APPENDIX A

HYDROGEOLOGICAL ASSESSMENT REVIEW

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Tutuka Power Station Ash Disposal Facility – Hydrogeological Assessment

Final Report

Version - 1

29 July 2019

Eskom Holdings SOC Ltd

GCS Project Number: 19-0217

Client Reference: GCS

Final Report
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29 July 2019

Eskom Holdings SOC Ltd

19-0217

DOCUMENT ISSUE STATUS

Report Issue	Final Version - 1		
GCS Reference Number	GCS Ref - 19-0217		
Client Reference	GCS		
Title	Tutuka Power Station Ash Disposal Facility – Hydrogeological Assessment		
	Name	**Signature**	**Date**
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Document Reviewer	Alkie Marais		29 July 2019
Director	Alkie Marais		29 July 2019

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CONTENTS PAGE

List of Figures

LIST OF TABLES

LIST OF APPENDICES

1 INTRODUCTION

GCS Water and Environment (Pty) Ltd (GCS) was appointed by Eskom Holdings SOC Ltd to undertake a hydrogeological assessment for the Tutuka Power Station Ash Disposal Facility required for the extension of the exemption granted by the Department of Environmental Affairs (DEA) for the continuous Ash Disposal Facility (ADF), located north of Standerton, in the Mpumalanga Province of South Africa.

1.1 Background

Tutuka Power Station applied for an environmental authorisation for the continuous Ash Disposal Facility (ADF), which was approved by the Department of Environmental Affairs (DEA) on 19 October 2015. Subsequent to this, the station applied for a 4-year exemption from installing the required liner (a Class-C liner) on an immediate ashing area since the approval. The equivalent footprint for the 4-year exemption was estimated to be 54ha, and was assessed and motivated by an independent environmental consultant. The DEA granted the 4-year exemption on 5 May 2016. The exemption period lapses on 4 May 2020 (4 years after the date of issue). Parallel to ashing on the area under the exemption, developmental work was executed for the Class C liner for the rest of the ADF, starting at the boundaries of the area under Exemption.

In 2018, the project realised that the 54ha approved under the exemption would not be fully utilised at the end of the 4-year exemption period, and Eskom undertook to evaluate alternatives that could be followed to manage this remaining area. From evaluation process of the alternatives a decision was made to apply for an extension of the exemption period, without extending the area under the exemption. The inability for full utilisation of the area under exemption was triggered by a reduction in the station’s Generation Load Factor (GLF), which happened after the exemption was approved. A meeting was held Eskom and the DEA to explain the challenge, and get guidance from the DEA on the most appropriate process to follow for extending the exemption period. Following this engagement a Part 1 amendment application was submitted to the DEA on 7 December 2018.

The DEA responded on 9 January 2019, with a requirement for the project to undertake a Part 2 amendment process; required all specialists that conducted the studies to confirm that the required extension would not have additional impacts on the environment; required a public participation process; and required results of all monitoring programmes that were requested to be developed in the exemption approval.

1.2 Terms of reference

The scope of work required by Eskom Holdings SOC Ltd is the verification of potential impacts determined from previous specialists' studies of the requested extension, developing a report of these investigations, undertaking public participation process, and reflecting on the status of compliance with the conditions of the exemption approval.

Environmental consultants are required to undertake the following:

- Respond to the DEA's requirement, which states, "Confirmation from all specialists that conducted the studies that the proposed amendment will not have additional impacts on the environment." This means the specialist in these respective specialist fields must assess the specialist reports produced during the exemption application, and confirm if their findings will change due to additional time used to ash over the same footprint (54ha) under the exemption approval;
- Provide results of monitoring programmes requested in the exemption approval; and
- Undertake public participation process for a Part 2 amendment process.

2 SCOPE OF WORK

GCS will conduct a desktop study level hydrogeological assessment in order to verify the potential impacts determined from the previous hydrogeological study. The scope of work consisted of the following tasks:

- A review of the previous specialist hydrogeological study;
- Review of available site monitoring and received data (incl. groundwater levels and quality);
- Verify the potential impacts from the ash disposal facility; and
- Recommendation to address identified potential gaps.

2.1 Limitations, assumptions and exclusions

The following limitations, assumptions and exclusions apply based on the scope of work:

- No site visit was conducted by GCS, i.e. no reconnaissance site visit, hydrocensus (incl. groundwater level measurements and quality sampling);
- Limited groundwater monitoring quality results were made available. Only data from July 2015 to December 2016 were made available;
- No intrusive studies were conducted during the GCS study, i.e. no drilling of boreholes;
- No aquifer hydraulic tests were conducted, i.e. no slug tests and pump tests;
- No geochemical assessment was conducted by GCS on the ash material;
- No geochemical or waste classification data from the site were received;

- No groundwater numerical model was compiled for the site by GCS. GCS will only review the previous modelled groundwater impacts made by SLR;
- This assessment does not evaluate the existing groundwater monitoring and management programme at Tutuka Power Station and the ash disposal facility; and
- This assessment does not include the appraisal of modelling results or in-depth review of the model constructed for a separate numerical groundwater model for the site (GHT Consulting Scientists – Ash Stack Pollution Plume Model 2015).

3 METHODOLOGY

3.1 Review of previous hydrogeological study

The previous hydrogeological study was conducted by SLR Consulting (Africa) (Pty) Ltd):

- Tutuka Power Station Proposed Continuous Ash Disposal at Tutuka Power Station: Groundwater Specialist Study – SLR Project No.: 721.23003.00014 – July 2014.

  The objectives of this report were:

  - To develop a hydrogeological conceptual site model (CSM) for Tutuka Power Station and document baseline groundwater conditions of the study area.
  - To assess in detail the impacts on the groundwater resources that may result from the continued ash disposal at Tutuka Power Station, considering construction, operation and decommissioning phases of the project.

- Tutuka Power Station Proposed Continuation of Ash Disposal: Hydrogeological Screening Report – SLR Project Ref.: 721.23003.00014 – October 2012.

  The objectives of this report were:

  - Conceptualise the groundwater regime based on the available geological report(s) and data.
  - Identify, through a risk-based process, areas within an 8km radius of the power station that are 'high risk' to groundwater and those that are 'low risk'. Risk to groundwater will be assessed using a simple risk-based model developed in GIS using available data.

3.2 Site data review

Data that was reviewed includes:

- Published 1:250 000 scale geological data and map (CGS,1986);
- Published hydrogeological data and map;
- Public domain climatic and topographic data for the site;
- Eskom Holdings (Pty) Ltd: Tutuka Power Station Water Use License (08/C11K/ABCFGI/1016);

- Groundwater monitoring reports:
  - GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 3rd Quarter 2016 (December 2016)
  - GHT Consulting Scientists – Annual Report Phase 52 – Final Report (December 2016)
  - GHT Consulting Scientists – Annual Report Phase 51 – Final Report (July 2016)
  - GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 2nd Quarter 2016 (July 2016)
  - GHT Consulting Scientists – Annual Report Phase 50 – Final Report (March 2016)
  - GHT Consulting Scientists – Farmers' Background Boreholes Annual Report March 2016 (March 2016)
  - GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 1st Quarter 2016 (March 2016)
  - GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 3rd Quarter 2015 Final Report (October 2015)
  - GHT Consulting Scientists – Monitoring Report Phase 48 – Final Report (October 2015)
  - GHT Consulting Scientists – Hazardous Waste Site 1st Quarter 2015 Annual Monitoring Site Assessment Report (July 2015)
  - GHT Consulting Scientists – Monitoring Report Phase 47 – May 2015 Final Report (July 2015)
- Groundwater investigation reports:
  - GHT Consulting Scientists – Drilling report for the installation of monitoring boreholes 2018 (March 2018)
  - GHT Consulting Scientists – Hydrocensus April 2017 (June 2017)
  - GHT Consulting Scientists – Ash Stack Pollution Plume Model 2015 (March 2016)

3.3 Verify potential impacts

The previous hydrogeological studies conducted during the original exemption application will be reviewed together with the site information received (as listed in Section 3.2). Findings will be made to determine if SLR's previously predicted groundwater impacts will change or not due to additional time used to ash over the same footprint (54ha) under the exemption approval area.

4 GENERAL PHYSIOGRAPHICAL AND GEOLOGICAL DESCRIPTION

4.1 Locality

Tutuka Power Station is located approximately 25 km north-east of Standerton, Mpumalanga Province, South Africa. Figure 4.1 illustrates the locality of the Tutuka ash disposal facility and power station.

4.2 Climate

The climate can be described as typical Highveld conditions with moderate and wet summers and cold dry winters. The mean annual precipitation is approximately 580mm/year with rain experienced predominantly in the summer months (October to April) (SLR, 2014).

4.3 Topography and drainage

The area is characterised by a strong undulating topography with low ridges east of the study area. The natural topography however has been disturbed as a result of various agricultural and power generation activities. Topography ranges approximately from a low of 1 613 meters above mean sea level (mamsl) on the southern site boundary, to a high of 1 640 mamsl on the northern site boundary. The topography of the Tutuka site and surrounding area is illustrated in Figure 4.2.

Several streams and rivers are present in the area surrounding the project site, with the Leeuspruit River and the Vaal River being the two main surface water features. The Leeuspruit River is approximately 12 km west of the site and flows south into the Grootdraai Dam. The Vaal River is approximately 12 km south of the site and flows west into the Grootdraai Dam. Local drainage is in a general southerly direction towards the Vaal River. The Grootdraai Dam is located approximately 15 km to the south of the ash disposal facility site.

The project area falls in the C11K quaternary catchment in the Upper Vaal Water Management Area.

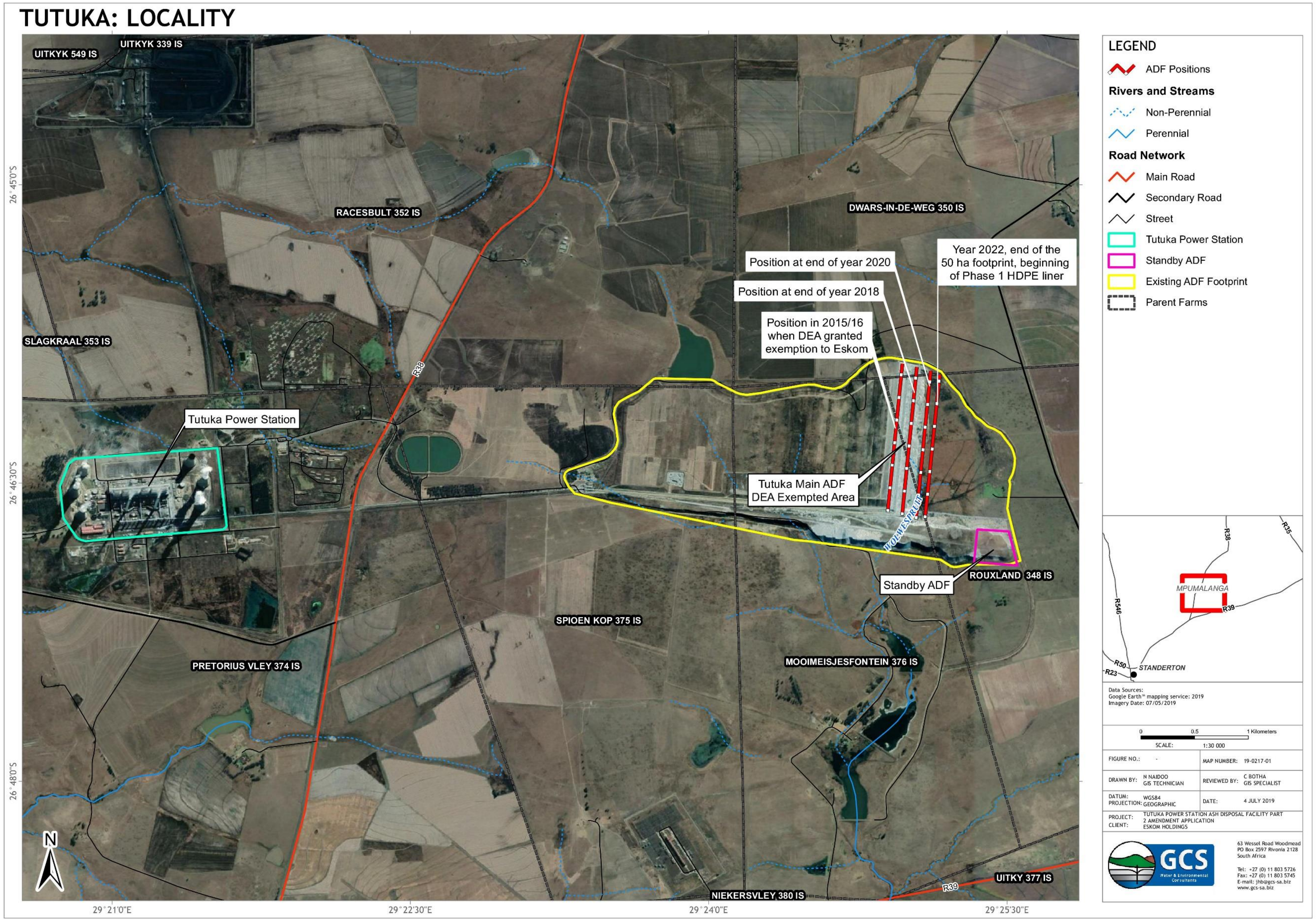

Figure 4.1: **Locality of the Tutuka power station and ash disposal facility site.**

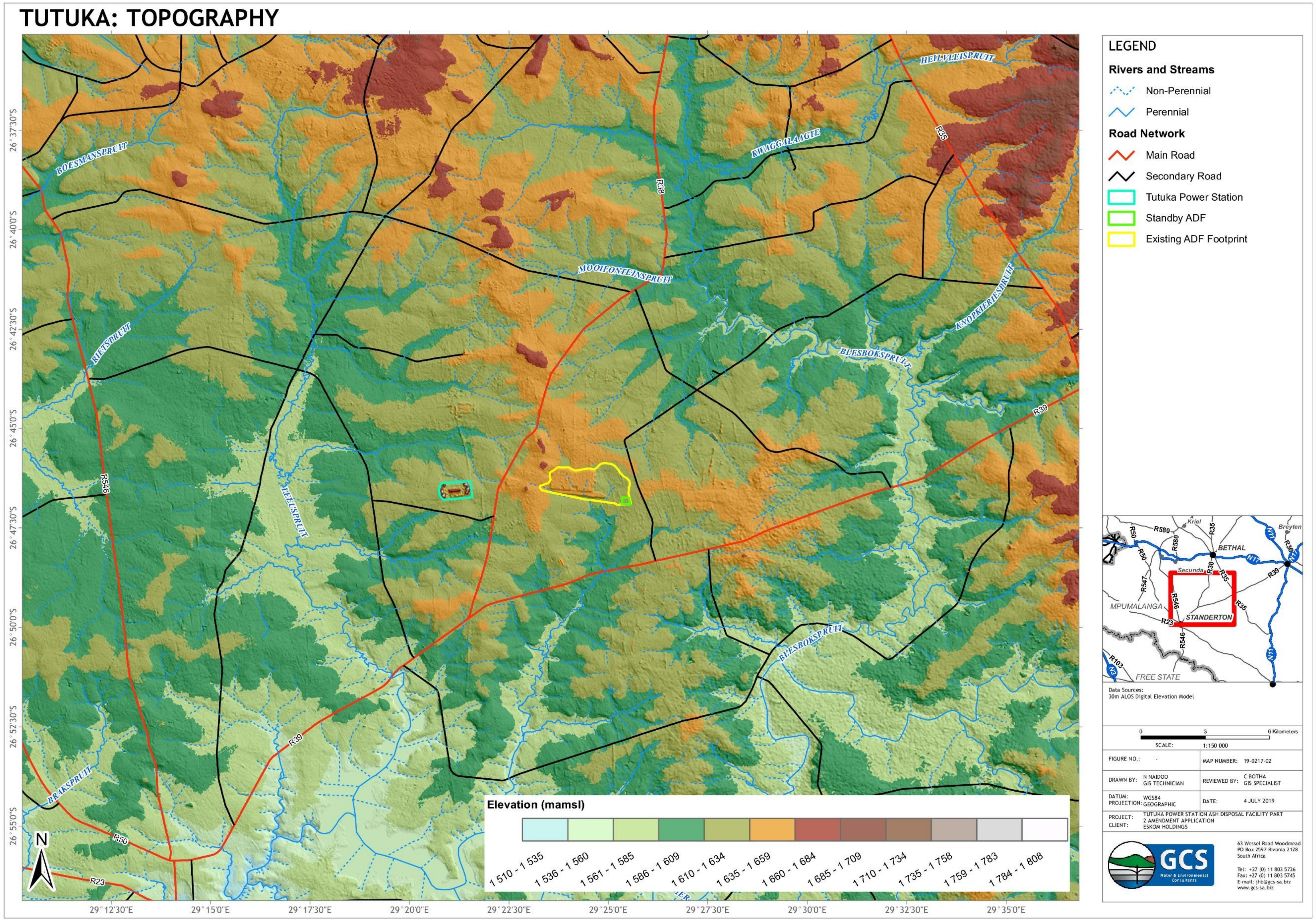

Figure 4.2: **Topography and major rivers/streams of Tutuka site and surrounding area.**

4.4 Geological Setting

The baseline geological information was sourced from previous studies (SLR, 2014) and available literature.

4.4.1 Regional geology

The Tutuka Power Station and the surrounding area are underlain by Karoo Supergroup lithology of Permian to Jurassic age and predominantly consists of the Permian Ecca Group (Vryheid Formation) and dolerite intrusions. All of the known coal deposits in South Africa are hosted in sedimentary rocks of the Karoo Basin, a large foreland basin which developed on the Kaapvaal Craton and filled between the Late Carboniferous and Middle Jurassic periods. The Karoo Supergroup is lithostratigraphically subdivided into the Dwyka, Ecca and Beaufort groups and succeeded by the Molteno, Elliot, Clarens, and Drakensburg formations. The coal ranges in age from early Permian (Ecca Group) through to Late Triassic (Molteno Formation) and is predominantly bituminous to anthracite in rank, which is classified in terms of metamorphism under influence of temperature and pressure.

The coal seams are usually separated by coarse to fine-grained sandstone, siltstone and/or shale at the top. Glauconitic sandstones, indicative of transgressive marine periods, are present above the No.4 and No.5 Seams. The coal zone is overlain by another deltaic sequence, which consists of sandstone and sandy micaceous shale and siltstone with varying thickness (approximately 60 to 100m thick).

The Karoo sediments are practically undisturbed and geological structures (e.g. faults, shears, associated fracturing) are rare. However, fractures are common in rocks such as sandstone and coal. Dolerite intrusions, in the form of sills or dykes cause in some locations various mining problems (i.e. devolatised coal, weakened roof strata and/or displaced coal seams), where near vertical dykes have very little displacement associated transgression through the seam.

Sill transgressions, on the other hand, generally results in displacement of the coal seams and strata. The magnitude of these displacement being dependent on a number of factors, including sill thickness and presence / orientation of pre-existing zones of weakness. These intrusions introduce local structural complexity by displacing seams relative to one another and isolating blocks of coal.

4.4.2 Local geology

As seen in Figure 4.3 the Tutuka site area is underlain by the Vryheid Formation and dolerite intrusions.

The Vryheid Formation is made up of various lithofacies arranged in upward coarsening cycles which are essentially deltaic in origin. The formation can generally be divided into a lower fluvial dominated deltaic interval, a middle fluvial interval and an upper fluvial-dominated deltaic interval which are associated with 'lower sandstone unit, 'coal zone' and 'upper sandstone unit'. It was noted that in the vicinity of Tutuka the geology is mainly arenaceous sandstone (SLR, 2014).

The area in the vicinity of Tutuka (and on a wider scale) is intruded by a network of dykes, sills and discordant sheets that are well developed in the sedimentary sequences. The intrusions predominately consist of ultramafic / mafic rocks consisting of dolerite, diabase, gabbro, norite, carbonatite, anorthosite and pyroxenite (SLR, 2014).

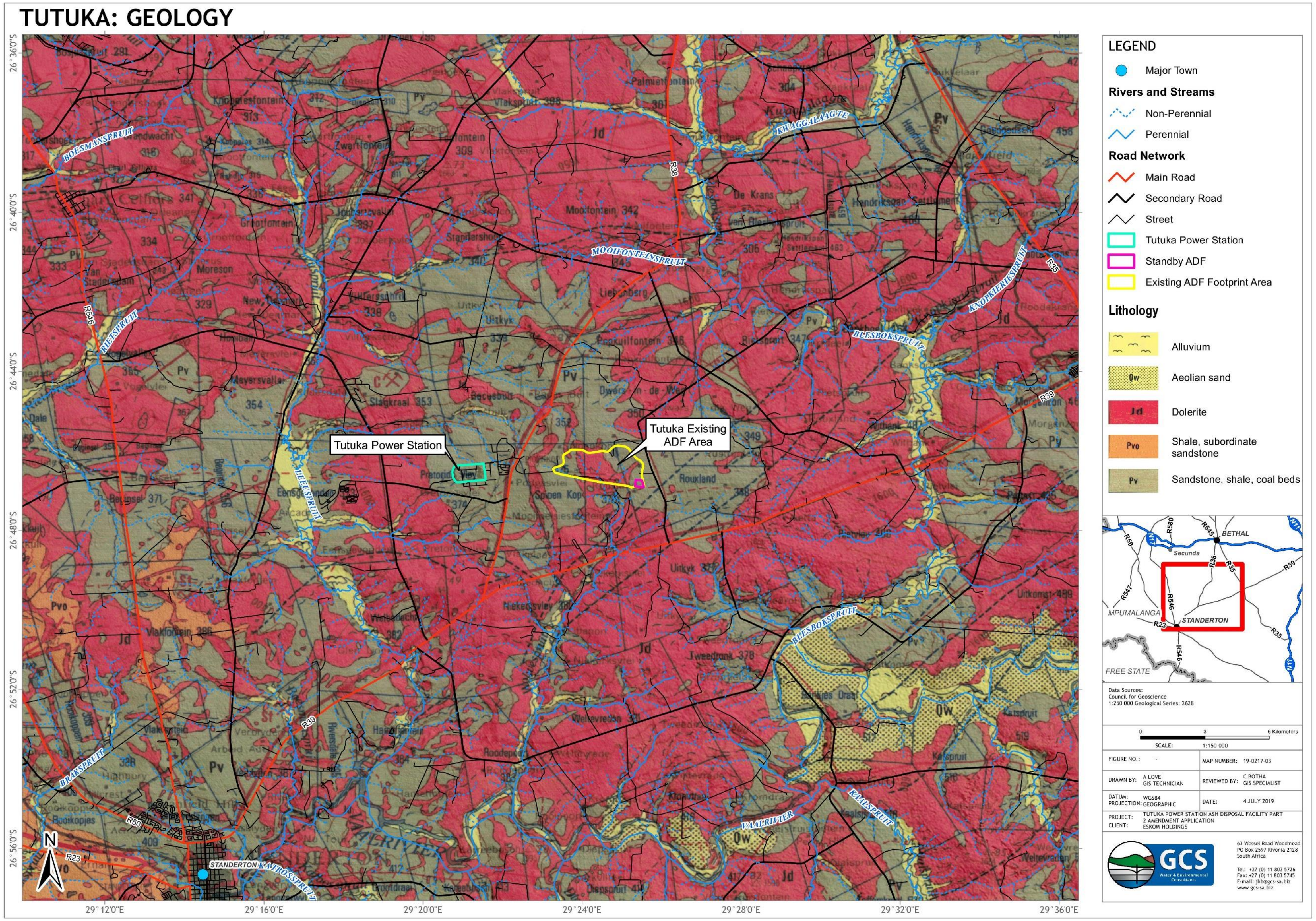

Figure 4.3: Regional geology of Tutuka site and surrounding area.

5 HYDROGEOLOGICAL SETTING

5.1 General Aquifer Description

Regional hydrogeological data was sourced from the published 1:500 000 Hydrogeological Map Series of the Republic of South Africa – Sheet 2526 (Johannesburg) and previous studies for the site.

The Tutuka site is underlain by Karoo sedimentary rocks and dolerite intrusions (Section 4.4) and the hydrogeological characteristics of the study are a function of the geological formations. The aquifers of the Karoo Supergroup display characteristics of intergranular and fractured rock. The borehole yielding potential of the aquifer is classified as d2, which implies an average borehole yield varying between 0.1 and 0.5 l/s. There are typically six different modes of groundwater occurrence associated with these formations (Barnard, 2000). According to Barnard (2000) the six different modes are:

- Weathered and fractured sedimentary rocks not associated with dolerite intrusions;
- Indurated and jointed sedimentary rocks alongside dykes;
- Narrow weathered and fractured dolerite dykes;
- Basins of weathering in dolerite sills and highly jointed sedimentary rocks enclosed by dolerite;
- Weathered and fractured upper contact-zones of dolerite sills; and
- Weathered and fractured lower contact-zones of dolerite sills.

Barnard (2000) found that the groundwater yield potential is classed as low since 83% of the boreholes on record (at that time) produce less than 2 L/s. The static groundwater level is generally encountered between 5 and 25 mbgl. Numerous springs occur at lithological contacts such as where sandstone overlies an impervious shale horizon, along fault zones and along impermeable dolerite dykes. Groundwater seepage in lower lying areas contributes substantially to sustaining the dry season flow in the stream systems that drain these landscapes.

According to SLR (2014) the aquifer units at the Tutuka site can then be divided into 2 main units:

- A shallow, weathered rock aquifer, referred to as the 'shallow aquifer'; and
- A deeper, hard rock fractured aquifer, referred as the 'deeper aquifer'.

Groundwater storage and transport in the unweathered (deeper aquifer) Vryheid Formation and in the Karoo dolerites is likely to be mainly via fractures, bedding planes, joints and other secondary discontinuities. To some extent, increased groundwater storage in the upper weathered zone will provide a resource of groundwater for the underlying fractured aquifer along with relatively thin local accumulations of alluvium. In general the rocks in the study area are together considered to constitute a minor aquifer (SLR, 2014).

5.2 Groundwater Levels

5.2.1 Previous SLR groundwater study recorded groundwater levels

Routine monitoring reports completed by GHT Consulting were provided to discuss groundwater levels in the vicinity of the Power Station. Results have been compared to data collected since 1993 and trends observed as presented in the GHT Consulting monitoring data that SLR reviewed are summarised below for the 'Wolwe Spruit Drainage System'. Boreholes in this area included those installed within the current ash disposal facility, up-gradient of the current ash disposal facility and down-gradient of the current ash disposal facility. In addition the drainage area includes boreholes located in the vicinity of dirty / clean water dams associated with the ashing area.

The results are summarised below:

- Groundwater levels recorded in boreholes located within the current ash disposal facility during the April 2012 monitoring round range between 6.60mbgl (AMB53) and 28.64mbgl (AMB24D). Long term trends show water levels are stable in the majority of boreholes. Increasing trends are observed in boreholes AMB52 and AMB53.
- Groundwater levels recorded in boreholes down-gradient of the current ash disposal facility during the April 2012 monitoring round range between 1.33mbgl (AMB90A) and 8.85mbgl (AMB55). It is noted that AMB02 is artesian. Long term records show stable trends with seasonal fluctuations in the majority of these boreholes.
- Groundwater levels recorded in boreholes located down-gradient of dirty / clean water dams in the vicinity of the Ashing Area during the April 2012 monitoring round range between 0.76mbgl (AMB63) and 6.13mbgl (AMB21). Borehole AMB77S is artesian. Mostly stable long-term trends are observed in these boreholes, although some seasonal fluctuations are observed.

SLR undertook a hydrocensus of accessible boreholes on the 18th of October 2012. Groundwater levels were measured at eight boreholes. The groundwater levels recorded during the SLR hydrocensus is summarised below in Table 5.1.

Table 5.1: Summary of SLR (2014) groundwater study groundwater levels.

BH ID	Location	Water level (mbgl) SLR Hydrocensus 18 October 2012	Water level (mbgl) GHT Report 2 April 2012
AMB55	100m from current ash disposal facility	8.47	8.85
AMB93	100m from current ash disposal facility	1.89	2.66
AMB67	South of current ash disposal facility	1.98	2.8
AMB64	South of current ash disposal facility	2.11	2.4
AMB25S	In current ash disposal facility	10.69	11.55
AMB25D	In current ash disposal facility	12.19	12.82

BH ID	Location	Water level (mbgl) SLR Hydrocensus 18 October 2012	Water level (mbgl) GHT Report 2 April 2012
AMB24S	In current ash disposal facility	25.42	25.85
AMB24D	In current ash disposal facility	27.14	28.64

Take note that the coordinates of the hydrocensus boreholes were not available.

5.2.2 Groundwater level monitoring

Tutuka monitors several boreholes within and surrounding the site as part of its groundwater monitoring programme. The water level results from July 2015 to December 2016 were made available. No monitoring borehole coordinates were present in the monitoring reports.

The GHT Consulting groundwater level monitoring results for the ash disposal facility monitoring area are summarised below:

GHT Consulting Scientists – Monitoring Report Phase 47 – May 2015 Final Report (July 2015)

Groundwater levels for 27 boreholes varied between artesian conditions and 28.65 mbgl. Artesian conditions were recorded at AMB02 and AMB63 and relatively deep groundwater level was recorded at AMB24D (28.65 mbgl).

GHT Consulting Scientists – Hazardous Waste Site 1st Quarter 2015 Annual Monitoring Site Assessment Report (July 2015)

Groundwater levels for 6 monitoring boreholes for the hazardous waste site varied between 12.09 mbgl and 19.84 mbgl. Relatively shallow water levels were recorded at AMB31 (12.09 mbgl) and relatively deep groundwater level was recorded at AMB54 (19.34 mbgl).

GHT Consulting Scientists – Monitoring Report Phase 48 – Final Report (October 2015)

Groundwater levels for 27 boreholes varied between artesian conditions and 28.84 mbgl. Artesian conditions were recorded at AMB02 and relatively deep groundwater level was recorded at AMB24D (28.84 mbgl).

GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 3rd Quarter 2015 Final Report (October 2015)

Groundwater levels for 6 monitoring boreholes for the hazardous waste site varied between 12.59 mbgl and 19.59 mbgl. Relatively shallow water levels were recorded at AMB31 (12.59 mbgl) and relatively deep groundwater level was recorded at AMB54 (19.59 mbgl).

GHT Consulting Scientists – Farmers' Background Boreholes Annual Report March 2016 (March 2016)

Only two groundwater levels were recorded in this study. The groundwater levels ranged between dry and 7.28 mbgl for boreholes FBB132 and AMB21, respectively.

GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 1st Quarter 2016 (March 2016)

Groundwater levels for 6 monitoring boreholes for the hazardous waste site varied between 12.59 mbgl and 19.59 mbgl. Relatively shallow water levels were recorded at AMB31 (12.59 mbgl) and relatively deep groundwater level was recorded at AMB54 (19.59 mbgl).

GHT Consulting Scientists – Annual Report Phase 50 – Final Report (March 2016)

Groundwater levels for 25 boreholes varied between 0.1 mbgl and 28.97 mbgl. Relatively shallow groundwater level was recorded at AMB02 (0.1 mbgl) and relatively deep groundwater level was recorded at AMB24D (28.84 mbgl).

GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 2nd Quarter 2016 (July 2016)

Groundwater levels for 5 monitoring boreholes for the hazardous waste site varied between 11.36 mbgl and 19.68 mbgl. Relatively shallow water levels were recorded at AMB25 (11.36 mbgl) and relatively deep groundwater level was recorded at AMB54 (19.68 mbgl).

GHT Consulting Scientists – Annual Report Phase 51 – Final Report (July 2016)

Groundwater levels for 25 boreholes varied between 0.1 mbgl and 29.04 mbgl. Relatively shallow groundwater level was recorded at AMB02 (0.1 mbgl) and relatively deep groundwater level was recorded at AMB24D (29.04 mbgl).

GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 3rd Quarter 2016 (December 2016)

Groundwater levels for 6 monitoring boreholes for the hazardous waste site varied between 11.68 mbgl and 19.76 mbgl. Relatively shallow water levels were recorded at AMB25 (11.68 mbgl) and relatively deep groundwater level was recorded at AMB54 (19.76 mbgl).

GHT Consulting Scientists – Annual Report Phase 52 – Final Report (December 2016)

Groundwater levels for 29 boreholes varied between 0.25 mbgl and 28.08 mbgl. Relatively shallow groundwater level was recorded at AMB02 (0.25 mbgl) and relatively deep groundwater level was recorded at AMB24D (28.08 mbgl). A slight rise in water table depth were noted and were determined to be potentially due to historic influences of brine water irrigation or recharge occurring through the top. Although the rise in water levels were extremely slow, it was recommended to further investigate as this could potentially be as a result of the ash disposal facility slowly becoming more saturated.

5.2.3 Other groundwater studies

GHT Consulting Scientists – Ash Stack Pollution Plume Model 2015 (March 2016)

The 'ash stack pollution plume model' study evaluated groundwater levels and stated that the groundwater level within the western part of the ash stack becomes lower as the brine irrigation progressed to the east.

GHT Consulting Scientists also noted that time and progress at which this lowering occurs was not well documented due to the limited number of boreholes in the ash stack. For the same reason, GHT Consulting Scientists stated that the influence of the streams on the natural water table below the ash stack is also not recorded. GHT Consulting Scientists noted from groundwater level monitoring that the water table is at the bottom or below the ash stack and that very little water exists in the ash stack itself where the brine irrigation has stopped.

GHT Consulting Scientists – Hydrocensus April 2017 (June 2017)

During the hydrocensus of 2017 a total number of 33 sites were sampled (29 boreholes/groundwater sites and 4 surface water sites). However, no groundwater levels were measured.

GHT Consulting Scientists – Drilling report for the installation of monitoring boreholes 2018 (March 2018)

The drilling report for ten additional monitoring boreholes did not include any water level measurements recorded after drilling.

5.2.4 Conclusions

Based on the results from the previous SLR groundwater study and historic on-site monitoring the following can be concluded related to groundwater levels:

- Monitoring data indicated groundwater levels that varied between artesian conditions and 29.04 mbgl;
- The artesian conditions and shallow groundwater levels were recorded in borehole AMB02, located approximately 800 metres south of the existing ash disposal facility;
- The relatively deep groundwater levels recorded was measured in borehole AMB24D, which is located within the current ash disposal facility. The shallow borehole pair AMB24S also had relatively deep groundwater level measurements of approximately ~26 mbgl;
- There were no indication of the final monitoring borehole depths, especially where dry boreholes were mentioned in the monitoring reports;
- The majority of the water levels measured during monitoring were less than 20 meters below surface.

- A slight rise in water table depth were noted by GHT Consulting Scientists and were determined to be potentially due to historic influences of brine water irrigation or recharge occurring through the top (dust suppression). Although the rise in water levels were extremely slow, it was recommended to further investigate as this could potentially be as a result of the ash disposal facility slowly becoming more saturated.

5.3 Aquifer Parameters

5.3.1 Recharge

Two recharge zones were first considered by SLR in the 2014 study across the groundwater model domain, based on the two rock types identified in the hydrogeological map (i.e. Karoo dolerite and arenaceous sandstone). However, due to limited information with regards to different recharge characteristics, a uniform recharge rate of 0.00008 metres per day (m/d) was chosen by SLR for the entire model domain. This rate is approximate to the GRA2 recharge rate for quaternary catchment C11K (i.e. 28 mm per year) and approximately 5% of the rainfall rate (mean annual rainfall of 580mm/year). A value of 0.00016 metres per day (10% of mean annual precipitation) (i.e. double the ambient recharge) was used by SLR in the 2014 study for the ash disposal facility and alternative sites.

The GHT Consulting Scientists 'Ash Stack Pollution Plume Model 2015' study reported precipitation in the region of Tutuka Power Station was in the order of 700 mm/annum with a natural recharge to groundwater ranging between approximately 2 – 3% of MAP. Recharge rate/seepage of the ADF was not specified.

5.3.2 Aquifer parameters

Transmissivity

SLR (2014) reported from model calibration that the site transmissivity ranged from 3.0 m^2/d to 10 m^2/day. SLR (2014) used a vertical anisotropy set to a Kh/Kv ratio of 3:1 for layer 1 and layer 2 of the model. No site aquifer hydraulic tests were performed during the SLR (2014) study.

The GHT Consulting Scientists 'Ash Stack Pollution Plume Model 2015' study reported from various aquifer test results transmissivity ranging between 0.06 m^2/day and 95 m^2/day. GHT Consulting Scientists stated that the relatively higher transmissivity was found in perched aquifers within the weathered zone, and deeper regional aquifers associated with fractured and 'baked' zones. However, this report poorly describes the aquifer parameters applied to each aquifer unit in the model and final calibrated parameters that were used.

The aquifer transmissivity values used in both studies differ vastly from each other and while the GHT Consulting Scientists model refers to perched conditions, this is not mentioned or evident from Kh/Kv values used in the SLR model.

Porosity

Porosity values of the different aquifer units are required for the transport model and influence the predicted migration of the simulated contamination plume, but do not influence the outcome of the steady-state flow model.

SLR (2014) used effective porosity values sourced from literature and were 'conservatively' specified as 0.27 (sandstone - medium) for the weathered zone, 0.18 for the deeper sandstone and mudstone aquifers (Layer II) and 0.1 fractured Karoo dolerite (layer II).

The GHT Consulting Scientists 'Ash Stack Pollution Plume Model 2015' study only referred to the weathered zone porosity and assigned a value of 0.01 to the model. Porosity of the other aquifer units were not described.

5.4 Groundwater Quality

5.4.1 Previous SLR groundwater study groundwater quality

SLR (2014) found from previous monitoring data that the groundwater quality of the sites on the current ash disposal facility shows signs of severe contamination. The deteriorating qualities of the deep piezometers from the existing ash disposal facility was reported to be impacting on the shallow aquifer directly below the current ash disposal facility. Severe contamination reported downstream of the current ash disposal facility was also reported by SLR (2014) to indicate that contaminant migration has occurred away from the current ADF and detrimental impacts on the groundwater quality have resulted primarily towards the east and south-east.

The hydrocensus conducted by SLR included the sampling of three groundwater samples and the results indicated:

- A number of elements were observed at concentrations above the SANS 241 (2011) limits and included:
    - Chromium – elevated above chronic health limit of 0.05mg/L in sample AMB93 (0.26mg/L);
    - Iron - elevated above aesthetic limit of 0.3mg/L in sample AMB64 (1.02mg/L) and above chronic health limit of 2mg/L in sample AMB55 (23mg/L);
    - Manganese – elevated above the chronic health limit of 0.76mg/L in sample AMB55 (0.76mg/L);
    - Selenium – elevated above the chronic health limit of 0.01mg/L in sample AMB93 (0.065mg/L);
- The electrical conductivity, total dissolved solids, chloride and sulphate concentrations were all significantly elevated above the most stringent water quality limits in sample AMB93.

5.4.2 Groundwater quality monitoring

Tutuka monitors several boreholes within and surrounding the site as part of its groundwater monitoring programme. The water quality results from July 2015 to December 2016 were made available.

The water quality results that were made available were classified by GHT Consulting Scientist according to:

- South Africa Water Quality Guidelines, Volume 1: Domestic Use, DWA&F, First Edition 1993 and Edition 1996.
- Quality of Domestic Water Supplies, DWA&F, Second Edition 1998.
- SABS South African National Standard: Drinking water SANS 241-2:2011 Edition 1 and SANS 241:2006 Edition 6.1.
- Tutuka Power Station Water Use License (08/C11K/ABCFGI/1016).

The GHT Consulting groundwater quality monitoring results for the ADF monitoring area are summarised below:

GHT Consulting Scientists – Monitoring Report Phase 47 – May 2015 Final Report (July 2015)

The majority groundwater sites on the ash stack shows signs of severe contamination. The deteriorating qualities of the deep piezometers indicated that the ash stack is impacting on the shallow aquifer directly below the ash stack.

The severe contamination was found and results indicated that contaminant migration has occurred away from the ash stack and detrimental impacts on the groundwater quality have resulted primarily towards the east and south-east, approximately 30 to 800 metres downstream of the ash stack.

It was concluded that the impact on the groundwater sites downstream from the ash stack were likely attributed to the dams and channels transferring dirty water from the ash stack than seepage from the ash stack. Contaminations were reported for monitoring boreholes located approximately one kilometre downstream from the dirty/clean water dams.

Contaminants of concern reported included fluoride, magnesium, sodium, chloride, and sulphate. Elevated electrical conductivity was also noted.

Sulphate concentrations from borehole samples ranged between 0.3 mg/L and 2 187.0 mg/L and electrical conductivity ranged between 62.2 mS/m and 689.0 mS/m.

GHT Consulting Scientists – Hazardous Waste Site 1st Quarter 2015 Annual Monitoring Site Assessment Report (July 2015)

A severe impact from the ash stack was reported with contaminants of concern listed as sodium, chloride, chromium and sulphate. Elevated electrical conductivity was also noted.

The study found that leachate from the ashing area is at present of greater concern to the groundwater quality than leachate from the hazardous waste site.

Sulphate concentrations from borehole samples ranged between 16 mg/L and 3 507.0 mg/L and electrical conductivity ranged between 49 mS/m and 955 mS/m.

GHT Consulting Scientists – Monitoring Report Phase 48 – Final Report (October 2015)

The majority of groundwater sites on the ash stack showed signs of severe contamination and the same conclusions were made as reported in Monitoring Report Phase 47 – May 2015 Final Report (July 2015).

Contaminants of concern reported included fluoride, magnesium, sodium, chloride, and sulphate. Elevated electrical conductivity was also noted.

Sulphate concentrations from borehole samples ranged between 0.3 mg/L and 2 285.0 mg/L and electrical conductivity ranged between 62.2 mS/m and 686.0 mS/m.

GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 3rd Quarter 2015 Final Report (October 2015)

A severe impact from the ash stack was reported with contaminants of concern listed as sodium, chloride, chromium and sulphate. Elevated electrical conductivity was also noted.

The study found that leachate from the ashing area is, at present, of greater concern to the groundwater quality than leachate from the hazardous waste site.

Sulphate concentrations from borehole samples ranged between 4 mg/L and 3 461.0 mg/L and electrical conductivity ranged between 47 mS/m and 923 mS/m.

GHT Consulting Scientists – Farmers' Background Boreholes Annual Report March 2016 (March 2016)

A total of 13 private land owners' boreholes were visited and seven groundwater samples were taken during this study. These boreholes were located approximately 1 – 5 kilometres to the north-east and east of the ash disposal facility.

The groundwater quality at the borehole located approximately 1 kilometre downstream from the Dirty/Clean Water Dams (AMB21) showed signs of severe contamination due to fluoride concentrations. The origin of fluoride was unknown and might have been attributed to the geology of the area according to GHT Consulting Scientists. The quality of the water at borehole AMB21 is above the recommended standard limit and above the maximum allowable limit for the electrical conductivity, magnesium and chloride which is unsuitable for human consumption.

The groundwater quality at boreholes FBB129, FBB134 and FBB901 depicted high nitrate concentrations and was above the recommended standard limit which is unsuitable for human consumption. The high nitrate concentration was attributed to agricultural activities, as fertilizers are the most common source of dissolved nitrate levels in groundwater.

GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 1st Quarter 2016 (March 2016)

A severe impact from the ash stack was reported with contaminants of concern listed as sodium, chloride, chromium and sulphate. Elevated electrical conductivity was also noted.

The study found that leachate from the ashing area is at present of greater concern to the groundwater quality than leachate from the hazardous waste site.

Sulphate concentrations from borehole samples ranged between 56.3 mg/L and 1 393.0 mg/L and electrical conductivity ranged between 62 mS/m and 551 mS/m.

GHT Consulting Scientists – Annual Report Phase 50 – Final Report (March 2016)

The majority groundwater sites on the ash stack shows signs of severe contamination and the same conclusions were made as reported in Monitoring Report Phase 47 – May 2015 Final Report (July 2015).

Contaminants of concern reported included fluoride, magnesium, sodium, chloride, chromium and sulphate. Elevated electrical conductivity was also noted.

Sulphate concentrations from borehole samples ranged between below detection limit and 1 736 mg/L and electrical conductivity ranged between 78 mS/m and 691 mS/m.

GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 2nd Quarter 2016 (July 2016)

A severe impact from the ash stack was reported with contaminants of concern listed as sodium, chloride, chromium and sulphate. Elevated electrical conductivity was also noted.

The study found that leachate from the ashing area is at present of greater concern to the groundwater quality than leachate from the hazardous waste site.

Sulphate concentrations from borehole samples ranged between 18.6 mg/L and 1 574.0 mg/L and electrical conductivity ranged between 58 mS/m and 510 mS/m.

GHT Consulting Scientists – Annual Report Phase 51 – Final Report (July 2016)

Water quality was not described in the report, but laboratory results were attached in Appendix B of the report.

Contaminants of concern from groundwater samples were sodium, chloride, chromium and sulphate. Elevated electrical conductivity was also observed. Sulphate concentrations ranged between below detection limit and 3 221.7 mg/L and electrical conductivity ranged between 91 mS/m and 940 mS/m.

GHT Consulting Scientists – Hazardous Waste Site Monitoring Report 3rd Quarter 2016 (December 2016)

A severe impact from the ash stack was reported with contaminants of concern listed as sodium, chloride, chromium and sulphate. Elevated electrical conductivity was also noted.

Sulphate concentrations from borehole samples ranged between 23.5 mg/L and 1 637.0 mg/L and electrical conductivity ranged between 59.9 mS/m and 565 mS/m.

GHT Consulting Scientists – Annual Report Phase 52 – Final Report (December 2016)

The majority groundwater sites on the ash stack shows signs of severe contamination and the same conclusions were made as reported in Monitoring Report Phase 47 – May 2015 Final Report (July 2015).

Contaminants of concern reported included calcium, magnesium, sodium, chloride, and sulphate. Elevated electrical conductivity was also noted.

Sulphate concentrations from borehole samples ranged between 0.352 mg/L and 1 835 mg/L and electrical conductivity ranged between 77.1 mS/m and 630 mS/m.

5.4.3 Surface water monitoring

Data for a number of surface water monitoring points for the ash disposal facility were evaluated and included:

- The stream approximately 600 metres to the south of the ash stack (AMS68);
- Two dirty water dams (AMD08 & AMD09) that receive direct surface water runoff;
- The 'clean' water dam water quality data (AMD07) located downstream of the dirty water dams; and
- Stream leaving the ashing area (WSS06) to the south of the clean water dam.

Coordinates for the surface water monitoring points were not available from the received data.

Stream south of ash disposal facility

Sulphate concentrations from AMS68 ranged between 5 412 mg/L and 10 315 mg/L and electrical conductivity ranged between 1 626 mS/m and 2 588 mS/m. GHT Consulting Scientists stated that surface runoff from the ash stack is directly flowing into this stream. Recommendations were made to consider installing a dirty water trench at the south-eastern side of the ash stack.

Dirty water dams

Sulphate concentrations from the dirty water dams ranged between 3 119 mg/L and 11 083.0 mg/L and electrical conductivity ranged between 1 173 mS/m and 4 222 mS/m.

Clean water dam

The clean water dam is situated downstream of the two dirty water dams. Sulphate concentrations from the 'clean' water dam ranged between 621 mg/L and 808 mg/L and electrical conductivity ranged between 299 mS/m and 413 mS/m. GHT Consulting Scientists stated that surface water impacts were evident from water quality data at this dam. This was due to overflows from the upstream dirty water dams as well as the previous overflows from the silted southern dirty water trenches (which has been cleaned) into the clean water streams, as well as the absence of south-eastern clean/dirty water separation at the stream south of the ash disposal facility (AMS68).

Stream south of clean water dam

Sulphate concentrations from the local stream ranged between 35.7 mg/L and 97.4 mg/L and electrical conductivity ranged between 64 mS/m and 131 mS/m. GHT Scientific Consultants noted that the upstream samples WSS61 coming from the overflow of dam AMD07, as well as the eastern tributary WSS32 were consistently dry.

5.4.4 Other groundwater studies

GHT Consulting Scientists – Ash Stack Pollution Plume Model 2015 (March 2016)

GHT Consulting Scientists updated and re-calibrated the previous numerical pollution plume model created in 2013 by GHT Consulting Scientists of the ash stack at Tutuka Power Station. The purpose was to simulate the completed ash stack (expected round 2055) and to compare the difference between lined and unlined scenarios (assuming seizing of excessive brine irrigation from 2015 onwards).

Constant sulphate concentration of 1500 mg/l was assigned as input parameter for the area covered by ash. Constant concentrations of 1000 mg/l on dirty water dams AMD09 and AMD08 and 100mg/l on the clean water dam AMD07. These concentrations were derived from monitoring quality data according to GHT Consulting Scientists. However, the sulphate concentrations from the monitoring results are much higher, which can underestimate the modelled groundwater impact predictions.

The simulated periods between 2015 and 2055 and up to 2105 the model results indicated that the pollution plume will most likely be localised.

GHT Consulting Scientists – Hydrocensus April 2017 (June 2017)

This report summarised the findings of hydrocensus that was conducted during April 2017 and in order to identify the water users and usage within the possible impact zone of the power station. These boreholes were located between approximately 1 – 8 kilometres from the Tutuka ash disposal facility. Coordinates of the hydrocensus boreholes were not available.

Boreholes FBB015, FBB132, FBB133, FBB135, FBB292, FBB293, FBB295, FBB301, FBB309, FBB310, FBB312, FBB314, FBB315 and FBB319 are classified as above recommended standard. The groundwater quality of borehole FBB015 was above recommended standard due to sodium and fluoride which were mainly attributed to the geology or natural occurrence.

The groundwater quality of boreholes FBB132, FBB133, FBB292, FBB293, FBB295, FBB301, FBB309, FBB310, FBB314, FBB315 and FBB319 were above drinking water standard due to exceeded nitrate, which is mainly attributed to fertilizers and agricultural activities.

The groundwater quality of borehole FBB135 was above drinking water standard due to fluoride and arsenic. These parameters are naturally occurring in groundwater and sometimes attributed to agricultural activities in the area.

The groundwater quality of borehole FBB312 was above drinking water standard due to exceeded chloride which was attributed to agricultural activities such as irrigation as well as industrial effluents which might be transported by surface run-off.

5.4.5 Conclusions

Based on the results from the previous SLR (2014) study and on-site monitoring the following can be concluded related to groundwater quality:

- SLR (2014) found from previous monitoring data that the groundwater quality of the sites on the current ash disposal facility showed signs of severe contamination.
- SLR (2014) noted that the deteriorating qualities of the deep piezometers from the current ash disposal facility was reported to be impacting on the shallow aquifer directly below the current ash disposal facility.
- Severe contamination reported downstream of the current ash disposal facility were reported by SLR (2014) to indicate that contaminant migration has occurred away from the current ash disposal facility and detrimental impacts on the groundwater quality have resulted primarily towards the east and south-east.
- The hydrocensus conducted by SLR (2014) included the sampling of three groundwater samples and the results indicated that chromium, iron, manganese and selenium were observed at concentrations above the SANS 241 (2011) limits. The electrical conductivity, total dissolved solids, chloride and sulphate concentrations were all significantly elevated above the most stringent water quality limits in one sample.
- The majority of groundwater monitoring sites on the ash stack shows signs of severe contamination.

- The deteriorating groundwater qualities of the deep piezometers was concluded by GHT Consulting Scientists to indicate that the ash stack has impacted the shallow aquifer directly below the ash stack. The contamination of groundwater quality away from the ADF indicated that contaminants have migrated away from the ash stack and detrimental impacts on the groundwater quality have resulted primarily towards the east and south-east, approximately 30 to 800 metres downstream of the ash stack at that point in time (2015).
- It was concluded by GHT Scientific Consultants that the impact on the groundwater sites downstream from the ash stack were likely attributed to the dams and channels transferring dirty water from the ash stack than solely seepage from the ash stack. Contaminations were reported for monitoring boreholes located approximately one kilometre downstream from the dirty/clean water dams.
- Contaminants of concern reported from monitoring and hydrocensus data were arsenic, fluoride, magnesium, sodium, chloride, and sulphate. Elevated electrical conductivity were also noted.
- Surface water samples of the stream south of the ash disposal facility, the dirty water dams and the clean water dams showed severe signs of contaminations with sulphate concentrations from the dirty water dams ranged between 621 mg/L and 11 083.0 mg/L and electrical conductivity ranged between 299 mS/m and 4 222 mS/m.

6 CONSTITUENTS OF CONCERN FROM COAL FLY ASH

Several case studies publicly available relating to typical contaminants of concern potentially emanating from coal ash and coal combustion residues were evaluated. The main findings are summarised below for each case study.

Kendal Power Station (Zitholele Consulting, 2018)

The waste classification of Kendal Power Station’s ash was undertaken in 2014 by Jones and Wagener. The contaminants of concern (COCs) were compared to the total concentration thresholds and leachable concentration thresholds detailed in the GN R. 635 of 2013 (National Norms and Standards for the assessment of waste for Landfill Disposal), and included, amongst others, aluminium, antimony, arsenic, barium, boron, cadmium, chlorine, chromium (total), chromium VI, cobalt, copper, fluoride, lead, manganese, mercury, molybdenum, nickel, selenium, vanadium, zinc, polycyclic aromatic hydrocarbons, sulphate and nitrate.

Matla Power Station (Dalton et al., 2018)

A site assessment was conducted at Matla coal fired power plant to determine whether surrounding soils were being enriched with trace metals resulting from activities at the power plant. It was found that deposition of fly ash from the flue stacks and the ash dump along with deposition of coal dust from the coal stock yard were the activities most likely to lead to such enrichment. Eighty (80) topsoil samples were gathered and analysed for total metal content. Results were interpreted within the context of background values. It was found that concentrations of arsenic, copper, manganese, nickel and lead exceeded local screening levels, but only arsenic and lead could be confidently attributed to anthropogenic intervention and actual enrichment.

Thabametsi Power Station (Geo Pollution Technologies, 2014)

Geo Pollution Technologies (Pty) Ltd (GPT) conducted a hydrogeological impact study for the proposed Thabametsi Coal Fired Power Station Project at the Grootgeluk coal mine in 2014. Potential contaminants of concern identified by GPT potentially emanating from an ash dump included calcium, sulphate, chloride, sodium, and mercury. Sulphate was identified as the most significant solute in drainage from the ash dump. A starting concentration of 2 000 mg/L was used in numerical transport modelling by GPT. GPT recommended that the ash material should be summited for geochemical analysis to determine the leachability, acid generation capacity and contamination potential.

Thabametsi Power Station (Downstream Strategies, 2018)

Downstream Strategies focused on the potential risks to water resources from the coal ash dump, including its pollution control dams (PCDs). A full set of Coal Combustion Residues (CCR)-related pollutants were recommended to be included in the groundwater monitoring programme. The following CCR-related pollutants were identified: antimony, arsenic, barium, beryllium, boron, cadmium, cobalt, lead, lithium, molybdenum, radium-226 and radium-228 combined, selenium, and thallium.

Kriel Power Station (Aurecon, 2016)

Aurecon undertook a geohydrological evaluation as part of an environmental impact assessment for the proposed expansion of the ash dam facility at Kriel Power Station. The study found high pH values due to the influence of the ash disposal facility. Elevated sulphate and sodium were also listed as contaminants of concern in the study. The main source of sulphate in fly ash water was found to be from the demineralisation effluent. Sulphate concentrations were stated to range between 200 – 1000 mg\L.

Tutuka Power Station (Akinyemi, 2011)

The study aimed to provide a comprehensive characterisation of weathered dry disposed ash cores, to reveal mobility patterns of chemical species as a function of depth and age of ash, with a view to assessing the potential environmental impacts. Fifty-nine samples were taken from 3 drilled cores obtained respectively from the 1 year, 8 year and 20-year-old sections of sequentially dumped, weathered, dry disposed ash in an ash dump site at Tutuka Power Station. Results showed older ash cores are enriched in arsenic, boron, chromium, molybdenum and lead were enriched in the residual fraction of older ash cores.

Georgia State - United States of America (EIP, 2018)

The Environmental Integrity Project (EIP) and Earthjustice examined state-wide monitoring data and determined that 92 percent (11 of 12) of Georgia's coal-fired power plants have contaminated groundwater with one or more toxic pollutants. Ten of the 11 plants had unsafe levels of one or more of the following pollutants:

- Antimony, which causes developmental toxicity (reduced fetal growth) and metabolic toxicity (reduced blood glucose levels). Antimony can also irritate the skin.
- Arsenic, which causes multiple types of cancer, neurological damage, and other health effects.
- Boron, which poses developmental risks to humans, such as low birth weight, and can result in stunted growth and plant toxicity in aquatic ecosystems.
- Cobalt, which harms the heart, blood, thyroid, and other parts of the body.
- Lithium, which presents multiple health risks including neurological impacts.
- Molybdenum, which damages the kidney and liver at high concentrations.
- Radium, which causes cancer and is a radioactive element.
- Selenium, which harms fish and other aquatic organisms at very low concentrations and is bioaccumulative. Selenium can also be toxic to humans.
- Sulphate, which causes diarrhea, and can be very dangerous to young children.

7 POTENTIAL IMPACTS FROM ASH DISPOSAL FACILITY

7.1 Previous predicted groundwater impacts

7.1.1 Groundwater levels

SLR (2014) noted that even though a dry ashing technique will be used during the operational phase from 2015 onward for the ash disposal facility, precipitation will collect on top of the ash disposal facility and eventually infiltrate through the ash and liner to the underlying aquifer. SLR stated that water will likely be stored within the ash disposal facility over time and subsequently increase the 'recharge' within the footprint of the facility which may cause mounding of groundwater. However, this ultimately depends of the volume of water that falls on the facility and the relative permeability of the ash, which were only estimated in the study. This may have the potential to cause a rise in the water table beneath the ash disposal facility and may impact local groundwater flow directions. Notwithstanding, it was considered by SLR unlikely that a significant rise in the water table beneath the ash disposal facility will occur as a direct result of the ash itself. SLR also noted that the use of toe drains, stormwater dams and other surface water impoundments close to the proposed ash disposal facility may lead to local water table rise.

7.1.2 Groundwater quality

The SLR numerical model predictions results suggested that the movement of leachate away from the ash disposal facility as a groundwater plume should take place relatively slowly, with predicted plume extents being generally less than 1 km from the ash disposal facility after 100 years. However, the input concentration for the model was only made as 100 % and the ash material was never characterised by means of geochemical analyses. Geochemical modelling to determine potential contaminants of concern and the final expected water quality emanating from the ash disposal facility has not been undertaken to date.

SLR (2014) concluded that the quality of groundwater beneath the site will most likely deteriorate, since natural groundwater will be mixing with the poorer quality ash leachate (either directly draining from the ash disposal facility, or leaking from surface water impoundments). Geochemical data for the ash at Tutuka was not made available for the SLR (2014) assessment, but typical constituents of concern (elements that are elevated above water quality standards) listed by SLR included: arsenic, boron, chromium, molybdenum, antimony, selenium, vanadium and wolfram. In addition, the pH of water was also mentioned to be impacted upon. It was noted however that groundwater quality data indicated that groundwater quality has already been impacted by the existing ash disposal facility.

SLR stated that if contaminated water was impounded at the surface in unlined ponds, there was a risk to both groundwater and surface water resources. SLR reviewed monitoring data and there were an indication that boreholes located near ponds were adversely impacted both in terms of groundwater levels and quality.

7.1.3 Impact summary

The cumulative impacts from the ash disposal facility of all three phases (construction, operation and decommissioning) determined by SLR (2014) were summarised as:

- A rise in water table in the vicinity of the site due to increased recharge from stored water within the ash disposal facility and any associated surface water impoundments.
- Deterioration in groundwater quality.

The potential impacts of the proposed ash disposal facility on the local groundwater were also qualitatively assessed by SLR and the nature of the impacts were assessed using a standard significance rating scale. The significance rating for the cumulative impacts from the ash disposal facility with and without mitigation measures were determined by SLR as medium to low respectively in terms of deterioration of groundwater quality due to leachate from ash disposal facility.

7.2 Verification of previous groundwater impacts

The previous hydrogeological study conducted by SLR (2014) during the original exemption application was reviewed together with the site information received (as listed in Section 3.2) in order to determine if SLR's previously predicted groundwater impacts will change or not due to additional time used to ash over the same footprint (54ha) under the exemption approval area.

Regarding groundwater levels, SLR concluded that there was a risk that a rise in water table in the vicinity of the site due to increased recharge from stored water within the ash disposal facility and any associated surface water impoundments could occur. A slight rise in water table depth were noted from monitoring data around the ash disposal facility and were determined by GHT Consulting Scientists to be potentially due to historic influences of brine water irrigation and/or recharge occurring through the top. Although the rise in water levels were extremely slow, it was recommended by GHT Consulting Scientists to further investigate as this could potentially be as a result of the ash disposal facility slowly becoming more saturated.

During the operational, decommissioning and post closure phases the main impact on groundwater that may result from the additional time used to ash over the same footprint under the exemption approval area is the contamination of the groundwater as a result of seepage from the ash disposal facility. Based on the results from the previous SLR (2014) study and on-site monitoring the following can be concluded related to groundwater quality:

- SLR (2014) found from previous monitoring data that the groundwater of the sites on the current ash disposal facility shows signs of severe contamination.
- SLR (2014) noted that the deteriorating qualities of the deep piezometers from the current ash disposal facility was reported to be impacting on the shallow aquifer directly below the current ash disposal facility.

- Severe contamination reported downstream of the current ash disposal facility were reported by SLR (2014) to indicate that contaminant migration has occurred away from the current ash disposal facility and detrimental impacts on the groundwater quality have resulted primarily towards the east and south-east.
- The hydrocensus conducted by SLR (2014) included the sampling of three groundwater samples and the results indicated that chromium, iron, manganese and selenium were observed at concentrations above the SANS 241 (2011) limits. The electrical conductivity, total dissolved solids, chloride and sulphate concentrations were all significantly elevated above the most stringent water quality limits in one sample.
- The majority of groundwater monitoring sites on the ash stack shows signs of severe contamination.
- The deteriorating qualities of the deep piezometers indicated, according to GHT Consulting Scientists, that the ash stack is impacting on the shallow aquifer directly below the ash stack. The water quality monitoring results indicated that contaminant migration has occurred away from the ash stack and detrimental impacts on the groundwater quality have resulted primarily towards the east and south-east, approximately 30 to 800 metres downstream of the ash stack at that period of time.
- It was concluded by GHT Scientific Consultants that the impact on the groundwater sites downstream from the ash stack were likely attributed to the dams and channels transferring dirty water from the ash stack than solely the seepage from the ash stack. Contaminations were reported for monitoring boreholes located approximately one kilometre downstream from the dirty/clean water dams.
- Contaminants of concern reported from monitoring data were fluoride, magnesium, sodium, chloride, and sulphate. Elevated electrical conductivity was also noted.
- Surface water samples of the stream south of the ash disposal facility, the dirty water dams and the clean water dams showed severe signs of contaminations with sulphate concentrations from the dirty water dams ranging between 621 mg/L and 11 083.0 mg/L and electrical conductivity ranging between 299 mS/m and 4 222 mS/m.
- Chemical constituents analysed during site monitoring do not include all contaminants of concern identified from groundwater case studies, conducted in South Africa as well as internationally, that may potentially be present in leachate emanating from similar ash disposal facilities.
- No geochemical assessment has been conducted during the SLR (2014) assessment and no geochemical data were received from the client in order to identify all the contaminants of concern that may have an impact on groundwater quality.

The available data in the previous hydrogeological study conducted by SLR (2014) during the original exemption application together with the site information received (as listed in Section 3.2) are not sufficient to enable GCS to quantify the groundwater impacts that may result from the additional time used to ash over the same footprint (54ha) under the exemption approval area. Additional geochemical and hydrogeological work is recommended to be performed before GCS can determine the final changes in potential groundwater impacts due to the additional time used to ash. The additional work is described in Section 8.

8 RECOMMENDATIONS

Although the groundwater impacts determined by SLR (2014) will still remain in terms of groundwater levels and quality, to quantify the changes to groundwater quality that may results from the additional time used to ash over the same footprint (54ha) under the exemption approval area, GCS recommends that the site consider conducting additional hydrological and hydrogeological work. The additional work will enable the site to better characterise and predict the changes to groundwater quality due to the use of the current ash dump facility and the extension area. Additional geochemical, hydrogeological, and hydrological work is recommended to be performed and is discussed in more detail below.

8.1 Groundwater monitoring

Continuous groundwater monitoring is recommended in order to quantify ongoing impacts and provide early warning of any potential contamination. Chemical constituents analysed during site monitoring by GHT Consulting Scientists did not include all contaminants of concern identified from other groundwater case studies, conducted in South Africa as well as internationally, that may potentially be present in leachate emanating from similar ash disposal facilities.

The quarterly water quality parameters should include: pH, EC, total alkalinity, chloride, sulphate, nitrate, ammonium, orthophosphate, fluoride, calcium, magnesium, sodium, potassium, aluminium, iron, manganese, cobalt, nickel, and total hardness. Parameters should include any metals identified future geochemical assessments that may potentially leach out from the ash material. The annual analysis should include the proposed quarterly parameters as well as the following parameters: antimony, arsenic, barium, boron, cadmium, chromium (total), chromium VI, cobalt, copper, lead, lithium, mercury, molybdenum, nickel, radium, selenium, vanadium, zinc.

Historically the following constituents have not been previously included in the site monitoring or only a very small number of samples were analysed for: antimony (Sb), barium (Ba), boron (B), cadmium (Cd), chromium VI (Cr VI), cobalt (Co), lead (Pb), lithium (Li), mercury (Hg), molybdenum (Mo), nickel (Ni), radium (Ra), selenium (Se), vanadium (V), zinc (Zn), and polycyclic aromatic hydrocarbons (PAH). Additionally, arsenic and selenium has been detected at elevated concentrations from the GHT Consulting Scientists and SLR (2014) hydrocensus studies, respectively.

A groundwater monitoring database should be created and updated with all available historic data and as new information becomes available. It is recommended that the data is stored in a dedicated database and that quarterly and annual reports are generated for the site's environmental management.

8.2 Geochemical assessment

A total of at least 10 (ten) geochemical samples will be required of the ash samples. The samples should be submitted to a SANAS accredited laboratory. For the geochemical characterisation of the ash material the following tests should be performed to characterise the ash material and determine the expected elements that may pose a risk to groundwater quality:

- Whole rock/sample analyses;
    - X-ray diffraction (XRD);
    - X-ray fluorescence (XRF) of major oxides;
    - Acid digestion with ICP on trace elements;
- Acid-mine drainage potential;
    - Acid-base accounting - paste pH, total %S and neutralisation potential (ASTM E1915-11);
    - Sulphur speciation (ASTM E1915-11);
    - Net acid generation (NAG) test (ASTM E1915-11);
- Leach tests;
    - Peroxide water extraction 1:4 and 1:20 ratio (250g sample 1L water; 18h) * (similar to ASTM D3987-06); and

  **The following analyses should be performed on the leachate: pH, EC, Total Alkalinity, Cl, NO3, NH4, SO4, F as well as ICP which should include at least the following: 1) Ca, Mg, Na, K, Si, 2) Al, Fe, Mn, As, Ba, Be, Bi, Cd, Co, Cr, Cu, Li, Mo, Ni, Pb, Sb, Se, Sn, Sr, Ti, U, V, W, Zn.*

- Ten (10) week humidity cell leach test (ASTM D5744-07) will be conducted and will be used to calibrate the geochemical models. Kinetic column leaching tests indicate the chemicals that will leach out from the rock material over time as well as the oxidation rate of the sulphide minerals in the material if no interference is present from secondary sulphate minerals.

The test results should be screened in order to determine the long-term acid generation potential of the samples, the expected elements that may be present at elevated concentrations in the ADF seepage, and to prepare input for the geochemical model.

Laboratory test work should be followed by geochemical modelling to provide a quantitative estimate of the expected mine water quality. Laboratory test data cannot be used directly to represent field conditions. The actual water-rock ratio, oxidation rate and chemical residence times can only be incorporated into a numerical geochemical model. Several of these factors depend also on the geometry of the ADF, its interaction with the atmosphere (oxidation) and the ADF water balance.

The following should be evaluated during geochemical modelling:

- The oxygen diffusion into the residue waste should be modelled.
- Geochemical reaction modelling should be performed in order to determine the actual ADF seepage water that will be expected.
- Equilibrium and mineral kinetic modelling should be performed.

Contaminants of concern identified from the geochemical assessment should be included into the groundwater monitoring network.

8.3 Site stormwater management plan

A conceptual SWMP design for the ash disposal facility (ADF) site should be undertaken including determination of existing clean and dirty water areas and size the required berms, channels and Pollution Control Dams (PCDs) to be sufficient. Concept design layouts should be provided for proposed stormwater infrastructure.

The SWMP management practices should include:

- Minimise dirty areas and divert clean water around potential contaminant sources;
- Limiting the exposure of sediment producing materials to erosive forces;
- Taking reasonable measures to limit or prevent offsite sediment transport; and
- Water conveying structures should be protected from erosion.

The storm water management plan should also incorporate best practice guidelines in terms of protecting the environment and minimising discharge of poor water quality. The SWMP should be devised in accordance with the South African Department of Water and Sanitation (DWS) (formerly the department of Water Affairs – DWA) Best Practice Guidelines G1: Storm Water Management (DWA, 2006) and should be adopted as these are strict guidelines that pave the way for responsible site water management.

8.4 Site water balance

Updated site climate data should be obtained from the South African Weather Service (SAWS) and/or databases of WR2012 to update the data used in the surface water specialist study.

A water balance modelling process is recommended and should provide hydrological inputs; these include obtaining recent information on meteorology, runoff and catchments. The water balance should include all components to be modelled such as water sources and losses to the system, and the following must be discussed with the site environmental management team:

- Documentation of operational philosophies;
- Documentation of User Requirements and Assumptions of relevant operations;
- Planned or projected volumes of water to be used within each component, and
- Linkages and routes between components.

These studies should be undertaken with adherence to the relevant South African Best Practice Guidelines and Acts. The Water Balance must be undertaken according to the South African Department of Water and Sanitation (DWS) (formerly the department of Water Affairs – DWA) Best Practice Guidelines (BPG) G2: Water and Salt Balances.

8.5 Updated conceptual and numerical groundwater flow and transport modelling

A high-level desktop study should be completed for the site prior to the conceptual and numerical model update, during which previous consultant reports as supplied by the client, as well as public domain data that is available for the site area will be analysed. Based on all compiled and reviewed data a gap analysis should be carried out to identify critical gaps in the available information. Based on the gap analysis recommendations for additional data collection and analysis should be provided, including any fieldwork and laboratory analyses that may need to be performed.

Updated site and monitoring data should be reviewed and integrated to construct an updated conceptual and numerical groundwater model for the ADF and whole site that describe and quantify aquifers, groundwater flow, boundary conditions and contaminant transport.

Groundwater modelling tools will also be employed in quantifying potential impacts. Risks to be investigated include:

- Groundwater contamination risk posed by the ADF seepage;
- Influence of the position of the site infrastructure (including dirty and clean water dams) on contaminant risk; and
- Post-closure groundwater scenarios.

8.6 Updated groundwater impact assessment

The potential groundwater impacts for the additional time used to ash should be quantified based on the results of updated site information, geochemical assessment, and the numerical groundwater flow and contaminant transport modelling. A significance rating should be used to class the impacts.

Groundwater management measures should be formulated based on the results of the above impact assessment. Such management measures should be discussed with the environmental project team and client. The Tutuka groundwater monitoring programme should be reviewed and recommendations to potential changes should be formulated as part of a site water management plan.

9 CONCLUSIONS

The Department of Environmental Affairs required the site to undertake a Part 2 amendment process and required all specialists that conducted the studies to confirm that the required extension would not have additional impacts on the environment. This required that GCS assess the specialist reports produced during the exemption application, and confirm if the findings will change due to additional time used to ash over the same footprint (54ha) under the exemption approval.

GCS conducted a desktop study level hydrogeological assessment in order to verify the potential impacts determined from the previous hydrogeological study.

The cumulative impacts from the ash disposal facility of all three phases (construction, operation and decommissioning) determined by SLR (2014) were summarised as:

- A rise in water table in the vicinity of the site due to increased recharge from stored water within the ash disposal facility and any associated surface water impoundments.
- Deterioration in groundwater quality.

It can be concluded that, an extension in the duration of ashing within the residual Exemption period to cover the residual area of 11 ha will not change the groundwater impacts determined by SLR (2014), the 2014 identified impacts will still remain in terms of groundwater levels and quality.

10 REFERENCES

Barnard, 2000. Department of Water Affairs and Forestry, South Africa, 2000: An Explanation of the 1:500 000 General Hydrogeological Map – Johannesburg 2526. Government Printers Pretoria.

SLR, 2012. SLR Consulting (Africa) (Pty) Tutuka Power Station Proposed Continuation of Ash Disposal: Hydrogeological Screening Report – SLR Project Ref.: 721.23003.00014 – October 2012.

SLR, 2014. SLR Consulting (Africa) (Pty) Tutuka Power Station Proposed Continuous Ash Disposal at Tutuka Power Station: Groundwater Specialist Study – SLR Project No.: 721.23003.00014 – July 2014.

APPENDIX A – PREVIOUS GROUNDWATER ASSESSMENT (SLR, 2014)

global environmental solutions

Tutuka Power Station

Proposed Continuous Ash Disposal at Tutuka Power Station:
Groundwater Specialist Study

SLR Project No.: 721.23003.00014

Report No.: 2
Revision No. 1

July 2014

THE SPECIALIST ENGINEERS

Tutuka Power Station

Proposed Continuous Ash Disposal at Tutuka Power Station:
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July 2014

Lidwala Consulting Engineers

DOCUMENT INFORMATION

Title	Proposed Continuous Ash Disposal at Tutuka Power Station: Groundwater Specialist Study
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Date last printed	2014/07/03 10:11:00 AM
Date last saved	2014/07/03 08:20:00 AM
Comments	
Keywords	Ash Disposal Facility, power station, groundwater assessment
Project Number	721.23003.00014
Report Number	2
Revision Number	Revision No. 1
Status	Final
Issue Date	July 2014

EXECUTIVE SUMMARY

SLR Consulting (South Africa) (Pty) Limited ("SLR") has been appointed by Lidwala Consulting Engineers ("Lidwala") to undertake a hydrogeological impact assessment for the proposed continued ashing at Eskom's Tutuka Power Station, near Standerton, Mpumalanga Province.

The hydrogeological report supports the Environmental Impact Assessment (EIA) that will be submitted to the Department of Environmental Affairs (DEA) for the site's Waste Licence application as required in accordance with the National Environmental Management Act (NEMA), ACT 107 of 1998 and National Environmental Management Waste Act (NEM:WA), Act 59 of 2008.

A hydrogeological conceptual site model (CSM) for the study area was developed based on a desk top study and data collected from a site visit. The CSM was converted into a numerical groundwater flow model to estimate groundwater flow directions and the rates of leachate plume development from the three alternative areas selected for continued ash disposal at the site.

A steady-state groundwater model using the internationally accepted MODFLOW code was set up and calibrated using groundwater levels collected from the surrounding area. A finite-difference transport model (MODFLOW and MT3DMS) was then developed and calibrated with groundwater levels collected from boreholes on surrounding land to predict the migration of pollutants released from the proposed ash disposal facility sites.

The modelled leachate plumes typically extend less than 1 km from the ash disposal facility, 100 years after the facility begins, suggesting limited risk to groundwater.

Finally, an impact assessment and site-preference ranking exercise was carried out. Alternative Site B and Site C were given a ranking of 3 (acceptable) in terms of potential groundwater impact. Alternative Site A was given a ranking of 2 (not acceptable) due to the higher proportion of exclusion zones, associated with non-perennial streams.

PROPOSED CONTINUOUS ASH DISPOSAL AT TUTUKA POWER STATION: GROUNDWATER SPECIALIST STUDY

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

Below is a list of acronyms and abbreviations used in this report.

Acronyms / Abbreviations	**Definition**
CSM	Conceptual Site Model
DEM	Digital Elevation Model
DWA	Department of Water Affairs
EIA	Environmental Impact Assessment
Ha	Hectare
Mamsl	Meters above mean sea level
MAP	Mean annual precipitation
NEMA	National Environment Management Act
NWA	National Water Act
WA	Waste Act

PROPOSED CONTINUOUS ASH DISPOSAL AT TUTUKA POWER STATION - GROUNDWATER SPECIALIST STUDY

1 INTRODUCTION

SLR Consulting (South Africa) (Pty) Limited ("SLR") has been appointed by Lidwala Consulting Engineers ("Lidwala") to undertaken a hydrogeological impact assessment for the proposed continued ashing at Eskom's Tutuka Power Station, near Standerton in Mpumalanga Province.

The hydrogeological report supports the Environmental Impact Assessment (EIA) that will be submitted to the Department of Environmental Affairs (DEA) for the site's Waste Licence application as required in accordance with the National Environmental Management Act (NEMA), ACT 107 of 1998 and National Environmental Management Waste Act (NEM:WA), Act 59 of 2008.

1.1 BACKGROUND

Tutuka Power Station is a base load coal fired power station located approximately 25km north-east of Standerton in Mpumalanga, and consists of 6 units. Ash is generated as a by-product through the combustion of coal from the power station and is currently disposed of by means of a 'dry ashing' system approximately 3 kilometres from the Tutuka Power Station area on Eskom property.

In order to continue with the operation of the power station, Eskom envisages the continuation of ash disposal in an environmentally responsible manner. It is proposed that the footprint of the existing ash disposal facilities would be extended by 759 Ha so that the ashing requirements of the power station are accommodated for the next 44 years from 2012 (when this assessment was commissioned) to 2055.

The land owned by Eskom was purchased before the commencement of relevant Environmental laws. With the promulgation of the National Environmental Management Waste Act, Act 59 of 2008, Eskom would like to align its proposed continued ashing activities with the requirements of the waste licencing processes.

This report addresses the potential impact associated with continued ash disposal on the hydrogeological system through all phases of the Project including construction, operation and decommissioning.

1.2 OBJECTIVES

The objectives of this report are:

- To develop a hydrogeological conceptual site model (CSM) for Tutuka Power Station and document baseline groundwater conditions of the study area.

- To assess in detail the impacts on the groundwater resources that may result from the continued ash disposal at Tutuka Power Station, considering construction, operation and decommissioning phases of the project.

1.3 LEGISLATIVE FRAMEWORK

This section summarizes the legislative framework as reported by Van Reenen (2009).

Prior to the promulgation of the National Water Act (NWA) 1998, the status of groundwater was regulated by the common law and the Water Act (WA) of 1956 which entrenched the principle that most groundwater was a private resource belonging to the owner of the overlying property. The ownership right was partially based on the 'riparian principle' which meant that the holder of the right to private property simultaneously held the rights to the water occurring or found on or below (i.e. groundwater) it. Once groundwater had been extracted from the ground it was considered to be private surface water and was governed by the WA (1956).

When the NWA came into effect in 1998, it abolished the aforementioned system and groundwater received no particular attention. Groundwater was henceforth simply considered to form part of the hydrological cycle and was regulated as such. The NWA does not define the concepts of 'water', 'groundwater' or 'surface water'.

The use of groundwater is regulated by the same legal rules as the uses of water from all (other) water resources. All types of uses are provided for in terms of 'entitlements' or 'statutory rights' in the NWA. These entitlements (in their different forms) differ fundamentally from the fundamental human rights to water guaranteed in the 'Bills of Rights' within the 'Constitution' of South Africa. Water supply for the latter type of rights is guaranteed by means of the water in the 'Reserve, i.e., the water that remains after the determination of the 'Reserve' is made available for access by water users in terms of the NWA, either by way of Schedule 1 uses, use as a continued existing lawful use, use under a general authorisation or a use in terms of a water licence.

The National Environment Management Act (NEMA, Act 107 of 1998) is the primary Act for all aspects of the environment and natural resources in South Africa. As a framework Act, NEMA applies to all law regulating the protection or management of the environment. It contains a number of environmental management principles that apply to all actions that may significantly affect the environment. These principles apply alongside, amongst others, the socio-economic rights in the Bill of Rights. They serve as the framework within which environmental management and implementation plans must be formulated; serve as guidelines by reference to which organs of state must exercise their functions or take decisions in terms of NEMA or any other statutory provision concerning the protection of the environment; guide the interpretation, administration and implementation of the Act (i.e. NEMA) and any other law concerned with the protection or management of the environment. NEMA also lays out obligations in terms of Environmental Impact Assessments.

The Department of Water Affairs (DWA) Best Practice Guidelines – Water Management for Mine Residue Deposits (DWA, 2008) suggests that the groundwater impacts of a mine residue deposit (similar to an ash disposal facility) should be identified before a final site is chosen. Suggested criteria include:

- The impact on downstream water users.
- Impacts on sensitive or protective areas.
- Impacts on any open-cast or underground workings, shafts or occupied premises, the stability of the underground / excavated workings can be affected by possible seepage and the mass of the mine residue deposit.
- Effect of seepage on dam stability.
- Groundwater quality impacts.

The above factors have been considered in this study.

1.4 STUDY APPROACH AND METHODOLOGY

The hydrogeological assessment for the Tutuka Power Station Project is divided into phases: the Scoping Phase (completed) and the Groundwater Specialist Study, which are described below.

1.4.1 SCOPING PHASE

This Scoping Phase of the project is detailed in SLR (2012) and consisted of a desk-top review of available report(s) and published data on geology and groundwater in the vicinity of Tutuka Power Station. A reconnaissance site visit to inspect the area and identify potential receiving environments (e.g. wetlands, water sources) was undertaken by SLR in September 2012.

A basic conceptual site model (CSM) was developed based on the available information and was used to identify, through a risk-based process, areas within an 8km radius of the power station, as defined in the scope of works, that were ‘high risk’ to groundwater and those that are ‘low risk’. The risk to groundwater was assessed using a simple risk-based model developed in GIS using available geology, hydrogeology data and proximity to surface watercourses.

The output of the assessment was a ‘groundwater vulnerability plan’ which identified ‘preferred’ and ‘less preferred’ areas associated with the possible location of the proposed extension and the risk to groundwater.

The Scoping Report was issued to Lidwala in October 2012 who combined the results (areas of high and low risk) with the results from all other disciplines being assess in the project scope. From the combined data and taking into account the area required to accommodate the volume of ash that would be produced, Lidwala identified 'alternative' areas which had potential for continued ash disposal.

Since the original Scoping Report was completed, the 'alternative' areas have changed. The new areas are presented in Figure 1.1 and consist of:

- Site A – Extension from the existing ash disposal facility to the east and south (+/- 672.70 ha).
- Site B – Extension from the existing ash disposal facility to the north (+/- 764.94 ha).
- Site C - Extension from the existing ash disposal facility to the south-west (+/-534.41 ha).

SLR undertook the screening process again based on the new alternative areas. The resultant 'groundwater vulnerability plan' which identifies 'preferred' and 'less preferred' areas associated with the possible location of the proposed extension and the risk to groundwater is presented in Figure 1.2.

FIGURE 1.1: POSITIONS OF THE THREE ALTERNATIVE EXTENSION AREAS TO THE ASH DISPOSAL FACILITY AT TUTUKA POWER STATION

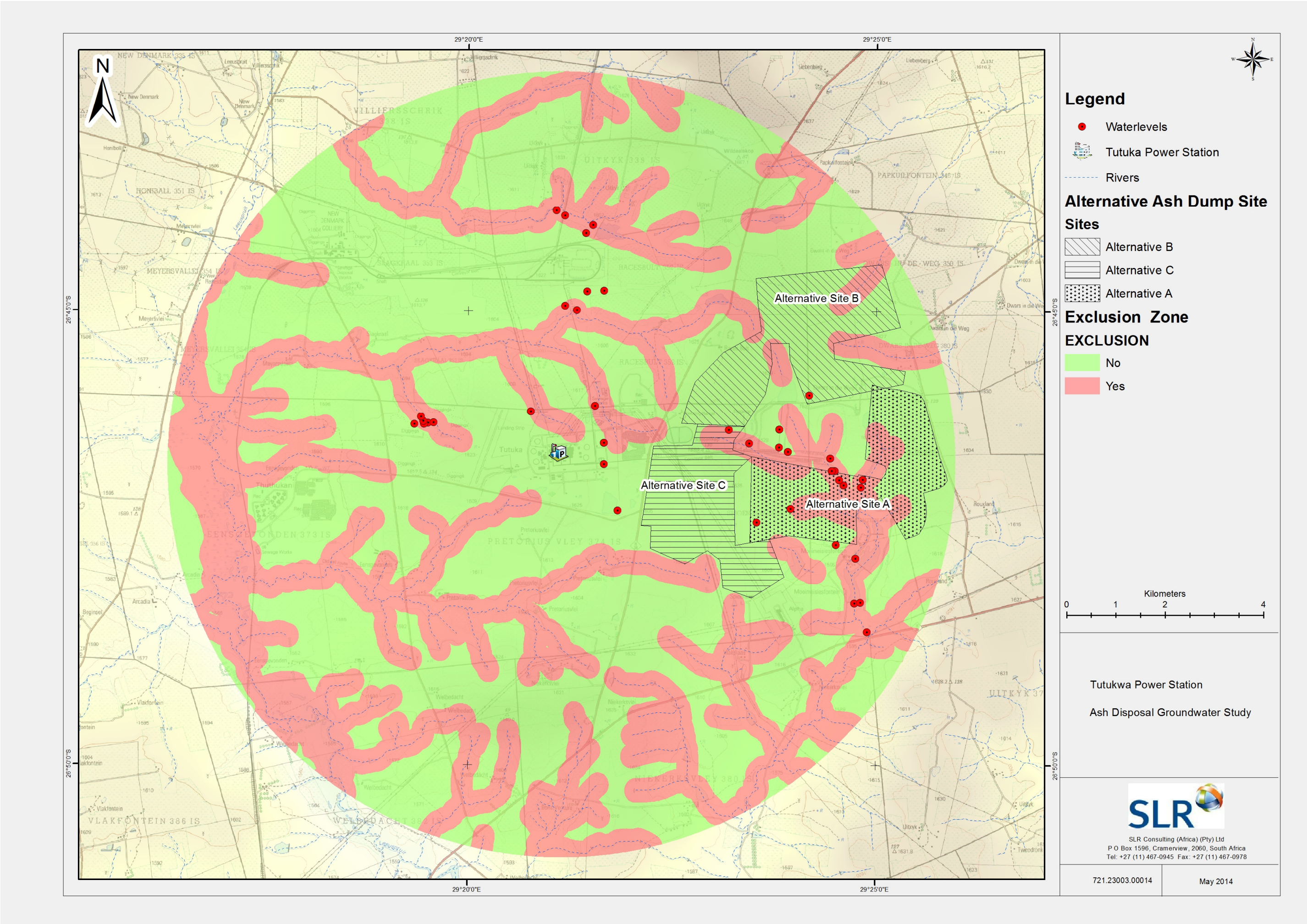


FIGURE 1.2: PLAN IDENTIFYING LESS PREFERRED AND PREFERRED AREAS FOR THE PROPOSED EXTENSION TO THE ASH DISPOSAL FACILITIES AT TUTUKA POWER STATION

1.4.2 HYDROGEOLOGICAL IMPACT ASSESSMENT PHASE

The hydrogeological impact assessment phase, as detailed in this report has evaluated the impact of each of the three alternative footprints proposed for the continuous ash disposal against the conceptual site model to determine the relative impacts on the local groundwater resource. The impact assessment and evaluation of potential impacts of the proposed ash disposal facilities have been supported by the construction of a numerical groundwater flow and transport model as described in Section 3.

1.5 ASSUMPTIONS AND LIMITATIONS

This assessment is limited to a consideration of groundwater and hydrogeology in the vicinity of Tutuka Power Station. Two site visits to the Tutuka Power Station were conducted by SLR staff members (the second to measure water levels and field parameters in boreholes, and to take water samples), however this study also relies on available published information about the geology and hydrogeology of the area. It is assumed that the available data is correct in its representation of the groundwater conditions in the area. This assessment does not evaluate the existing groundwater monitoring and management programme at Tutuka. The effects of underground mining or similar workings (if any) near to or beneath the ‘alternative’ areas selected for continued ash disposal have not been taken into account since it is assumed that no such workings are present.

1.6 DECLARATION OF INDEPENDENCE

- SLR acts as the independent specialist in this application.
- SLR will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant.
- SLR declares that there are no circumstances that may compromise my objectivity in performing such work.
- SLR has expertise in conducting the specialist report relevant to this application, including knowledge of the Act, Regulations and any guidelines that have relevance to the proposed activity.
- SLR will comply with the Act, Regulations and all other applicable legislation.
- SLR has no, and will not engage in, conflicting interests in the undertaking of the activity.
- SLR undertakes to disclose to the applicant and the competent authority all material information in its possession that reasonably has or may have the potential of influencing any decision to be taken with respect to the application by the competent authority; and the objectivity of any report, plan or document to be prepared SLR for submission to the competent authority.

2 DEVELOPMENT OF THE CONCEPTUAL SITE MODEL

A Conceptual Site Model (CSM) has been developed for the Tutuka site based on the available information. A CSM summarises conditions at a site and identifies the type and location of all potential sources of contamination. The CSM for Tutuka is detailed in the following sections.

2.1 DATA SOURCES AND DEFICIENCIES

The Conceptual Site Model (CSM) was developed though review of the following data:

- 1:250 000 scale geological map 2728 Frankfort produced by the Council for Geoscience.
- 1:500 000 scale hydrogeological map 2526 (Johannesburg) published by the Department of Water Affairs.
- Explanation of the 1:500 000 scale hydrogeological map 2526 published by the Department of Water Affairs.
- Quaternary catchment boundaries obtained from the Department of Water Affairs.
- Rainfall, groundwater recharge and groundwater level data obtained from the Groundwater Resources Assessment Phase II (GRA2) dataset, Department of Water Affairs.
- River / stream locations derived from the South African 1:50 000 scale topographic maps obtained from the Chief Directorate: Surveys and Mapping.
- Digital Elevation Model (DEM) based on 20 m contours obtained from the Chief Directorate: Surveys and Mapping and converted into a 50 m x 50 m grid.
- Shape files for the three alternative ash disposal facility sites – provided by Lidwala.
- Borehole and groundwater elevation data retrieved from groundwater monitoring reports produced by GHT Consulting Scientists as well as new water level data gathered by SLR in October 2012.

Limitations in data availability included the following:

- Limited groundwater level measurements across the entire model domain, necessary both for specification of initial model conditions and for model calibration.
- No site-specific data for infiltration rates beneath ash disposal facilities.
- No information on sub-surface mining activities in the area (if any).
- No source concentration for contaminant transport modelling of the ash disposal facilities.
- No chemical and biological reaction rates.

2.2 SITE SETTING

Tutuka Power Station is located approximately 25 km north-east of Standerton, Mpumalanga Province, South Africa. The area is characterised by a strong undulating topography typical of Mpumalanga

Province with low ridges east of the study area. The natural topography however has been disturbed as a result of various agricultural and power generation activities.

The climate can be described as typical Highveld conditions with moderate and wet summers and cold dry winters. The mean annual precipitation is approximately 580mm/year with rain experienced predominantly in the summer months (October to April).

2.3 GEOLOGICAL SETTING

2.3.1 REGIONAL GEOLOGY

The geological map for the area, as present in Figure 2.1 suggests that the Tutuka Power Station and the surrounding area are underlain by rocks of Permian to Jurassic age. More specifically:

- Permian Ecca Group - Vryheid Formation.
- Karoo Supergroup – Karoo Dolerite.

2.3.1.1 Vryheid Formation

The Vryheid Formation is made up of various lithofacies arranged in upward coarsening cycles which are essentially deltaic in origin. The formation can generally be divided into a lower fluvial dominated deltaic interval, a middle fluvial interval and an upper fluvial-dominated deltaic interval which are associated with ‘lower sandstone unit, ‘coal zone’ and ‘upper sandstone unit’ (Johnson *et al*, 2006).

It is noted that in the vicinity of Tutuka the geology is mainly arenaceous sandstone.

2.3.1.2 Karoo Dolerite

The area in the vicinity of Tutuka (and on a wider scale) is intruded by a network of dykes, sills and discordant sheets that are well developed in the sedimentary sequences (Johnson *et al*, 2006).

The intrusions predominately consist of ultramafic / mafic rocks consisting of dolerite, diabase, gabbro, norite, carbonatite, anorthosite and pyroxenite.

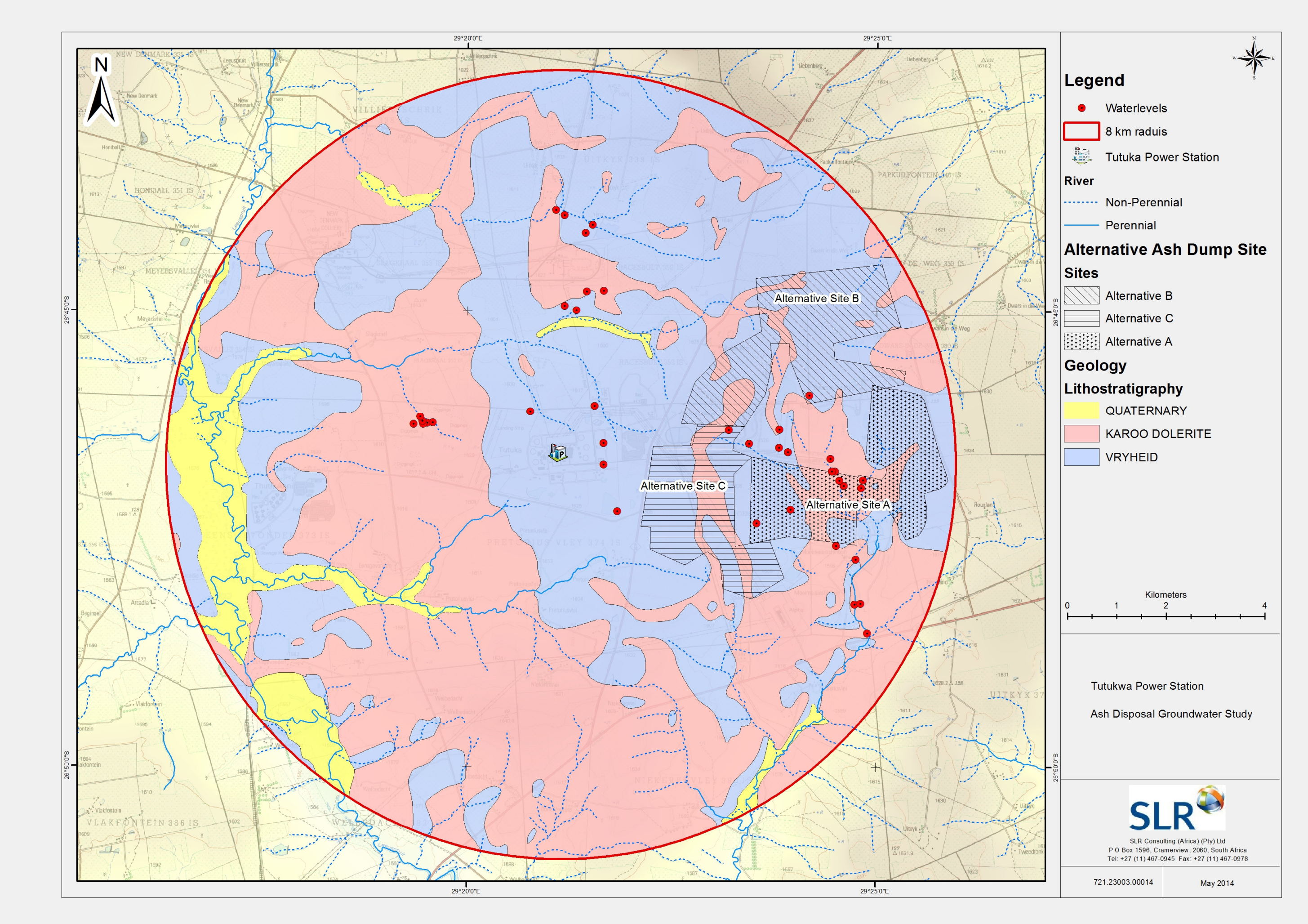


FIGURE 2.1: EXTRACT OF THE GEOLOGICAL MAP FOR THE AREA IN THE VICINITY OF TUTUKA POWER STATION SHOWING THE EXISTING ASH DISPOSAL FACILITY

2.3.2 Local Geology

No site specific geological information was made available to SLR for this review.

Quaternary deposits are shown on the 1:250 000 geology map published by the Council for Geoscience within an 8 km radius of Tutuka Power Station, predominately associated with the Leeuspruit River which flows to the west of the power station. Quaternary deposits are not present within the footprint of the three alternative sites selected for continued ash disposal at Tutuka.

2.4 Hydrogeological Setting

2.4.1 Aquifer Type and Classification

The Department of Water Affairs (DWA) have produced a series of 1:500 000 scale hydrogeology maps (General Hydrogeology Map Series), that cover the whole of South Africa. Analysis of median borehole yields and aquifer types has allowed DWA to classify the aquifers of the country according to an alphanumeric code incorporating aquifer type and borehole yield, as presented in Table 2.1.

TABLE 2.1: GENERAL HYDROGEOLOGY MAP CLASSIFICATION OF SOUTH AFRICA

Aquifer Type	Borehole Yield Class (L/s)				
	Class "1" 0 - 0.1	**Class "2" 0.1 - 0.5**	**Class "3" 0.5 - 2.0**	**Class "4" 2.0 - 5.0**	**Class "5" >5.0**
Type "a": Inter-granular	A1	A2	A3	A4	A5
Type "b": Fractured	B1	B2	B3	B4	B5
Type "c": Karst	C1	C2	C3	C4	C5
Type "d": Inter-granular and fractured	D1	D2	D3	D4	D5

The DWA 1:500 000 scale hydrogeology map of the area (Sheet 2526 Johannesburg) shows that the area within an 8 km radius of the Tutuka site is entirely classified as "D2", suggesting the underlying aquifer is inter-granular and fractured and the average borehole yield is reasonably low ranging between 0.1 and 0.5 litres per second (L/s). There are no major groundwater abstractions shown on the hydrogeological map within 8km of the site.

An extract of the hydrogeological map is presented in Figure 2.2.

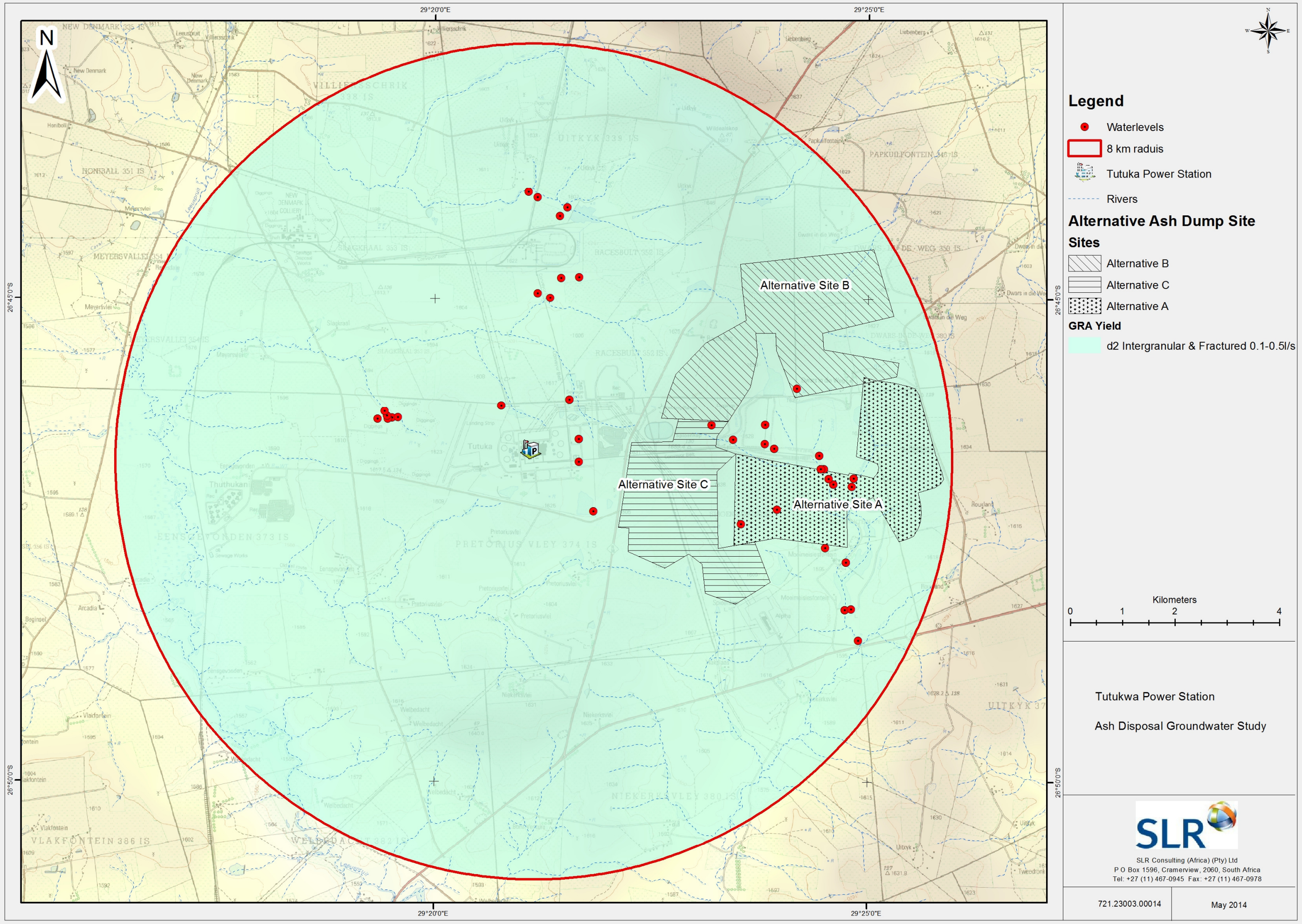


FIGURE 2.2: EXTRACT OF THE HYDROGEOLOGICAL MAP FOR THE AREA IN THE VICINITY OF TUTUKA POWER STATION

Based on the geology, it is considered that there are two main aquifer systems that exist in the area of interest:

- A shallow, weathered rock aquifer, referred to as the '*shallow aquifer'*.
- A deeper, hard rock fractured aquifer, referred as the *'deeper aquifer'.*

Groundwater storage and transport in the unweathered (deeper aquifer) Vryheid Formation and in the Karoo dolerites is likely to be mainly via fractures, bedding planes, joints and other secondary discontinuities. To some extent, increased groundwater storage in the upper weathered zone will provide a resource of groundwater for the underlying fractured aquifer along with relatively thin local accumulations of alluvium. In general the rocks in the study area are together considered to constitute a **minor aquifer** (Parsons and Conrad, 1998).

2.4.2 HYDRAULIC PROPERTIES

The geological map for the area, as presented in Figure 2.1 shows that the site is underlain predominantly by intrusive Karoo Dolerite and the sandstones of the Vryheid Formation.

The Karoo dolerite is likely to exhibit low primary porosity and permeability which would suggest a low risk to groundwater; however the dolerite is likely to exhibit fractures and fissures, with higher permeabilities often associated with the contact between an intrusion and the host rock. These features could increase the risk to groundwater as they act as significant pathways for contaminants to travel. However anticipated borehole yields are reasonably low and the porosity and / or permeability of the aquifer (i.e. the ability to transport contaminants) may be low.

2.4.3 QUATERNARY CATCHMENT AREA

The area within an 8km radius of the Tutuka site is located in quaternary catchment C11K (GRAII), within the Upper Vaal Water Management Area. The GRAII data for the quaternary catchment C11K is summarized in Table 2.2 below.

TABLE 2.2: SUMMARY OF THE GRAII DATA

QUATERNARY CATCHMENT	C11K
Area (km^2)	340
Average water level (meters below ground level)	7.61
Volume of water in aquifer storage (Mm^3/km^2)	258.96
Specific Yield	0.003
Harvest Potential (Mm^3/a)	7.41
Contribution to river base flow (Mm^3/a)	1.82
Utilizable groundwater exploitation potential in a wet season (Mm^3/a)	2.44
Utilizable groundwater exploitation potential in a dry season (Mm^3/a)	1.58

The GRAII data is based on data for South African groundwater, geology and water resources that was available at the time. The data was assessed at a 1 km x 1 km scale, and then aggregated to give summary data for each quaternary catchment. The reliability of the GRAII data is therefore dependent on the underlying information.

The Groundwater Harvest Potential Map of South Africa (Baron et al, 1998) classifies the study area as having an estimated groundwater harvest potential of 15 000 to 25 000 $m^3/km^2/year$ (i.e. relatively low). It also suggests that the average borehole yield is > 0.4 litres per second (L/s), and the total dissolved solids concentration of the (unpolluted) groundwater is between 200 and 300 mg/l (i.e. relatively fresh).

2.4.4 GROUNDWATER ELEVATION AND FLOW

2.4.4.1 Routine Monitoring

Routine monitoring reports completed by GHT Consulting were provided to SLR as part of this review and discuss groundwater levels in the vicinity of the Power Station. At the time of writing, the most recent report made available was the 40th routine monitoring investigation report which details measurement collected on 2nd and 3rd April 2012. Based on this report the groundwater monitoring network at Tutuka is divided into four different monitoring areas as follows:

- **Effected Drainage Area 1** – Wolwe Spruit Drainage System:
  - Boreholes on, and up-gradient of the current ash disposal facility;
- **Effected Drainage Area 2** – Pretorius Spruit Drainage Area:
  - Boreholes south of the Power Station
- **Effected Drainage Area 3** – Racesbult Spruit Drainage System:
  - Boreholes north of the Power Station, north of the Domestic Waste Site and south of the Coal Stockyard Area;
- **Effected Drainage Area 4** – Uitkyk Spruit Drainage System:
  - Boreholes north of the Coal Stock Yard Area

Results have been compared to data collected since 1993 and trends observed as presented in the GHT report are summarized below.

<u>Effected Drainage Area 1 – Wolwe Spruit Drainage System</u>

Boreholes in this drainage area include those installed within the current ash disposal facility, up-gradient of the current ash disposal facility and down-gradient of the current ash disposal facility. In addition the drainage area includes boreholes located in the vicinity of dirty / clean water dams associated with the ashing area.

- Groundwater levels recorded in boreholes located *within the* current ash disposal facility during the April 2012 monitoring round range between 6.60mbgl (AMB53) and 28.64mbgl (AMB24D). Long term trends show water levels are stable in the majority of boreholes. Increasing trends are observed in boreholes AMB52 and AMB53.
- Groundwater levels recorded in boreholes *down-gradient of the current ash disposal facility* during the April 2012 monitoring round range between 1.33mbgl (AMB90A) and 8.85mbgl (AMB55). It is noted that AMB02 is artesian. Long term records show stable trends with seasonal fluctuations in the majority of these boreholes.
- Groundwater levels recorded in boreholes located *down-gradient of dirty / clean water dams in the vicinity of the Ashing Area* during the April 2012 monitoring round range between 0.76mbgl (AMB63) and 6.13mbgl (AMB21). Borehole AMB77S is artesian. Mostly stable long-term trends are observed in these boreholes, although some seasonal fluctuations are observed.

<u>Effected Drainage Area 2 – Pretorius Spruit Drainage Area</u>
Boreholes in this drainage area include those boreholes to the *south of the power station*. Groundwater levels were measured in three boreholes; PMB04, PMB75 and PMB76.

- Groundwater levels range between 1.85mbgl (PMB75) and 6.35mbgl (PMB76) with boreholes exhibiting a stable but slightly increasing overall trend.

<u>Effected Drainage Area 3 – Racesbult Spruit Drainage System</u>
Boreholes in this drainage area include boreholes *north of the Power Station, north of the Domestic Waste Site and south of the Coal Stockyard Area*.

- Groundwater levels located to the *north of the power station* were recorded in three boreholes; PMB06, PMB07 and PMB09.
- Groundwater levels in these three boreholes ranged between 0.78mbgl (PMB06) and 2.75 (PMB06).
- An overall stable trend was observed in boreholes. The increased water level observed in PMB07 since the last monitoring round could be influenced by the water level of dam PMD13.
- Groundwater levels to the north of *Domestic Waste Site* are measured in three boreholes; DMB35, DMB33 and DMB34.
- Groundwater levels in these three boreholes range between 1.18mbgl (DMB34) and 4.70mbgl (DMB35).
- Groundwater levels have increased when compared to the last monitoring round, however an overall stable trend is observed.

Groundwater levels to the *south of the Coal Stock Yard Area* are measured in four boreholes; CMB10, CMB69, CMB71 and CMB70.

- Groundwater levels in these four boreholes ranged between 2.58mbgl (CMB71) and 14.69mbgl (CMB10) during the April 2012 monitoring round. Borehole CMB69 is artesian.
- Stable trends are observed in the boreholes.

Effected Drainage Area 4 – Uitkyk Spruit Drainage System

Boreholes in this drainage area include those located to the *north of the Coal Stock Yard Area*; CMB32, CMB19, CMB12 and CMB72.

- Groundwater levels in the four boreholes range between 0.88mbgl (CMB32) and 1.3mbgl (CMB19).
- Water levels are stable but show seasonal fluctuation.

2.4.5 SLR HYDROCENSUS – GROUNDWATER LEVELS

SLR attended site on 18th October 2012 and undertook a hydrocensus of accessible boreholes. Groundwater levels were measured at eight boreholes.

Water levels were consistent with current trends observed by GHT Consulting through routine monitoring.

Details from the hydrocensus, along with water levels reported in the most up-to-date GHT report provided to SLR, are presented in Table 2-3 below.

TABLE 2-3 SUMMARY OF WATER LEVELS

BH ID	Effective Drainage Area	Location	Water Level (mbgl) Hydrocensus 18th October 2012	Water Level (mbgl) GHT Report 2nd April 2012
AMB55	1 – Wolwe Spruit	Within 100m from current ash disposal facility	8.47	8.85
AMB93	1 – Wolwe Spruit	Within 100m from current ash disposal facility	1.89	2.66
AMB67	1 – Wolwe Spruit	South of current ash disposal facility	1.98	2.8
AMB64	1 – Wolwe Spruit	South of current ash disposal facility	2.11	2.4
AMB25S	1 – Wolwe Spruit	In current ash disposal facility	10.69	11.55
AMB25D	1 – Wolwe Spruit	In current ash disposal facility	12.19	12.82
AMB24S	1 – Wolwe Spruit	In current ash disposal facility	25.42	25.85
AMB24D	1 – Wolwe Spruit	In current ash disposal facility	27.14	28.64

2.4.6 GROUNDWATER QUALITY

Routine monitoring reports completed by GHT Consulting were provided to SLR as part of this review which discusses groundwater quality in the vicinity of the Power Station.

The most recent report made available as part of this study (40th routine monitoring investigations) details measurement collected on 2nd and 3rd April 2012.

GHT Consultants used six parameters as indicators of contamination in the monitoring of the pollution potential in this system; electrical conductivity (EC), sodium (Na), calcium (Ca), chloride (Cl) sulphate (SO4) and iron. Concentrations were compared to applicable South African water quality standards.

The results for the April 2012 monitoring round are summarized below.

Effected Drainage Area 1 – Wolwe Spruit Drainage System

- The groundwater of the sites on the current ash disposal facility shows signs of severe contamination. The quality of the water at boreholes AMB26D, AMB25D AMB25S, and AMB53 exceeds the recommended standard limit and is unsuitable for human consumption. The quality of the water at borehole AMB24D and AMB24S is above the maximum allowable and recommended standard limits and is unsuitable for human consumption. The water qualities of the shallow piezometers are expected to be poor as the piezometers are installed within the ash. The deteriorating qualities of the deep piezometers indicate however (as expected) that the current ash disposal facility is impacting on the shallow aquifer directly below the current ash disposal facility.
- Boreholes AMB90 to AMB93, AMB64 and AMB02 are all located downstream of the current ash disposal facility and show signs of severe contamination. The above observations show that contaminant migration has occurred away from the current ash disposal facility and detrimental impacts on the groundwater quality have resulted primarily towards the east and south-east.
- The groundwater quality at three of the sites located downstream from the Dirty/Clean Water Dams show signs of severe contamination. Site AMB01 (monitoring borehole south clean water dam) has a fluoride concentration above recommended limits. The origin of fluoride is unknown and might be attributed to the geology of the area. The quality of the water at borehole AMB63 is above the recommended standard limit and is unsuitable for human consumption. AMB63 is downstream from the first dirty water settling dam AMD09 and is therefore an indication that polluted water from this dam is seeping into the groundwater. The quality of the water at borehole AMB61 (monitoring borehole west of ashing east of tar road) is above the recommended standard limit and is unsuitable for human consumption.
- The GHT report suggests that the majority of boreholes are in satisfactory condition, however the following are in a damaged / poor state, which may have some impact on the results:
  - AMB24S and AMD25D – casing is rusted and damaged.
  - AMB62 – casing damaged.
  - AMB63 – cap damaged.
  - AMB61 – No casing and no cap.

Effected Drainage Area 2 – Pretorius Spruit Drainage Area

- The groundwater quality at boreholes PMB75 and PMB76 shows signs of contamination. The quality of the groundwater at these sites can be classified as water with above recommended concentrations. This can be attributed to power station activities.
- The GHT report suggests that both boreholes are in satisfactory condition.

Effected Drainage Area 3 – Racesbult Spruit Drainage System

Coal Stockyard - Drainage to the south

- The groundwater quality at boreholes CMB10, CMB71 and CMB70 shows signs of contamination. The quality of the groundwater at these sites can be classified as water with above recommended concentrations. This can be attributed to the Coal Stockyard activities.

Power Station - Drainage to the North

- The groundwater quality at borehole PMB09 shows signs of contamination with high sodium concentrations. The quality of the groundwater at this site can be classified as water with an above recommended concentration of sodium.

Domestic waste site - Drainage to the North

- The groundwater quality at boreholes DMB35 and DMB33 show signs of contamination with high NO_3 and NH_4 concentrations respectively. The quality of the groundwater at these sites can be classified as water with above recommended concentrations. This can be attributed to decomposition at the domestic waste site.
- The GHT report suggests that the majority of boreholes are in satisfactory condition, however the following are in a damaged / poor state, which may have some impact on the results:
  - CMB10 – no cap.
  - PMB09 – no lock out nut or pin.
  - DMB35 – locking pin damage.

Effected Drainage Area 4 – Uitkyk Spruit Drainage System

Coal Stockyard - Drainage to the north

- The water quality at all the clean surface water sites sampled for the Uitkyk Spruit Drainage system showed signs of severe contamination. The quality of the surface water at these sites can be classified as water with a dangerous quality, exceeding the maximum allowable limits and above the recommended concentrations. This can be attributed to the Coal Stockyard activities.
- The groundwater quality at sites CMB32 and CMB72 sampled for the Uitkyk Spruit Drainage system showed signs of contamination. The quality of the surface water at these sites can be classified as water exceeding the recommended concentration limits. This can be attributed to the Coal Stockyard activities.
- The GHT report states that both boreholes have missing caps.

2.4.7 SLR HYDROCENSUS – GROUNDWATER QUALITY

During their site visit in October 2012, SLR took three groundwater samples for water quality purposes from accessible boreholes. The three samples were submitted to an accredited laboratory for analysis of trace metals and major anions and cations.

Samples were collected from the following boreholes:

- AMB55 – located within 100m from current ash disposal facility.
- AMB93 – located within 100m from current ash disposal facility (down-gradient).
- AMB64 – located to the south down-gradient of current ash disposal facility.

Observed concentrations were compared to the South African National Standards (SANS) 241 (2011) water quality limits for:

- Operational.
- Aesthetics.
- Acute Heath.
- Chronic Health.

Review of the data shows:

- A number of elements were observed at concentrations above the SANS 241 (2011) limits. Of particular interest were;
  - *Chromium* – elevated above chronic health limit of 0.05mg/L in sample AMB93 (0.26mg/L);
  - *Iron* - elevated above aesthetic limit of 0.3mg/L in sample AMB64 (1.02mg/L) and above chronic health limit of 2mg/L in sample AMB55 (23mg/L);
  - *Manganese* – elevated above the chronic health limit of 0.76mg/L in sample AMB55 (0.76mg/L);
  - *Selenium* – elevated above the chronic health limit of 0.01mg/L in sample AMB93 (0.065mg/L);
- The electrical conductivity, total dissolved solids, chloride and sulphate concentrations were all significantly elevated above the most stringent water quality limits in sample AMB93.

The results are consistent with current trends observed by GHT Consulting through routine monitoring.

2.5 HYDROLOGICAL SETTING

A number of perennial and ephemeral surface water courses have been identified in the vicinity of Tutuka Power Station through review of the 1:50 000 topography map as presented on Figure 2.3. It is likely that shallow groundwater is in hydraulic continuity with surface water features, especially in areas where quaternary deposits exist.

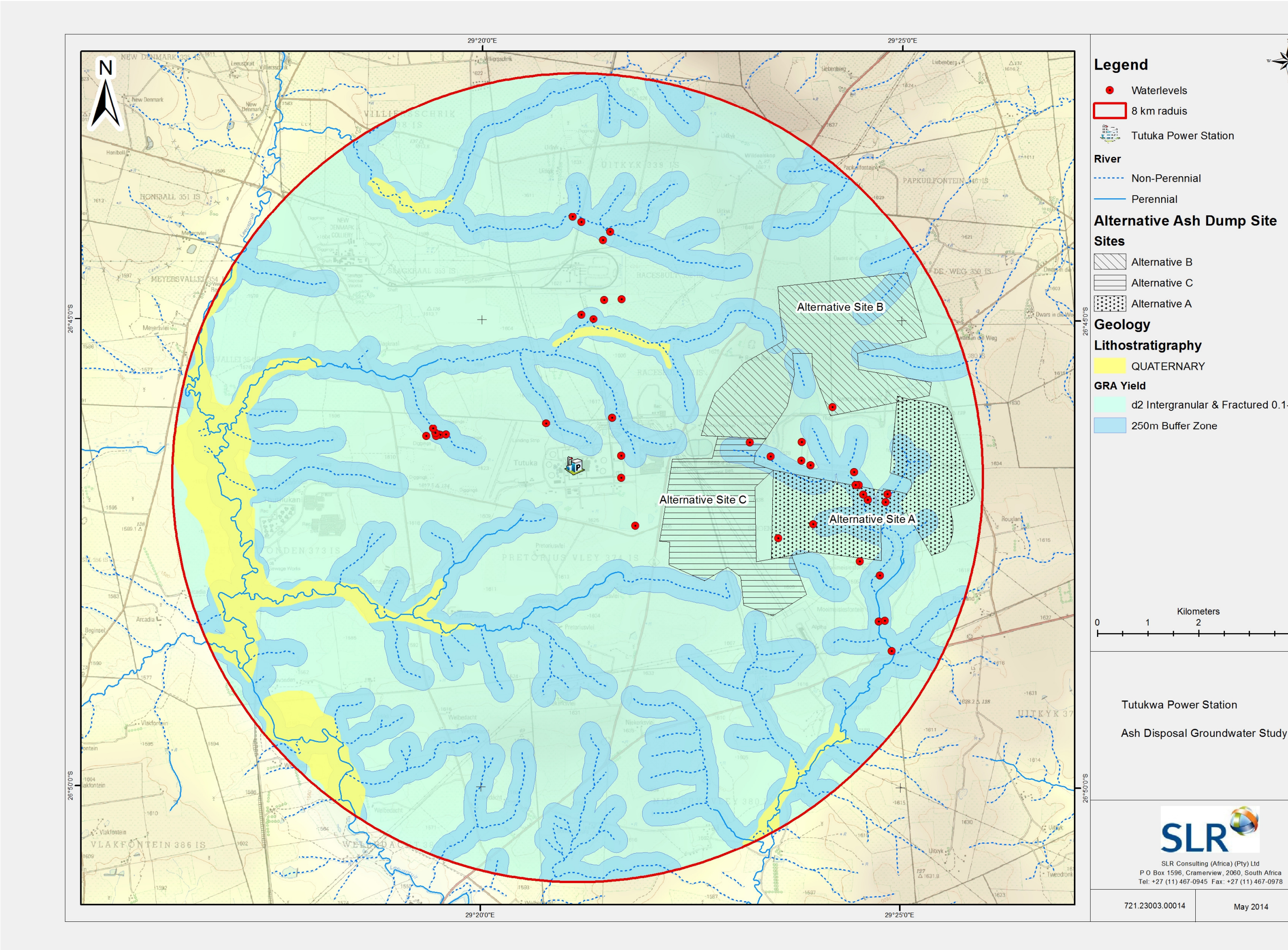


FIGURE 2.3: POSITION OF THE PERENNIAL AND NON-PERENNIAL STREAM IN THE VICINITY OF THE EXISTING AS POWER STATION

3 NUMERICAL GROUNDWATER MODEL

To assess the impact of the proposed continuation of ash disposal at Tutuka on the surrounding hydrogeological system, a numerical groundwater flow and solute transport model has been developed and is described in the following section.

3.1 MODELLING OBJECTIVES

The objectives of the groundwater numerical model are:

- To characterise and conceptualise the aquifer conditions in the study area.
- To determine the flow path of the potential contaminate plum from the proposed ash disposal facility.
- To determine the contaminant transport rates of the potential contaminant plume.

In the absence of South African guidelines, the numerical groundwater model has been developed in accordance with Australian Groundwater Modelling Guidelines (Barnet *et al*, 2012) which promotes a consistent and sound approach to the development of numerical groundwater flow and solute transport models. It is noted that no sensitivity analysis was conducted.

3.2 MODEL CODE DESCRIPTION

The conceptual groundwater model for the Tutuka Site was converted into a numerical groundwater model. The software code chosen for the numerical modelling work was the modular 3D finite-difference groundwater flow model MODFLOW, developed by the United States Geological Survey (USGS) (MacDonald and Harbaugh, 1998). The code was first published in 1984 and has since undergone a number of revisions. MODFLOW is widely accepted by environmental scientists and associated professionals. Groundwater modelling system 'GMS' package (Version 8.0) was used as the software interface for the MODFLOW code.

MODLFOW uses the finite-difference approximation to solve the groundwater flow equation where the model domain is divided into a number of equally sized cells by specifying the number of rows and columns across the model domain.

Hydraulic properties are assumed to be uniform within each cell and an equation is developed for each cell based on the surrounding cells. A series of iterations are then run to solve the resulting matrix problem and the model is said to have 'converge' when errors are reduced to within an acceptable range.

MODFLOW is able to simulate steady and non-steady flow in aquifers of irregular dimensions as well as confined and unconfined flow.

MT3DMS (MT3D package) is a modular 3-D transport model for the simulation of advection, dispersion and chemical reactions of dissolved constituents in groundwater systems, originally developed by Zheng (1990). MT3DMS is designed to work with any block centred finite difference flow model, such as MODFLOW (under assumption of constant fluid density and full saturation). MT3DMS is unique in that it includes three major classes of transport solution techniques in a single code, i.e., the standard finite difference method; the particle-tracking based Eulerian-Lagrangian methods; and the higher-order finite-volume TVD method. Since no single numerical technique has been shown to be effective for all transport conditions, the combination of these solution techniques, each having its own strengths and limitations, is believed to offer the best approach for solving the most wide-ranging transport problems (Zheng and Wang, 1999).

3.3 MODEL LIMITATIONS

The conceptualisation of a complex groundwater flow system into a simplified groundwater management tool, i.e. a numerical model, has a number of uncertainties, assumptions and limitation. These limitations include (but are not limited to these only):

- Input data on the types and thickness of hydrogeological units, water levels, and hydraulic properties are only estimates of actual values.
- All the physical and chemical processes in a catchment cannot be represented completely in a numerical model.
- The numerical model is a non-unique solution that can calibrated with a number of acceptable parameters.
- A numerical model is a simplification of the natural world.
- The numerical model necessarily covers a large area, which reduces the cell size (and therefore model resolution) that can be practically achieved.
- The complex geology in three dimensions (3D) which exists at the site has been greatly simplified by assuming that surface outcrop is equivalent to the geology at depth. This assumption is justified partly by the very limited data on the 3D geology, and partly by the similarity in hydraulic properties of the three main lithological units in the study area.

3.4 WATER SOURCES AND SINKS

3.4.1 GROUNDWATER RECHARGE

Groundwater enters the model domain as direct recharge from precipitation as well as seepage from the ash disposal facility.

Two recharge zones were first considered across the model domain, based on the two rock types identified in the hydrogeological map (i.e. Karoo dolerite and arenaceous sandstone). However, due to limited information with regards to different recharge characteristics, a uniform recharge rate of **0.00008**

metres per day (m/d) was chosen for the entire model domain. This rate is approximate to the GRA2 recharge rate for quaternary catchment C11K (i.e. 28 mm per year) and approximately 5% of the rainfall rate (580mm/year).

3.4.2 Ash Disposal Facilities

Ash disposal facilities were incorporated into the model domain for the predictive simulations as recharge boundaries with specified source concentrations. Locally increased groundwater "recharge" rates due to seepage from the ash disposal facilities have been estimated in the absence of site specific data and applied to the existing ash disposal and the proposed ash disposal facility. A value of 0.00016 metres per day (i.e. double the ambient recharge) was used for each ash disposal facility alternative in turn to simulate leakage from the facility. It is acknowledged that this may be a "worst-case scenario" or conservative value since the ash disposal facility is likely to be lined (to be confirmed), compaction / cementation of ash might occur or other measures to decrease leachate movement may be taken such as the installation of a liner. Lower levels of leachate movement imply smaller plumes and / or lower concentrations of dissolved species in the leachate plumes. At present, actual measurements of leakage rates beneath the existing ash disposal facility at Tutuka are not available.

The source concentrations were set as 100% as starting concentration.

3.4.3 Groundwater Sinks

Groundwater leaves the model domain by evapotranspiration, groundwater outflow and discharge to surface water courses (perennial and non-perennial rivers).

Surface water courses were incorporated into the model using the 'drainage boundary' function. The elevation of each 'drain' was aligned with the height of the Digital Elevation Model (DEM) data at that point and an incision of 2.5 m below the surrounding topography was assumed.

All surface water courses were classified as continuously gaining river courses i.e. groundwater can only discharge into the rivers with no loss of water from the river. This approach ensures no water losses occur from the non-perennial rivers into the model domain. An equivalent drain or river bed conductance of 1.0 m^2/day per meter of river or drain length was assumed, describing a good hydraulic connection between the weathered and alluvial aquifers.

3.5 Model Domain

3.5.1 Finite Difference Flow Model

The finite-difference model was set-up as a 3-dimensional, 2 layer steady-state groundwater model. As with the finite-difference model, the different model layers represent the weathered zone (Sandstone and dolerite) (layer I, 20m thick) and the deeper fractured Volksrust Sandstone, mudstone and Karoo dolerite aquifer (layer II). The top elevation of layer I was based on the 25m digital elevation model while the bottom elevations of the layers were offset by 20 metres below ground level (layer I), and 150 below ground level (layer II) respectively. The steady-state groundwater model was converted into a transient groundwater model using the same model setup.

The model domain was discretised into a 853 X 698 grid block uniform mesh, with uniform horizontal grid block sizes of 50m X 50m and a vertical thickness up to a depth of 150 m below surface. The model domain is presented in Figure 3.1.

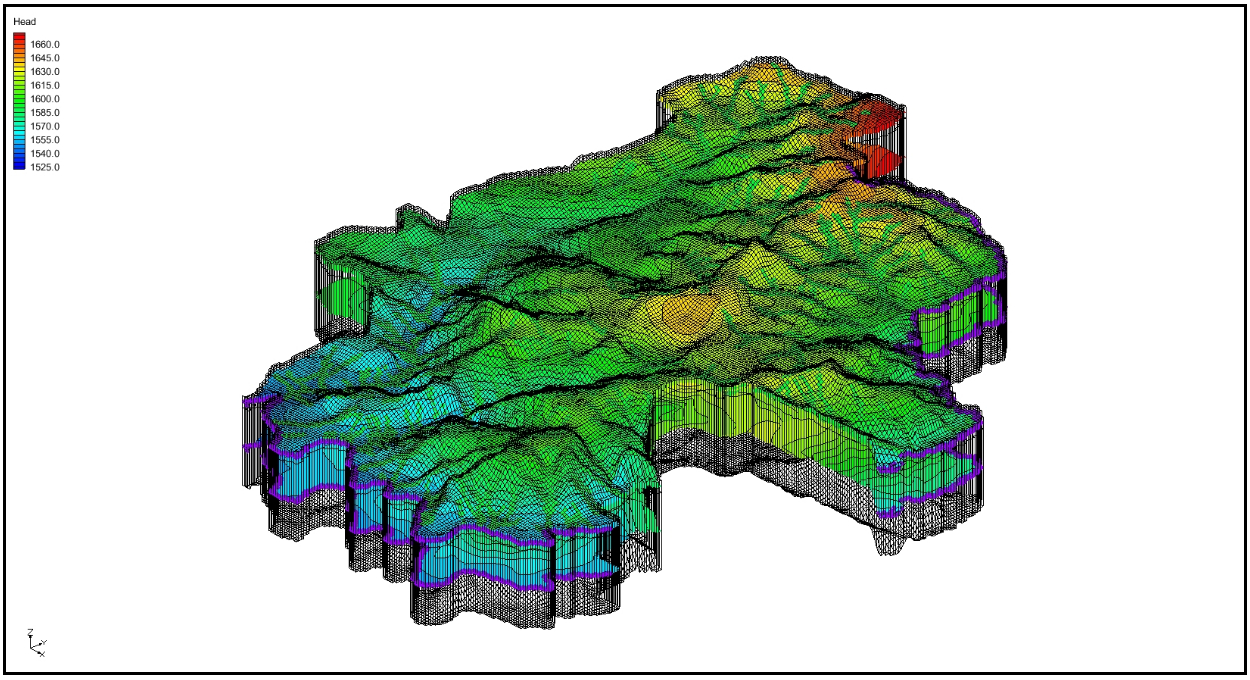


FIGURE 3.1: MODEL DOMAIN FOR TUTUKA POWER STATION

3.5.2 FINITE DIFFERENCE TRANSPORT MODEL

The finite-difference model was set-up as a 3-dimensional, 2 layer steady-state groundwater model. As with the finite-difference model, the different model layers represent the weathered zone (Sandstone and dolerite) (layer I, 20m thick) and the deeper fractured Volksrust Sandstone, mudstone and Karoo dolerite aquifer (layer II). The top elevation of layer I was based on the 25m digital elevation model while the bottom elevations of the layers were offset by 20 metres below ground level (layer I), and 150 m below ground level (layer II) respectively. The steady-state groundwater model was converted into a transient groundwater model using the same model setup.

The model domain was discretised into a 285 X 233 grid block uniform mesh, with uniform horizontal grid block sizes of 150m X 150m and a vertical thickness up to a depth of 150 m below surface.

Following the precautionary principle, only advective-dispersive (longitudinal dispersivity 50m) transport of potential pollutants, without any retardation or transformation was assumed. Therefore, all impact assessments of potential pollution sources on the groundwater quality below are conservative.

3.6 BOUNDARY CONDITIONS

Based on the previously mentioned correlation between the topography and groundwater elevation the surface water catchment boundaries and the groundwater divides were incorporated into the model as no-flow boundaries. The models outer boundary therefore coincides with the surface water catchment boundaries and was implemented in the model as a first-type no-flow boundary condition. Furthermore, constant head boundary conditions, based on water levels 2.5 m below surface, were incorporated at different river stages of the outer boundary condition.

Lastly, the boundary conditions were spatially chosen to have no or minimum impact on the flow and transport model based on the project-and model objectives.

3.7 HYDRAULIC PARAMETERS

The flow and transport models incorporate five different hydraulic conductivity (K) zones, based on the geological units; weathered sandstone (Vryheid Formation) and weathered Karoo dolerite in model Layer I and the fractured Karoo sandstone and mudstone and Karoo dolerite in model Layer II.

The vertical anisotropy was set to a Kh/Kv ratio of 3:1 for layer 1 and layer 2. Effective porosity values (based on McWorter and Sunanda, 1977) were conservatively specified as 0.27 (sandstone - medium) for the weathered zone, 0.18 for the deeper sandstone and mudstone aquifers (Layer II) and 0.1 fractured Karoo dolerite (layer II). Porosity values affect only the transport model and do not influence the outcome of the steady-state flow model.

3.8 INITIAL PARAMETERS

The starting heads for the model run were set to 20 m below surface elevation for first phase model run, based on average groundwater levels. Due to the limited number of groundwater level measurements for the entire model domain no interpolation from measured field data was conducted for staring heads for the model run.

3.9 SELECTION OF CALIBRATION PARAMETERS AND TARGETS

The available groundwater levels (in metres above mean sea level (mamsl) based on the DEM elevation) observed in 40 boreholes were used as calibration targets. No groundwater discharge measurements in the river courses were available for calibration purposes and the leakage coefficients for the river courses were therefore left constant.

Since the modelled groundwater levels are directly related to the recharge rates and hydraulic conductivities, an independent estimate of one or more of the other parameter is required to arrive at a potentially unique solution. The estimated regional recharge (0.00008 m/d) was therefore considered fixed for the final model calibration and only hydraulic conductivities of the different zones considered variable.

The project team adopted a root mean squared residual (between modelled and simulated water levels) lower than 10 for all monitoring boreholes as the calibration target. The objective was therefore to represent the overall flow pattern in the vicinity of Tutuka Power Station using uniform aquifer parameters rather than to achieve a good fit for individual boreholes using a multitude of fitting parameters.

3.10 DEGREE OF CONFIDENCE IN MODEL PREDICTIONS

Internationally excepted software (MODFLOW and MT3DMS) was used to represent the conceptual site model developed for the site at an appropriate scale. A numerical model is a management tool that is typically used to help understand why a system is behaving in a particular observed manner or to predict how it will behave in the future. Its precision depends on chosen simplifications (in a conceptual model) as well as on the completeness and accuracy of input parameters. In particular, data on input parameters like water levels and aquifer properties is often scarce and limits the precision and confidence of numerical groundwater models. While some of these uncertainties inherent in the regional numerical groundwater flow and transport models were addressed by varying model parameters, other sensitive model parameters like porosities or source concentrations for the transport model were chosen conservatively to present worst case scenarios of environmental impacts.

Overall, the model shows a reasonable correlation between the observed and calibrated groundwater heads, with a root mean squared residual of 6.7 %. Furthermore, the calibrated flow model indicates an acceptable groundwater flow budget (error less than 1%). However, the lack of detailed geological data (including site-specific hydraulic properties) reduces the accuracy of the model predictions. The overall confidence in the model predictions, especially transport predictions, is therefore classified as low to medium.

3.11 STEADY STATE CALIBRATION

The MODFLOW model uses iterative methods (iterations) to obtain the solution to the system of finite-difference equations for different time step, i.e. calculate best fit groundwater heads to fit the model solutions. A procedure of calculation is initiated which alters estimated values, producing a new set of head values which are in closer agreement with the system of equations. This procedure is repeated successively until convergence is met, i.e. calculated groundwater heads resemble the measured groundwater heads.

The original model was run with the initial conditions. Using the 40 (average) groundwater level data points observed in the groundwater monitoring boreholes within the model domain; a steady-state calibration of the groundwater flow model was performed. Figure 3.2 illustrates the calibration between the observed and modelled groundwater levels for the MRP model.

A root mean square error of 6.7 and an average correlation coefficient (R^2), between modelled and observed values of 62% was achieved for the steady-state calibration (Figure 3.2). No attempt was therefore made to change hydraulic conductivity values. The hydraulic conductivities are presented in Table 3-1. The modelled groundwater contours are presented in Figure 3.3.

TABLE 3-1 HYDRAULIC CONDUCTIVITIES USED IN THE MODEL

Aquifer	Hydraulic Conductivity (m/d)
Weathered Sandstone and Mudstone (Vryheid Formation)	0.5
Weathered Karoo dolerite	0.15
Fractured Karoo dolerite	0.04
Fractured sandstone and mudstone (Vryheid Formation)	0.065

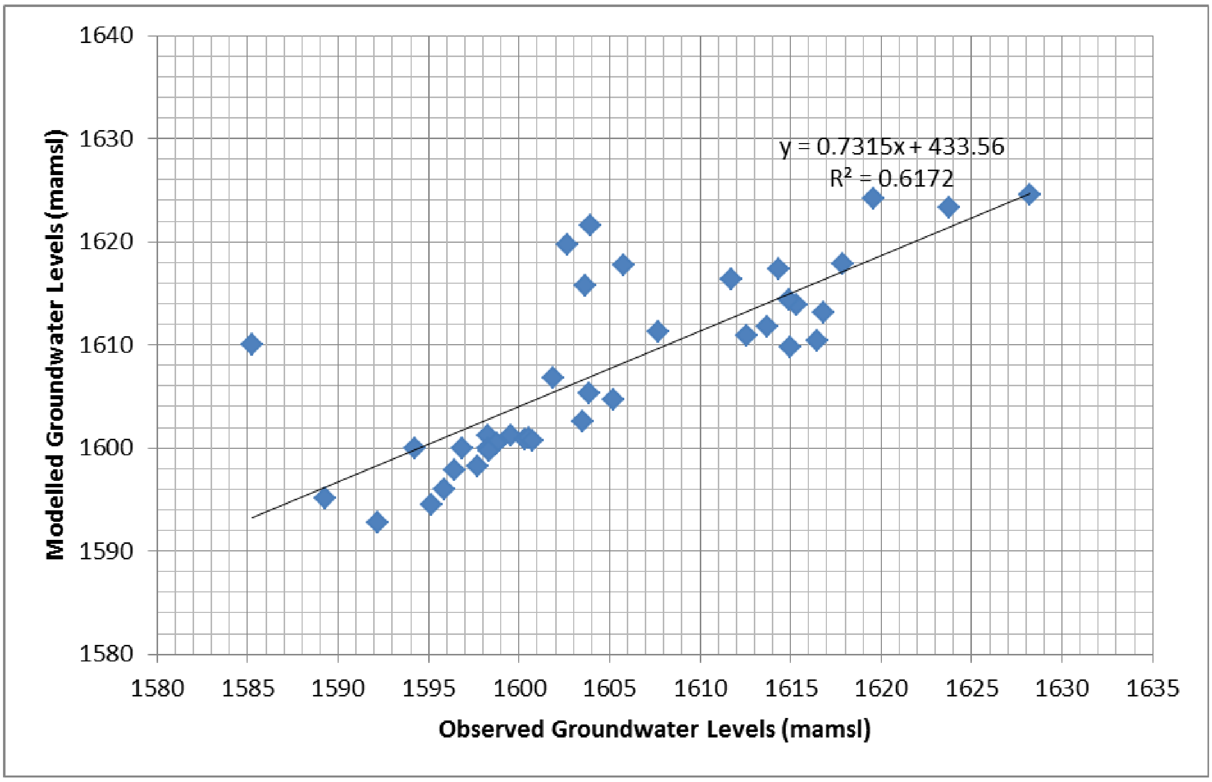


FIGURE 3.2: STEADY STATE CALIBRATION OF THE TUTUKA GROUNDWATER MODEL

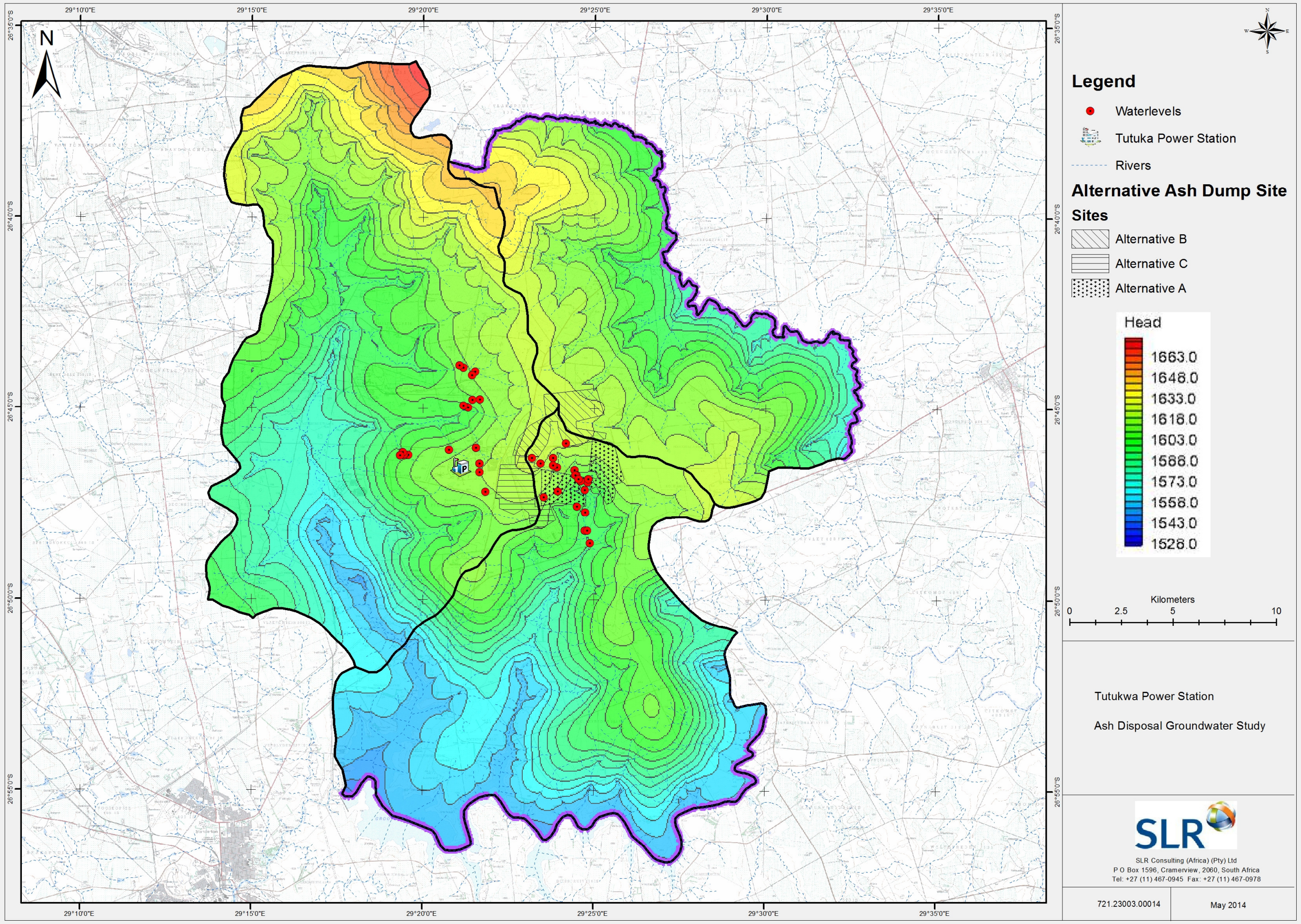


FIGURE 3.3: MODELLED GROUNDWATER CONTOURS ACROSS THE MODEL DOMAIN

With model convergence, iteration convergence criteria of <1m, and an acceptable root mean square error of 6.7 representing an average correlation between observed and calibrated groundwater levels the model flow budget furthermore indicates acceptable calibration targets (Table 3.2).

The flow budget represents the total inflows and outflows into and from the model domain, calculated by the input parameters of the numerical model. The difference between the total inflow and total outflow represents and error of less than 1 % contributing to the confidence level of the calibration for the Tutuka power station model.

TABLE 3.2: FLOW BUDGET CALCULATED FROM CALIBRATED MODEL PARAMETERS

Sources and Sinks	Flow In	Flow Out
Constant Head	279.2376	-5566.77
Drain (River)	0.001166	-56640.1
Recharge	61908.4	0
Total Flow	62187.64	-62206.8
Summary	**In – Out**	**% difference (error)**
TOTAL	-19.188	-0.03085

3.12 MODEL PREDICTIVE SIMULATIONS

The calibrated steady-state groundwater flow model was used as a basis for transient contaminant transport simulations using MT3DMS.

Each alternative site for continue ash disposal was considered as potential source of pollution and incorporated into the model domain as a recharge boundary with an initial concentration of 100 (i.e. contours derived by the model represent percentages of the initial start concentration for any given contaminant, assuming no reactive transport). Following the precautionary principle, only advective-dispersive (longitudinal dispersivity 50 m) transport of potential pollutants without any retardation or transformation was assumed.

The predicted development of the source concentration plumes due to seepage from the alternative area are presented in Figure 3.4,Figure 3.5 and Figure 3.6.

It is noted that off-site migration of leachate from the ash disposal facilities via surface flow might occur earlier if not retarded and potentially reduced by surface water impoundments, and that no account has been taken of potentially high permeability structures that have not been mapped.

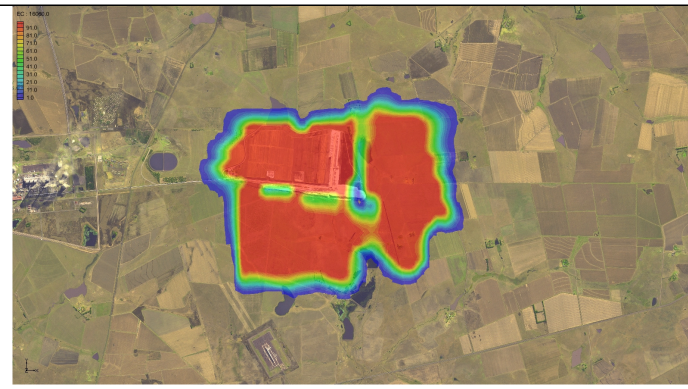
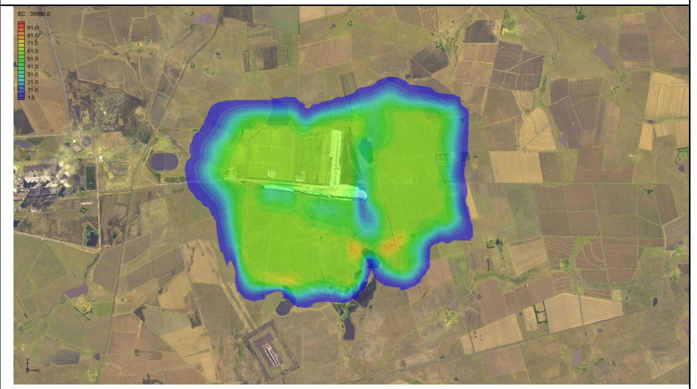
ALTERNATIVE SITE A				
	5 years after deposition Starts	**25 years after deposition Starts**	**44 years after deposition Starts**	**100 years after Deposition Starts**
Layer 1				
Layer 2				

FIGURE 3.4: PLUME DEVELOPMENT FOR ALTERNATIVE ASH DISPOSAL FACILITY SITE A

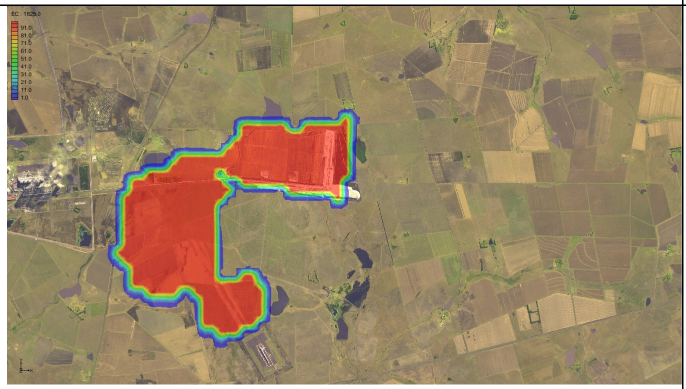
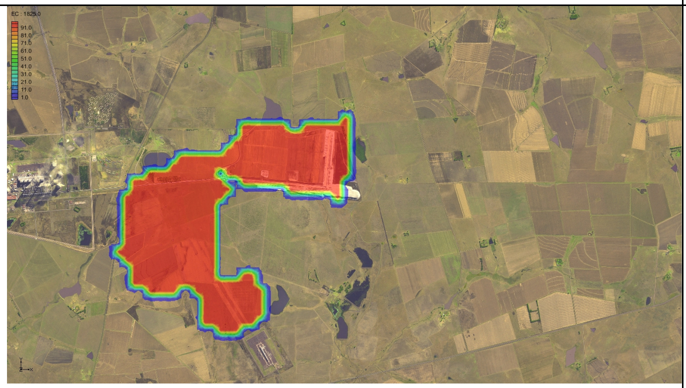
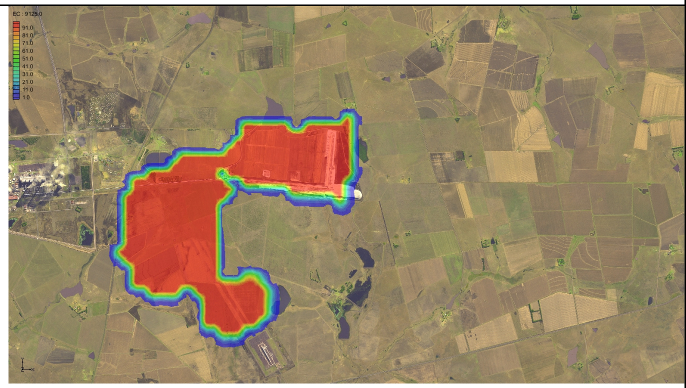
ALTERNATIVE SITE B				
	5 years after deposition Starts	**25 years after deposition Starts**	**44 years after deposition Starts**	**100 years after Deposition Starts**
Layer 1				
Layer 2				

FIGURE 3.5: PLUME DEVELOPMENT FOR ALTERNATIVE ASH DISPOSAL FACILITY SITE B

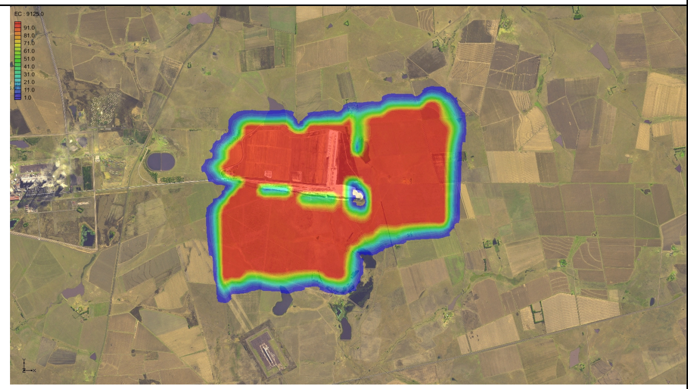
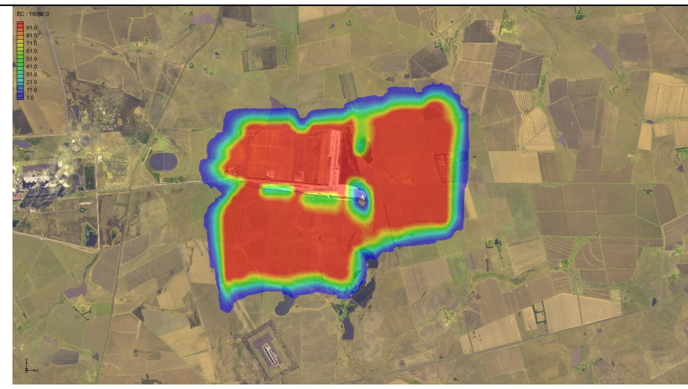
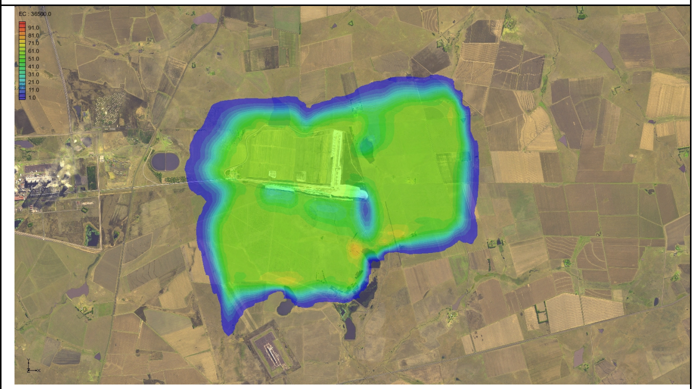
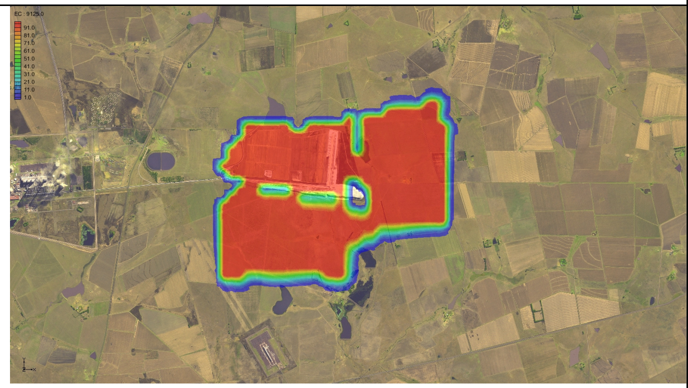
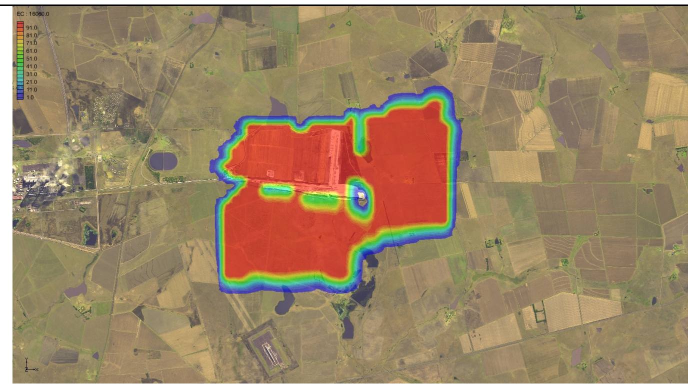
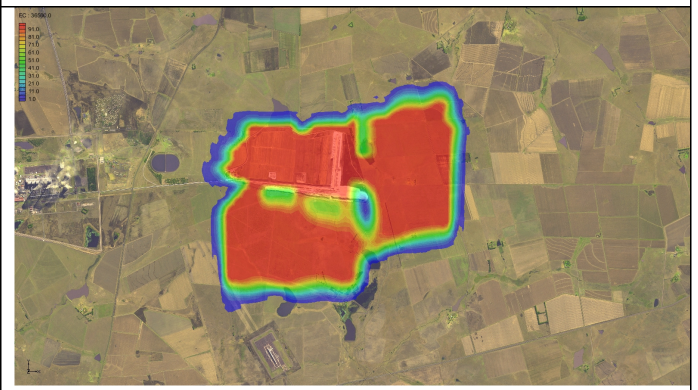
ALTERNATIVE SITE C				
	5 years after deposition Starts	25 years after deposition Starts	44 years after deposition Starts	100 years after Deposition Starts
Layer 1				
Layer 2				

FIGURE 3.6: PLUME DEVELOPMENT FOR ALTERNATIVE ASH DISPOSAL FACILITY SITE C

3.13 MODEL SUMMARY AND CONCLUSIONS

The groundwater numerical model has identified the extent of groundwater contamination from the proposed alternative ash disposal facilities.

Leachate plumes are likely to move with the ambient groundwater flow in a direction determined largely by the surface topography. Conservative assumptions made in the modelling exercise lead to the simulations shown in Figure 3.4, Figure 3.5 and Figure 3.6.

It must however be noted that the predictions depend on aquifer properties and on leachate seepage rates, neither of which are well constrained in the study area.

4 ASSESSMENT OF POTENTIAL IMPACTS

The following section assesses the potential impact on groundwater of the three 'alternative' sites identified for the continuous ash disposal. As the alternative sites are located in similar hydrogeological settings, the potential impacts during the various stages of the project are discussed together, although an overview of each site is presented first.

4.1 SUMMARY OF THE ALTERNATIVE SITES

4.1.1 ALTERNATIVE SITE A

Alternative site A is located to the south and east of the existing ash disposal facility and comprises an area of 672.70 hectares.

The site is predominantly underlain by the Vryheid Formation (arenaceous sandstones), although a substantial percentage of the footprint is underlain by the Karoo dolerite. Both geological units exhibit low permeability which suggests low risk to groundwater, although the dolerite is likely to exhibit fractures and fissures, with a higher permeability associated with the contact between an intrusion and the host rock which could increase the risk to groundwater. Notwithstanding, anticipated borehole yields are reasonably low.

A number of non-perennial rivers flow through the footprint, however it is noted that the existing ash disposal facility covers the end sections of these water courses.

4.1.2 ALTERNATIVE SITE B

Alternative site B is located to the north of the existing ash disposal facility and comprises an area of 764.94 hectares.

The site is predominantly underlain by the Vryheid Formation (arenaceous sandstones), although a small percentage of the footprint is underlain by the Karoo dolerite. As previously discussed, both geological units exhibit low permeabilities which suggests low risk to groundwater, although higher permeability may exist at the contact between an intrusion and the host rock which could increase the risk to groundwater. Notwithstanding, anticipated borehole yields are reasonably low.

One non-perennial river flows through the footprint of the site, towards the north-east corner. The source of two other non-perennial streams lie on the edge of Alterative Site B; one on the east and one on the west.

4.1.3 ALTERNATIVE SITE C

Alternative site C is located to the south-west of the existing ash disposal facility and comprises an area of 534.41 hectares.

The site is underlain predominantly by the Vryheid Formation (arenaceous sandstones), although a small percentage of the footprint is underlain by the Karoo dolerite. As previously discussed, both geological units exhibit low permeabilities which suggests low risk to groundwater, although higher permeability may exist at the contact between an intrusion and the host rock which could increase the risk to groundwater. Notwithstanding, anticipated borehole yields are reasonably low.

A small section of a non-perennial river is shown to flow through the footprint of the site (towards the north); however the remaining section falls within the footprint of the existing ash disposal facility.

4.2 POTENTIAL GROUNDWATER IMPACT

4.2.1 CONSTRUCTION PHASE

- The construction Phase is expected to consist of:
  - clearing the site.
  - removal of any infrastructure at the site.
  - installation of a liner.
  - installation of under-drain systems and related pipework.
  - installation of piezometers for groundwater monitoring.
- The use of earth-moving plant and trucks brings a risk of hydrocarbon spillages and other polluting fluids during the construction phase.
- Removal of topsoil during the construction phase can worsen any spillages that may subsequently occur as the soil zone is an important barrier to the downward migration of potential groundwater contaminants (both a physical barrier and a microbiological and chemical barrier).

4.2.2 OPERATIONAL PHASE

- Even though a dry ashing technique will be used, precipitation will collect on top of the ash disposal facility and eventually infiltrate through the ash and liner to the underlying aquifer. Water is likely to be stored within the ash disposal facility over time and subsequently increase the 'recharge' within the footprint of the facility which may cause mounding of groundwater. However, this ultimately depends of the volume of water that falls on the facility and the relative permeability of the ash. This may have the potential to cause a rise in the water table beneath the ash disposal facility and may impact local groundwater flow directions. Notwithstanding, it is considered unlikely that a significant rise in the water table beneath the ash disposal facility will occur as a direct result of the ash itself.

However the use of toe drains, stormwater dams and other surface water impoundments close to the proposed ash disposal facility may lead to local water table rise.

- The quality of groundwater beneath the site is likely to deteriorate, since natural groundwater will be mixing with the poorer quality ash leachate (either directly draining from the ash disposal facility, or leaking from surface water impoundments). Geochemical data for the ash at Tutuka was not made available for this assessment, but typical constituents of concern (elements that are elevated above water quality standards) are As, B, Cr, Mo, Sb, Se, V and W. In addition, the pH of water is likely to be impacted. It is noted however that the proposed alternative sites at Tutuka are adjacent to the existing ash disposal facility. Groundwater quality data show that groundwater quality has been impacted by the existing ash disposal facility.
- If contaminated water is impounded at the surface in unlined ponds, there is a risk to both groundwater and surface water resources. Existing data show that boreholes located near ponds are impacted both in groundwater levels and quality.
- If infrastructure designed to minimize and contain contaminated runoff from the ash disposal facility and surrounds falls into disrepair, the risk to groundwater and / or surface water contamination would occur.
- Diesel spills from equipment or plant (e.g. ash stackers) carry a risk of hydrocarbon contamination, and standard precautions i.e. availability of appropriate sorbent material and prompt clean-up should be taken to minimize this risk. Hydrocarbons and fuels should be stored in bunded areas.

4.2.3 De-Commissioning Phase

- Decommissioning of the ash disposal facility will involve halting ash disposal and removing ash disposal equipment (e.g. stackers). The use of plant and trucks brings a risk of hydrocarbon spillages.
- If infrastructure designed to minimize and contain contaminated runoff from the ash disposal facility and surrounds falls into disrepair, the risk to groundwater and / or surface water contamination would occur.

4.3 Summary of Impacts

The likely cumulative impacts of all three phases (construction, operation and decommissioning) are likely to be:

- a rise in water table in the vicinity of the site due to increased recharge from stored water within the ash disposal facility and any associated surface water impoundments.
- Deterioration in groundwater quality.

4.4 QUALITATIVE IMPACT ASSESSMENT - SIGNIFICANCE RATING EXERCISE

The potential impacts of the proposed ash disposal facility on the local groundwater have been qualitatively assessed. The assessment of risk is outlined in a matrix within an Excel spreadsheet. Each potential impact is briefly described, and the nature of the impact is assessed using a standard significance rating scale that takes into account the following:

- Extent the impact (Score between 1 (low) and 5 (high)).
- Duration the impact (Score between 1 (low) and 5 (high)).
- Magnitude the impact (Score between 1 (low) and 10 (high)).
- Probability of the impact (Score between 1 (low) and 5 (high)).

This leads to an estimate of "significance" for each impact (low, medium or high) with an associated numerical value. Each assessment is also given a confidence rating (low, medium or high). Table 4.1 sets out the format. The Spreadsheets for Tutuka are presented in Appendix A.

This approach provides a mechanism for identifying the areas where mitigation measures are required and for identifying mitigation measures appropriate to the risk presented by the development. This approach allows effort to be focused on reducing risk where the greatest benefit may result.

TABLE 4.1: EXAMPLE OF THE SIGNIFICANCE RATING TABLE

Tutuka Ash Disposal Facility - EIA and Waste License Application									
Groundwater Specialist Study									
Significance Rating Table									
Decommissioning Phase									
Ash Disposal Facility - All alternatives									
Potential Impact	**Mitigation**	**Extent (E)**	**Duration (D)**	**Magnitude (M)**	**Probability (P)**	**Significance (S=(E+D+M)*P)**		**Status (+ve or -ve)**	**Confidence**
Deterioration of groundwater quality due to spillages during Decommissioning	**Nature of impact:**	Spillages of hydrocarbons (e.g. diesel) or solvents or other pollutants during the construction phase may have an impact on the quality of local groundwater resources.							
	Without Mitigations	2	2	6	2	20	Low	-	High
	With Mitigation	1	1	4	1	6	Low	-	High
	Degree to which impact can be reversed:	Once fuel, solvents or other pollutants are spilled and begin to migrate downwards, reversing the impact is difficult and expensive - i.e. the degree to which the impact can be reversed is low. However, if appropriate precautions are taken during the construction phase (e.g. the bunding of refuelling and fuel storage areas, control of all potentially polluting substances at the site), the threat of this impact can be nearly eliminated.							High
	Degree of impact on irreplaceable resources:	Impact likely to be on local groundwater only, which is not irreplaceable.							Medium

Note: For the Extent (E), Duration (D), Magnitude (M) and Probability (P), 1 is low and 5 is high in the case of E, D and P and 10 is high for M.

5 PROPOSED MITIGATION AND MANAGEMENT MEASURES

The following section presents possible mitigations and management measures that could be put in place to reduce the potential impact on groundwater of the three 'alternative' sites identified for the continuous ash disposal.

5.1.1 CONSTRUCTION PHASE

Impact: Deterioration of Groundwater Quality due to Spillages during Construction

- This can be mitigated by taking steps to prevent any leaks or spills of fuels, solvents or other polluting liquids. This could include the provision of separate, bunded (concrete floors) refueling and fuel storage areas. In addition spill kits should be readily available.
- Suitable training of staff on 'clean up operations' should a spill of fuels, solvent or other polluting liquid occur.
- Preventing the disposal of any waste at the site, particularly into the trenches / holes that will be dug. Disturbing the surface layer / soil layer makes the aquifer more vulnerable to surface pollution.
- Ensuring that any systems for the draining of leachates and / or supernatant water from the ash disposal facility are installed correctly.
- Under-drain systems should be checked for integrity once they have been completed.
- Systems for removing or preventing blockages (e.g. rodding eyes, water traps) must be installed correctly as blocked under-drains can cause leaks, and lead to additional groundwater pollution.
- All work should be supervised by a suitably qualified professional.

5.1.2 OPERATIONAL PHASE

Impact: Rise in Local Groundwater Table and change in Local Groundwater Flow Direction

- Minimizing the volume of leachate percolating through the ash disposal facility and migrating downwards into the aquifer is the key to reducing this impact.
- Operating an adequate groundwater monitoring network in the vicinity of the ash disposal facility in order to detect any problems early.
- Ensuring that any under-drain, penstock and return water dam systems are in good working order.

Impact: Deterioration of groundwater quality from Ash Disposal Facility

- Minimizing the volume of leachate percolating through the ash disposal facility and migrating downwards into the aquifer is the key to reducing all of this impact.
- Operating an adequate groundwater monitoring network in the vicinity of the ash disposal facility in order to detect any problems early.
- Ensuring that any under-drain, penstock and return water dam systems are in good working order.

- Preventing the disposal of any “foreign” waste material (e.g. hydrocarbons or solvents) to the ash disposal facility (it is acknowledged that Eskom does not intend to do this).

Impact: Deterioration of groundwater Quality from Contaminated Surface Water

- Minimizing the volume of leachate percolating through the ash disposal facility and migrating towards drains is the key to reducing all of this impact.
- Ensuring sufficient freeboard and other measures in holding ponds, toe drains and storm water dams, to prevent any spills of contaminated water onto adjacent land.
- Operating an adequate groundwater monitoring network in the vicinity of the ash disposal facility in order to detect any problems early.
- Consider lining surface impoundments of poor-quality water such as return water dams.

Impact: Deterioration of groundwater quality due to spillages of hydrocarbons

- Careful storage and handling of hydrocarbons (e.g. diesel, lubricants, hydraulic fluids, etc.), preferably in bunded areas.
- Operating an adequate groundwater monitoring network in the vicinity of the ash disposal facility in order to detect any problems early.

5.1.3 De-Commissioning Phase

Impact: Deterioration of groundwater quality due to spillages

- Preventing any leaks or spills of fuels, solvents or other polluting liquids. This could include the provision of separate, bunded (concrete floors) refueling and fuel storage areas. In addition to have spill kits readily available.
- Continuous groundwater monitoring in order to quantify ongoing impacts and provide early warning of any problems.

Impact: Deterioration of groundwater quality due to leachate from ash disposal facility

- Encourage re-vegetation of the ash disposal facility, since this is likely to reduce the volume of rainwater percolating down into the facility through natural evapotranspiration and to improve the quality of runoff from the ash disposal facility. If possible a layer of top soils should be added to the ash disposal facility once deposition ceases.
- Maintenance of the under-drain and return water systems (and liner if fitted), in whatever final state is considered best.
- Continuous groundwater monitoring in order to quantify ongoing impacts and provide early warning of any problems.
- Ensure that no other waste is disposed of at the ash disposal facility.

Impact: Minor changes to local water table and local groundwater flow direction

- Encourage re-vegetation of the ash disposal facility, since this is likely to reduce the volume of rainwater percolating down into the facility through natural evapotranspiration and to improve the quality of runoff from the ash disposal facility. If possible a layer of top soil should be added to the ash disposal facility once deposition ceases.
- Continuous groundwater monitoring in order to quantify ongoing impacts and provide early warning of any problems.

Impact: Groundwater contamination in local area due to infiltration from polluted surface water features

- Continuous groundwater monitoring in order to quantify ongoing impacts and provide early warning of any problems.
- Maintain the structural integrity of the ash disposal facility, to prevent slipping and gulley erosion.
- Ensure that no other waste is disposed of at the ash disposal facility.

6 SITE PREFERENCE RANKING

The site preference ranking that has been used for the three alternative areas selected for the continued disposal of ash at Tutuka Power Station is presented in
Table 6-1:

TABLE 6-1 SPECIALIST CRITERIA FOR SITE PREFERENCE RATINGS

Site preference Rating	Criteria
Preferred (4)	Impacts on groundwater limited or negligible, and small in nature
Acceptable (3)	Impacts on groundwater limited to the site or to the local area, and moderate in nature
Not Preferred (2)	Impacts on groundwater have the potential to pollute a wider area, or are more severe in nature
No-Go (1)	Serious impacts on groundwater which are very expensive or impossible to remediate

Based on the geological and hydrogeological data collected and presented as part of this assessment, the three proposed alternative sites have been ranked, as presented in Table 6-2.

TABLE 6-2 FINAL SITE RANKING MATRIX

Specialist Discipline	Alternative Site A	Alternative Site B	Alternative Site C
Groundwater	2	3	3

Alternative Site B and C have been given a rating of 3 which suggests they are both acceptable sites, where the impacts on groundwater are limited to the site or the local area. Due to the higher proportion of non-perennial streams, Alternative site A has been given a ranking of 2 which is not preferred.

7 CONCLUSIONS

SLR Consulting (South Africa) (Pty) Limited ("SLR") has been appointed by Lidwala Consulting Engineers ("Lidwala") to undertaken a hydrogeological impact assessment for the proposed continued ashing at Eskom's Tutuka Power Station, near Standerton, Mpumalanga.

The hydrogeological report addresses the potential impact continued ash disposal would have on the hydrogeological system through all phases of the Project including construction, operation and decommissioning and would support the Environmental Impact Assessment (EIA) that would be submitted to the relevant authority for the site's Waste Licence application.

The main impacts on groundwater of the proposed ash disposal facility are likely to be:

- Deterioration in water quality; and
- Rise in groundwater levels in the immediate vicinity of the ash disposal facility due to additional recharge and groundwater mounding, which mat alter the local groundwater flow direction.

The numerical model results suggest that the movement of leachate away from the ash disposal facility as a groundwater plume should take place relatively slowly, with plume extents being generally less than 1 km from the ash disposal facility after 100 years.

The main way to mitigate these impacts is to maintain the ash disposal facility in good condition (especially the drainage system). Once the ash disposal facility is decommissioned, it should be re-vegetated to minimise infiltration and to improve runoff quality, and the drainage system maintained to reduce downward movement of leachate from the base of the ash disposal facility. Groundwater monitoring from suitable boreholes should be undertaken during all phases of ash disposal and after closure. If required the numerical model could be updated with new monitoring data.

In terms of the risk to groundwater, Alternative Site B and C have been given a rating of 3 which suggests they are both acceptable sites, where the impacts on groundwater are limited to the site or the local area. Due to the higher proportion of non-perennial streams, Alternative site A has been given a ranking of 2 which is not preferred.

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APPENDIX A: SIGNIFICANCE RATING TABLE

Tutuka Ash Disposal Facility - EIA and Waste License Application

Groundwater Specialist Study

Significance Rating Table

Construction Phase

Ash Disposal Facility - All alternatives

Potential Impact	Mitigation	Extent (E)	Duration (D)	Magnitude (M)	Probability (P)	Significance (S=(E+D+M)*P)		Status (+ve or -ve)	Confidence
Deterioration of groundwater quality due to spillages during construction	Nature of impact:	Spillages of hydrocarbons (e.g. diesel) or solvents or other pollutants during the construction phase may have an impact on the quality of local groundwater resources.							
	Without Mitigations	2	2	6	2	20	Low	-	High
	With Mitigation	1	1	4	1	6	Low	-	High
	Degree to which impact can be reversed:	Once fuel, solvents or other pollutants are spilled and begin to migrate downwards, reversing the impact is difficult and expensive - i.e. the degree to which the impact can be reversed is low. However, if appropriate precautions are taken during the construction phase (e.g. the bunding of refuelling and fuel storage areas, control of all potentially polluting substances at the site), the threat of this impact can be nearly eliminated.							High
	Degree of impact on irreplaceable resources:	Impact likely to be on local groundwater only, which is not irreplaceable.							Medium

Tutuka Ash Disposal Facility - EIA and Waste License Application

Groundwater Specialist Study

Significance Rating Table

Operational Phase

Ash Disposal Facility - All alternatives

Potential Impact	Mitigation	Extent (E)	Duration (D)	Magnitude (M)	Probability (P)	Significance (S=(E+D+M)*P)		Status (+ve or -ve)	Confidence
Rise in local water table due to additional recharge caused by ash deposition and possible concentration of recharge	**Nature of impact:**	Possible rise in the water table as ash is deposited and recharge is potentially concentrated / increased. The rate of rise will depend on the rate of leachate migration in the ash disposal facility, and this is not known with certainty.							
	Without Mitigations	1	4	4	4	36	Medium	-	Medium
	With Mitigation	1	4	2	3	21	Low	-	Medium
	Degree to which impact can be reversed:	Difficult to entirely reverse this impact. A full liner used under the ash disposal facility would mostly prevent it, but would be very expensive.							Medium
	Degree of impact on irreplaceable resources:	Impact likely to be on local groundwater only, which is not irreplaceable.							Medium
Change in local groundwater flow directions due to possible rise in local water table	**Nature of impact:**	It is possible that the groundwater flow directions will be altered locally due to the rise or "mounding" of the local water table. This may affect some local springs and seeps (both in terms of volume and quality).							
	Without Mitigations	2	4	2	3	24	Low	-	Medium
	With Mitigation	1	4	2	3	21	Low	-	Medium
	Degree to which impact can be reversed:	Difficult to entirely reverse this impact unless a full liner is used under the ash disposal facility. Once the ash disposal facility is closed and revegetated groundwater levels in the vicinity will probably slowly return to their original state.							Medium
	Degree of impact on irreplaceable resources:	Impact likely to be on local groundwater only, which is not irreplaceable.							Medium
Deterioration of groundwater quality due to leachate from ash disposal facility	**Nature of impact:**	Rainwater percolating through the ash disposed will dissolve potential contaminants in the ash (e.g. SO4, Hg, F, Na) and carry these contaminants downwards into the local groundwater.							
	Without Mitigations	2	4	4	4	40	Medium	-	Medium
	With Mitigation	1	4	2	4	28	Low	-	Medium
	Degree to which impact can be reversed:	It will be difficult to reverse this impact during ash dam operation. It is more feasible to reduce the amount of leachate as much as possible by ensuring that the under-drain and related systems work as designed. When deposition ceases, natural attenuation over many years is likely to slowly reverse the impact.							Medium
	Degree of impact on irreplaceable resources:	Impact likely to be on local groundwater only, which is not irreplaceable.							Medium
Groundwater contamination in local area due to infiltration from surface water polluted by the ash disposal facility.	**Nature of impact:**	Surface water that is being impounded near the ash disposal facility and which is polluted by runoff from the ash disposal facility may leak from surface water impoundments into surface water system, and infiltrate into groundwater some distance (most likely local area) from the ash disposal facility.							
	Without Mitigations	2	4	4	3	30	Low	-	High
	With Mitigation	1	2	2	2	10	Low	-	High
	Degree to which impact can be reversed:	Impact can be reversed successfully if all surface water infrastructure kept in good condition and appropriately designed (e.g. for flood events)							Medium
	Degree of impact on irreplaceable resources:	Impact likely to be on regional groundwater which may be expensive to replace if it is a sole source of supply to a nearby farm, for example.							Medium
Deterioration of groundwater quality due to spillages of hydroarbons	**Nature of impact:**	Spillages of hydrocarbons (e.g. diesel) or solvents or other pollutants may have an impact on the quality of local groundwater resources.							
	Without Mitigations	2	2	4	2	16	Low	-	High
	With Mitigation	1	1	2	1	4	Low	-	High
	Degree to which impact can be reversed:	Once fuel, solvents or other pollutants are spilled and begin to migrate downwards, reversing the impact is difficult and expensive - i.e. the degree to which the impact can be reversed is low. However, if appropriate precautions are taken during the construction phase (e.g. the bunding of refuelling and fuel storage areas, control of all potentially polluting substances at the site), the threat of this impact can be nearly eliminated.							High
	Degree of impact on irreplaceable resources:	Impact likely to be on local groundwater only, which is not irreplaceable.							Medium

Tutuka Ash Disposal Facility - EIA and Waste License Application									
Groundwater Specialist Study									
Significance Rating Table									
Decommissioning Phase									
Ash Disposal Facility - All alternatives									
Potential Impact	**Mitigation**	**Extent (E)**	**Duration (D)**	**Magnitude (M)**	**Probability (P)**	**Significance (S=(E+D+M)*P)**		**Status (+ve or -ve)**	**Confidence**
Deterioration of groundwater quality due to spillages during Decommissioning	**Nature of impact:**	Spillages of hydrocarbons (e.g. diesel) or solvents or other pollutants during the construction phase may have an impact on the quality of local groundwater resources.							
	Without Mitigations	2	2	6	2	**20**	**Low**	-	High
	With Mitigation	1	1	4	1	**6**	**Low**	-	High
	Degree to which impact can be reversed:	Once fuel, solvents or other pollutants are spilled and begin to migrate downwards, reversing the impact is difficult and expensive - i.e. the degree to which the impact can be reversed is low. However, if appropriate precautions are taken during the construction phase (e.g. the bunding of refuelling and fuel storage areas, control of all potentially polluting substances at the site), the threat of this impact can be nearly eliminated.							High
	Degree of impact on irreplaceable resources:	Impact likely to be on local groundwater only, which is not irreplaceable.							Medium
Deterioration of groundwater quality due to leachate from ash disposal facility	**Nature of impact:**	Leachate from the ash disposal facility is likely to continue to percolate downwards even when ash disposal has ceased, albeit at a much lower rate.							
	Without Mitigations	2	3	2	4	**28**	**Low**	-	Medium
	With Mitigation	2	2	2	4	**24**	**Low**	-	Medium
	Degree to which impact can be reversed:	This impact can be significantly mitigated against, but cannot be entirely reversed. If the drainage system is kept functional, groundwater monitoring continues and the ash disposal facility is vegetated then downward drainage of leachate into the groundwater will be minimised.							Medium
	Degree of impact on irreplaceable resources:	The impact on local groundwater is thought to be low and localised.							Medium
Minor changes to local water table and local groundwater flow direction	**Nature of impact:**	Once decommissioned, the water table under the ash disposal facility should begin to decline again, since the volume of water migrating							
	Without Mitigations	2	4	2	3	**24**	**Low**	-	Medium
	With Mitigation	2	3	2	3	**21**	**Low**	-	Medium
	Degree to which impact can be reversed:	The impact can be lessened by vegetating the ash disposal facility and preventing erosion etc, which will reduce movement of water /leachate downwards once ash depostion has ceased. The full impact would be difficult to reverse however, since this would most likely involve removing the rehabilitated ash disposal facility.							Medium
	Degree of impact on irreplaceable resources:	Minor impact only.							Medium
Groundwater contamination in local area due to infiltration from surface water polluted by the ash disposal facility.	**Nature of impact:**	Surface water that is being impounded near the ash disposal facility and which is polluted by runoff from the ash disposal facility may leak							
	Without Mitigations	2	4	4	3	**30**	**Low**	-	High
	With Mitigation	1	2	2	2	**10**	**Low**	-	High
	Degree to which impact can be reversed:	Impact can be reversed successfully if all surface water infrastructure kept in good condition and appropriately designed (e.g. for flood events)							Medium
	Degree of impact on irreplaceable resources:	Impact likely to be on regional groundwater which may be expensive to replace if it is a sole source of supply to a nearby farm, for example.							Medium

Tutuka Ash Disposal Facility - EIA and Waste License Application

Groundwater Specialist Study

Significance Rating Table

Cumulative Impacts									
Ash Disposal Facility - All alternatives									
Potential Impact	**Mitigation**	**Extent (E)**	**Duration (D)**	**Magnitude (M)**	**Probability (P)**	**Significance (S=(E+D+M)*P)**		**Status (+ve or -ve)**	**Confidence**
Deterioration of groundwater quality due to leachate from ash disposal facility	**Nature of impact:**	The ash disposal facility is likely to lead to deterioration of local groundwater quality, which will be most severe during facility operation but							
	Without Mitigations	2	4	6	4	**48**	**Medium**	-	Medium
	With Mitigation	2	4	4	4	**40**	**Medium**	-	Medium
	Degree to which impact can be reversed:	The impact can be lessened but not reversed completely by maintaining good practices during ash disposal facility construction and operation, and by revegetating and maintaining the ash disposal facility after closure.							Medium
	Degree of impact on irreplaceable resources:	The degree of impact on irreplaceable resources is thought to be low, since local groundwater resources are limited and are theoretically replaceable with alternatives. However, local groundwater users who have no other convenient alternatives may need to have alternative supplies provided, which may be expensive.							Medium
Rise in local water table and minor changes to local groundwater flow directions	**Nature of impact:**	Once decommissioned, the water table under the ash disposal facility should begin to decline again, since the volume of water migrating							
	Without Mitigations	2	4	4	4	**40**	**Medium**	-	Medium
	With Mitigation	1	3	2	3	**18**	**Low**	-	Medium
	Degree to which impact can be reversed:	The impact can be lessened by vegetating the ash disposal facility and preventing erosion etc, which will reduce movement of water /leachate downwards once ash depostion has ceased. The full impact would be difficult to reverse however, since this would most likely involve removing the rehabilitated ash disposal facility.							Medium
	Degree of impact on irreplaceable resources:	The degree of impact on irreplaceable resources is thought to be low, since local groundwater resources are limited and are theoretically replaceable with alternatives							Medium
Groundwater contamination in local area due to infiltration from surface water polluted by the ash disposal facility.	**Nature of impact:**	Surface water that is being impounded near the ash disposal facility and which is polluted by runoff from the ash disposal facility may leak							
	Without Mitigations	2	4	4	3	**30**	**Low**	-	High
	With Mitigation	1	2	2	2	**10**	**Low**	-	High
	Degree to which impact can be reversed:	Impact can be reversed successfully if all surface water infrastructure kept in good condition and appropriately designed (e.g. for flood events)							Medium
	Degree of impact on irreplaceable resources:	Impact likely to be on regional groundwater which may be expensive to replace if it is a sole source of supply to a nearby farm, for example.							Medium

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RECORD OF REPORT DISTRIBUTION

SLR Reference:	721.23003.00014
Title:	Proposed Continuous Ash Disposal at Tutuka Power Station: Groundwater Specialist Study
Site name:	Tutuka Power Station
Report Number:	2
Client:	Lidwala Consulting Engineers

Name	Entity	No. of copes	Date issued	Issuer
Danie Brummer	Lidwala Consulting Engineers (SA) (Pty) Ltd	1	July 2014	J. Ellerton
SLR Library	SLR Consulting (South Africa) (Pty) Limited	1	July 2014	J. Ellerton

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