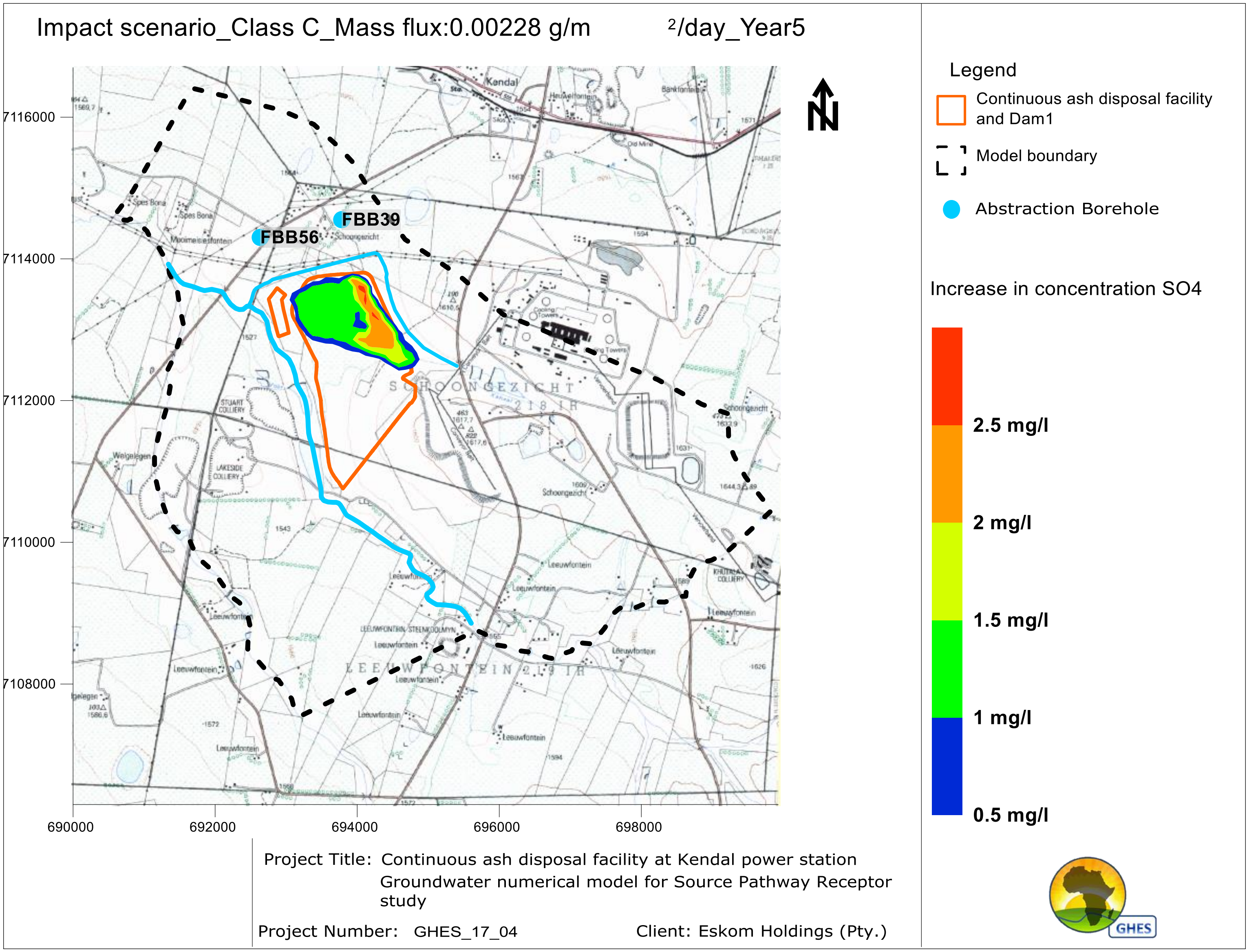


Figure 30: Simulated pollution plume impact for Class C liner after 5 years

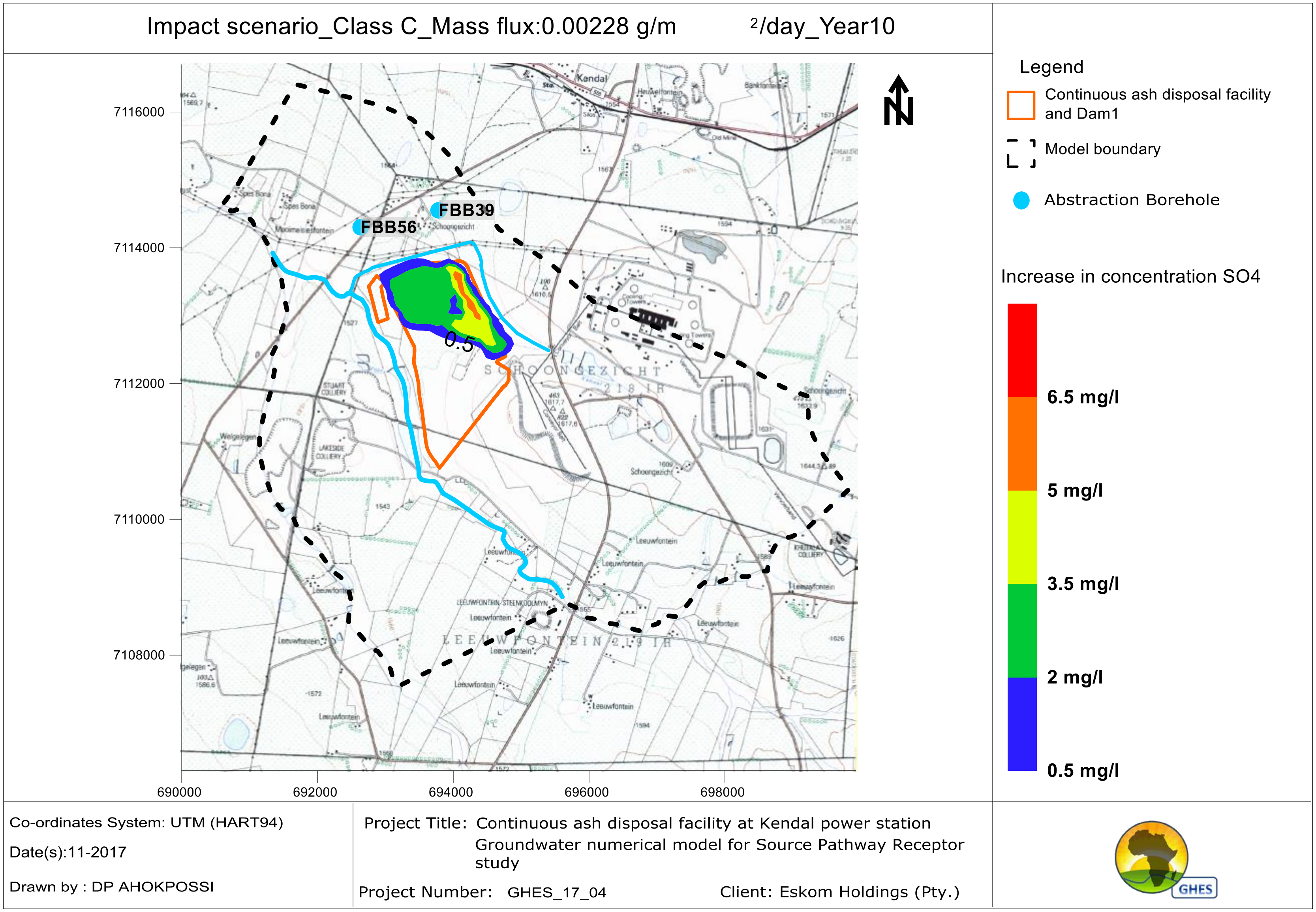


Figure 31: Simulated pollution plume impact for Class C liner after 10 years

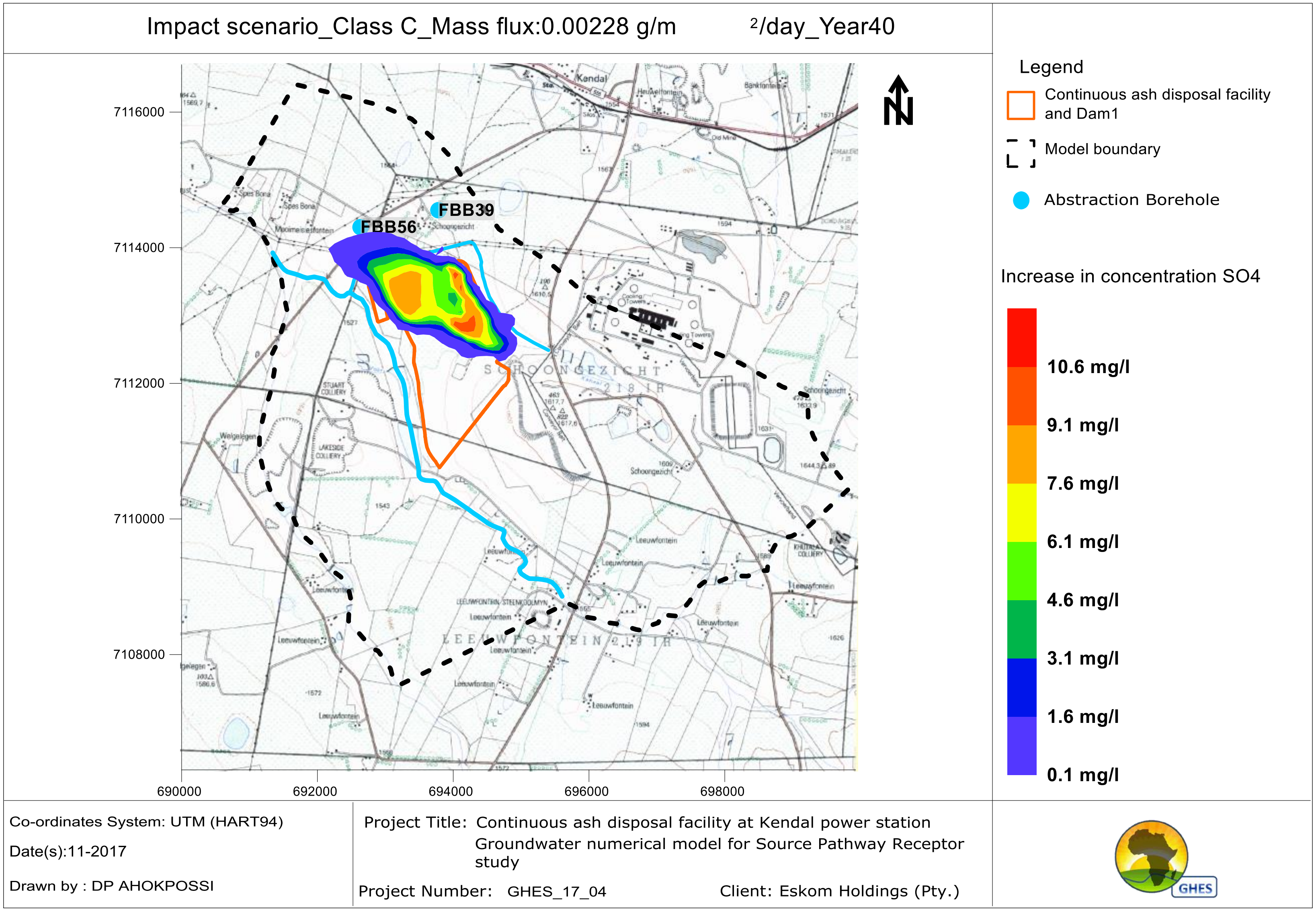


Figure 32: Simulated pollution plume impact for Class C liner after 40 years

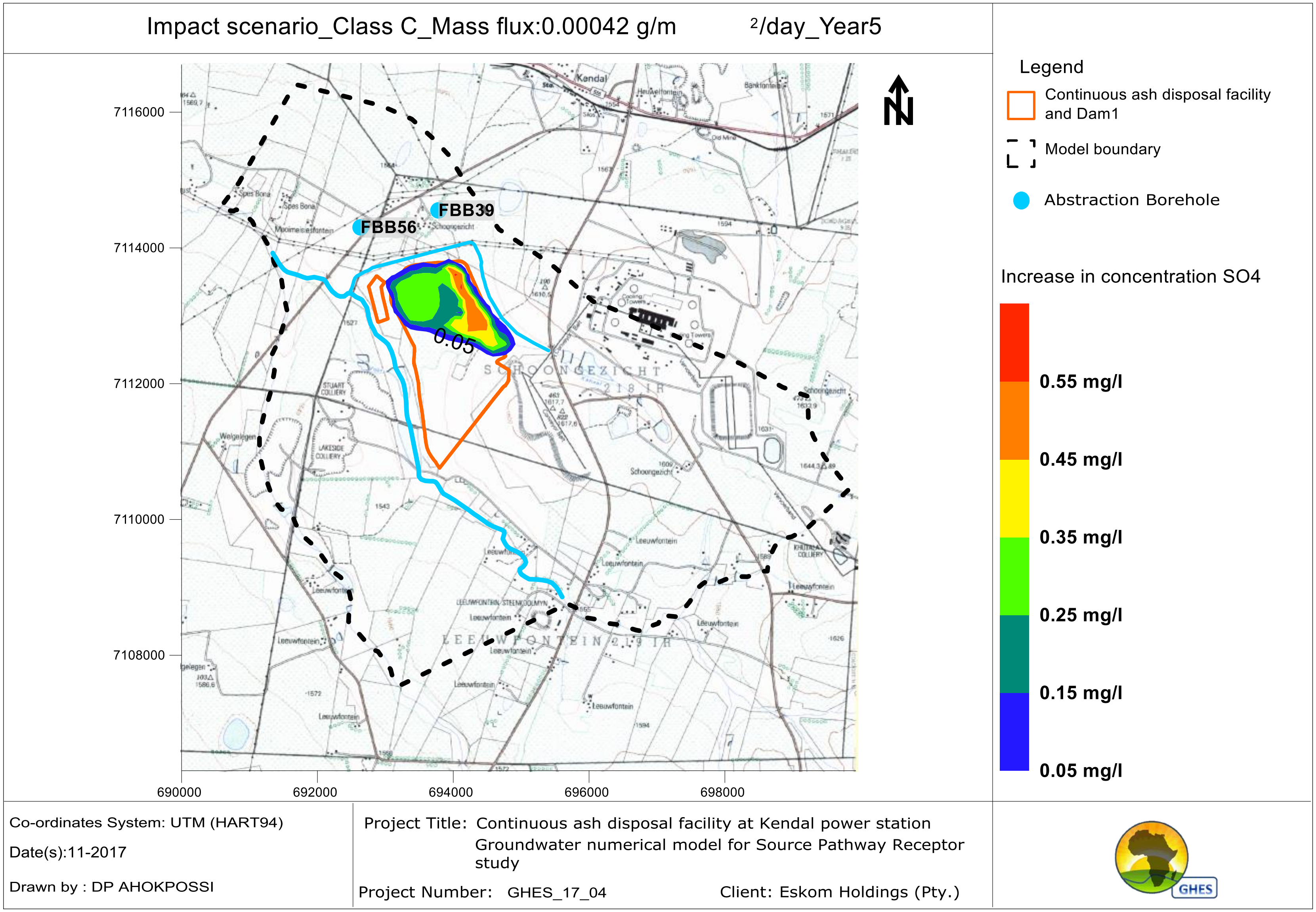


Figure 33: Simulated pollution plume impact for Intermediate Class C liner after 5 years

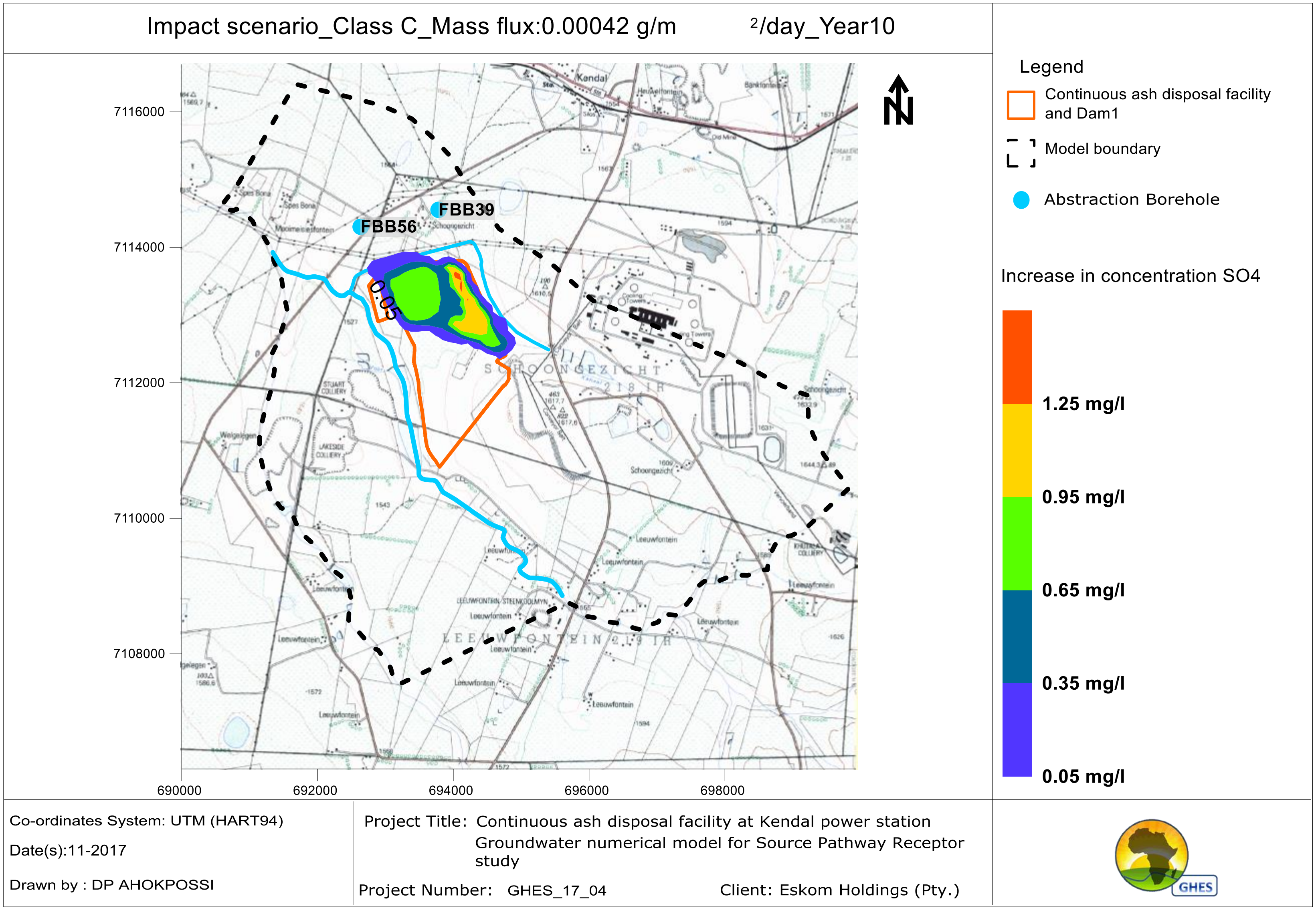
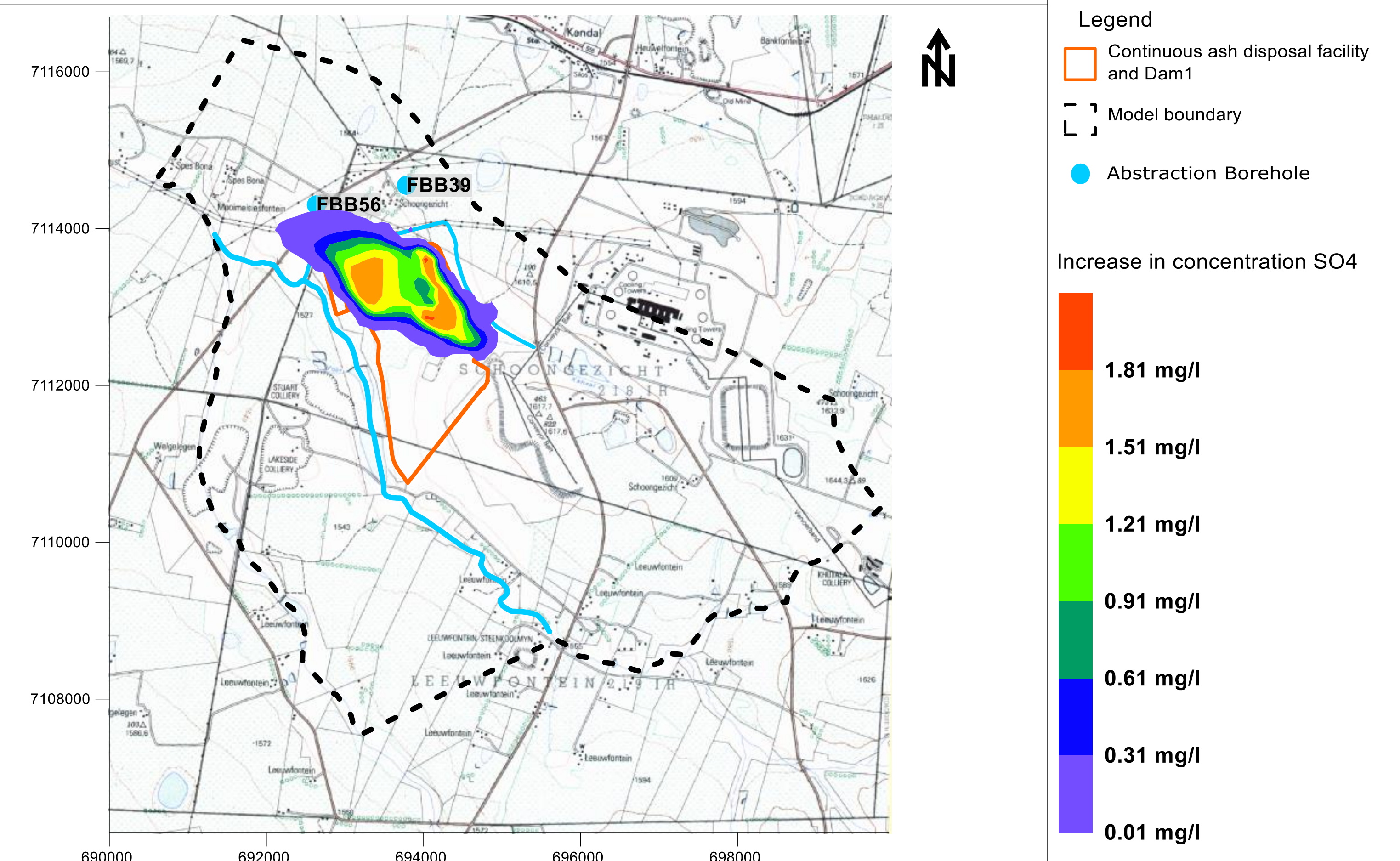


Figure 34: Simulated pollution plume impact for Intermediate Class C liner after 10 years

Impact scenario_Class C_Mass flux:0.00042 g/m²/day_Year40



Co-ordinates System: UTM (HART94)

Date(s):11-2017

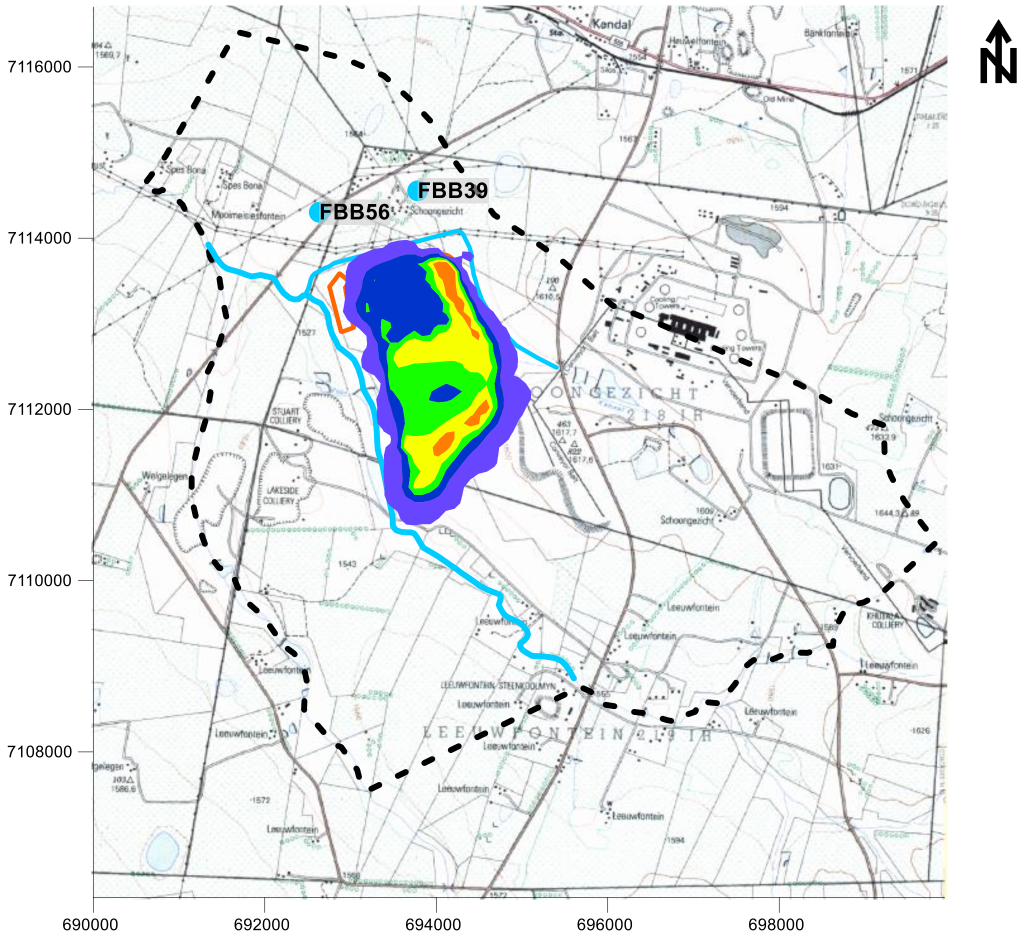
Drawn by : DP AHOKPOSSI

Project Title: Continuous ash disposal facility at Kendal power station Groundwater numerical model for Source Pathway Receptor study

Project Number: GHES_17_04 Client: Eskom Holdings (Pty.)

Figure 35: Simulated pollution plume impact for Intermediate Class C liner after 40 years

Impact scenario_Class C_Mass flux:0.052 g/m²/day_Year5



Legend

- Continuous ash disposal facility and Dam1
- Model boundary
- Abstraction Borehole

Increase in concentration SO4

- 75.5 mg/l
- 60.5 mg/l
- 45.5 mg/l
- 30.5 mg/l
- 15.5 mg/l
- 0.5 mg/l

Co-ordinates System: UTM (HART94)

Date(s):11-2017

Drawn by : DP AHOKPOSSI

Project Title: Continuous ash disposal facility at Kendal power station Groundwater numerical model for Source Pathway Receptor study

Project Number: GHES_17_04

Client: Eskom Holdings (Pty.)

Figure 36: Simulated pollution plume impact for Class D liner after 5 years

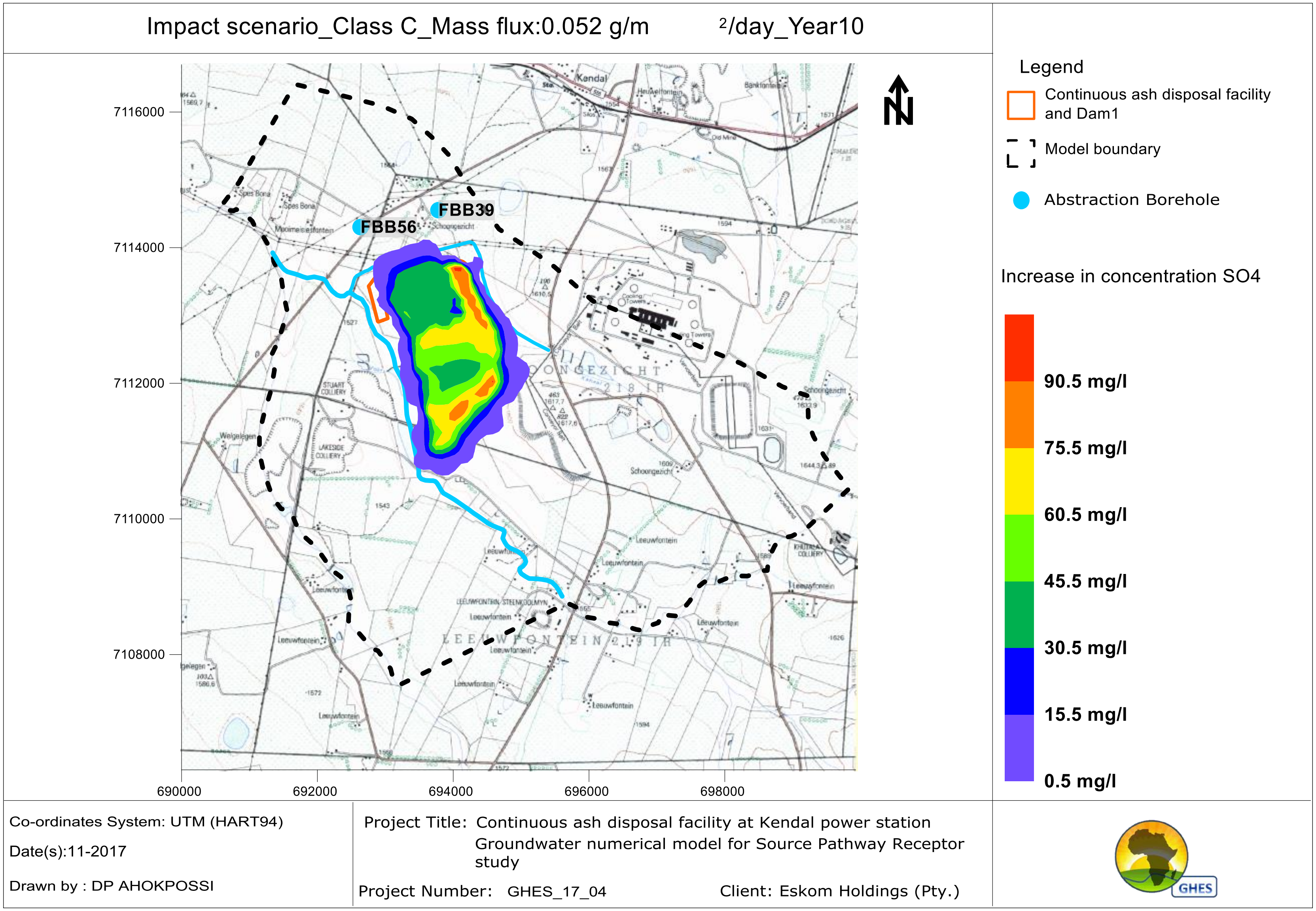
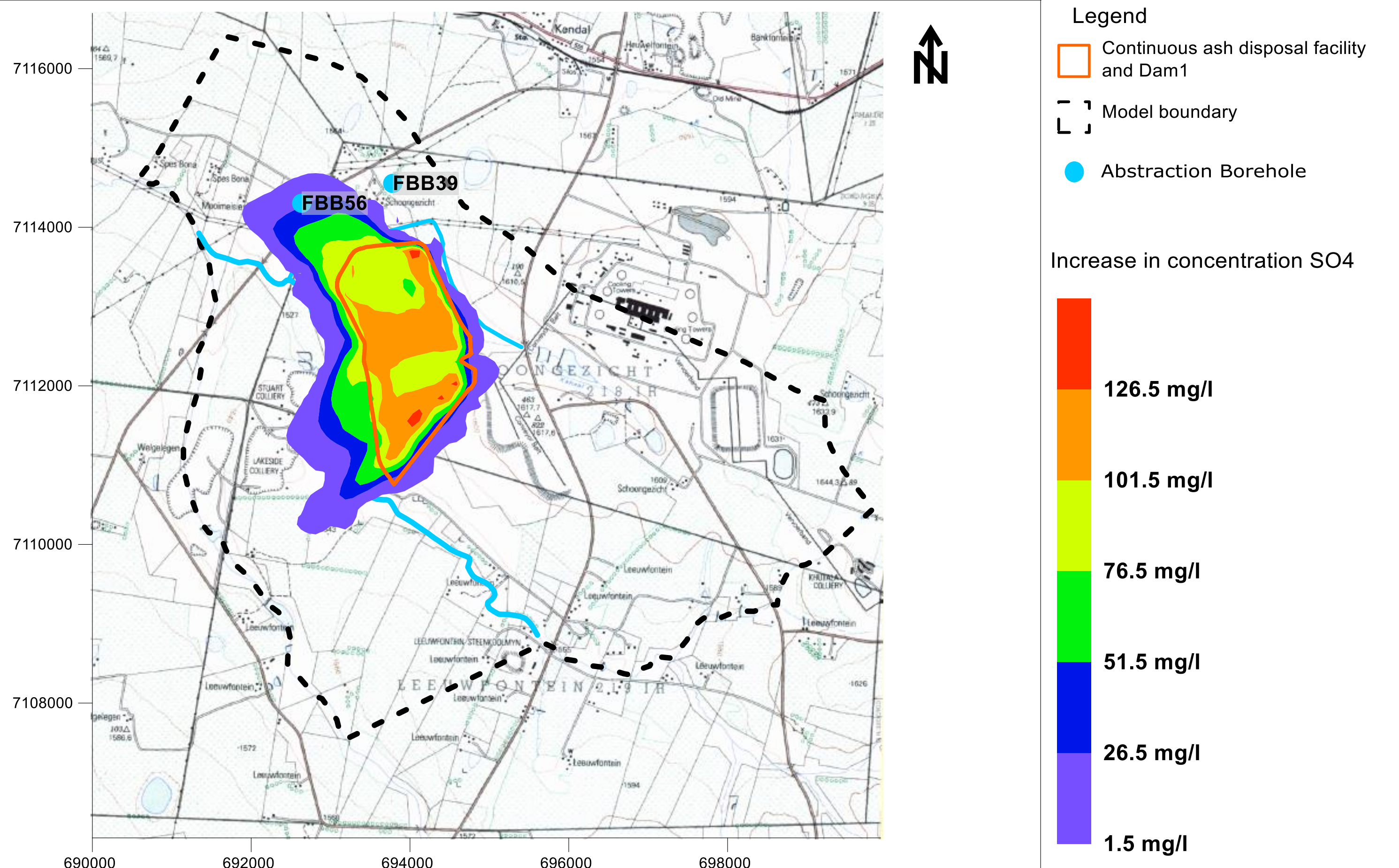


Figure 37: Simulated pollution plume impact for Class D liner after 10 years

Impact scenario_Class C_Mass flux:0.052 $g/m^2/day$_Year40



Co-ordinates System: UTM (HART94)

Date(s):11-2017

Drawn by : DP AHOKPOSSI

Project Title: Continuous ash disposal facility at Kendal power station Groundwater numerical model for Source Pathway Receptor study

Project Number: GHES_17_04

Client: Eskom Holdings (Pty.)

Figure 38: Simulated pollution plume impact for Class D liner after 40 years

5 Conclusions and Recommendations

GHES completed the numerical groundwater investigation as part of the Source Pathway Receptor study for the continuous ash disposal facility of the Kendal power station, and the following conclusions are reached:

- Due to the possibility of leaking of lining (barrier) system, the continuous ash disposal facility with its associated dirty water management infrastructures, constitutes the potential sources of contaminants which are specifically associated with the project. The potential contaminants of concern include Mn, SO_4, Fe, and F;
- Based on 03 different lining scenarios (Class C, Intermediate Class C, and Class D), the leakage rates were calculated by the Engineering team of Zitholele consulting and provided to GHES;
- Local groundwater is one of the potential pathways for the migration of the contaminants to receptors (borehole water users, and receiving surface water). Potential contamination from ground surface will mostly impact on the shallow weathered and fractured aquifer system;
- The thickness of the local shallow aquifer was estimated to be between 5 and 25 m, and consists mainly of clay, granites and dolerites of the Karoo Supergroup;
- The thickness and the geometry of local sill and lineaments in the area are expected to control the groundwater flow and possible pollution emanating from ground surface;
- One privately owned borehole (Kendal2/ FBB56) is located within less than 1 km to the north of the continuous ash disposal facility's site, risks to be impacted by potential contaminants from the project. The background water quality at the borehole represents unpolluted groundwater.
- The wetland study conducted by Wetland Consulting Services for the continuous ash disposal facility suggest that surface runoff inflow and interflow inflow are likely to be the main hydrological drivers supporting the overall wetness within a wetland, and that minor dependence of the local wetland on shallow saturated groundwater flow may be expected.
- The increases in the concentrations of sulphate in the local aquifer were simulated for each alternative simulated over 40 years after closure using a finite element numerical model:

- Intermediate Class C is the preferable alternative if only the migration of contaminants into the aquifer has to considered since the induced increase of sulphate's concentration after 40 years of simulation at FBB56, is less than 0.01 mg/l, compare to an increase of 0.02 mg/l and 22 mg/l, respectively, for "Class C" and "Class D".
- The predicted increase of concentration of contaminant in the aquifer at the continuous ash disposal facility area is lesser for "Intermediate Class C", than for "Class C" and "Class D";

The following recommendations are to be considered:

- Intensify monitoring of water levels and quality along surface drainage to better characterise the local interactions between surface and ground waters;
- Collect monitoring and topographic data from surrounding mine (East of the facility), and abstractions data from the receptive borehole owner (FBB56), to update the current numerical model;
- Conduct additional sampling and testing to confirm the tests results presented in existing geochemical test data sheet;
- Field Kinetic tests should be conducted on site to model and predict leachate water quality;
- Develop a geochemical model to predict leachate water quality, using suitable software such PREEQC or equivalent.